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ORIGINAL ARTICLE

# Runoff capture through vegetative barriers and planting methodologies to reduce erosion, and improve soil moisture, fertility and crop productivity in southern Orissa, India

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**Abstract** Use of perennial grasses as vegetative barriers to reduce soil erosion from farm and non-farm lands is increasing world-over. A number of perennial grasses have been identified for their soil conserving properties, but their effectiveness varies with location and method of planting. Installing vegetative barriers in combination with suitable mechanical measures, like bunds or trenches or both, on the appropriately spaced contours may enhance their conservation potential. Hence, the effect of vegetative barriers, *viz*., *sambuta* (*Saccharum* spp.)—a local grass, vetiver (*Vetiveria zizanioides*) and lemongrass (*Cymbopogon citratus*) planted in combination with trench-cum-bund, on runoff, soil loss, nutrient loss, soil fertility, moisture retention and crop yield in the rainfed uplands, was studied in Kokriguda watershed in southern Orissa, India through 2001–2005. However, runoff, soil and nutrient losses were studied for 2002, 2003 and 2004 only. Analysis of the experimental data revealed that on a 5% slope, the lowest average runoff (8.1%) and soil loss (4.0 Mg ha$^{-1}$) were observed in the *sambuta* + trench-cum-bund treatment followed by vetiver + trench-cum-bund (runoff 9.8%, soil loss 5.5 Mg ha$^{-1}$). Lemongrass permitted the highest runoff and soil loss. Further, the conservation effect of grass barriers was greater under bund planting than *berm* planting. Minimum organic C (50.02 kg ha$^{-1}$), available N (2.49 kg ha$^{-1}$) and available K (1.56 kg ha$^{-1}$) loss was observed under *sambuta* with bund planting. The next best arrester of the soil nutrients was vetiver planted on bund. Significantly better conservation of nutrients under *sambuta* and vetiver resulted in the soil fertility build-up. Soil moisture content was also higher in the *sambuta* and vetiver than lemongrass treated plots. Increase in the yield of associated finger millet (*Eleusine coracana* (L.) Gaertn.) due to vegetative barriers ranged from 18.04% for lemongrass to 33.67% for *sambuta*. Further, the *sambuta* and vetiver treated plots produced 13.23 and 11.86% higher yield, respectively, compared to the plots having lemongrass barrier (1.17 Mg ha$^{-1}$). Considering the conservation potential, and crop yield and soil fertility improvements, the *sambuta* barrier with trench-cum-bund is the best conservation technology for treating the

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cultivated land vulnerable to water erosion. Farmers also showed greater acceptance for the *sambuta* barrier as it is erect growing and available locally. Vetiver with-trench-cum bund can be the second best option.

**Keywords** Soil and water conservation methods · Vegetative barrier · Erosion · Nutrient loss · Soil fertility · Finger millet

## Introduction

Land degradation is widely recognized as a serious problem. In India, 187.8 million ha (about 57% of the geographical area) area is under various forms of degradation (Sehgal and Abrol 1994). Soil erosion by water is the principal cause of land degradation and declining soil productivity. It has been estimated that a total of 5,334 million Mg of soil is lost every year at the rate of 16.4 Mg ha$^{-1}$ year$^{-1}$ by water erosion (Narayana and Ram 1983). Particularly, southern Orissa with an area of 6.6 million ha and 11.1 million population (Anonymous 2005) is severely affected by the water erosion-induced land degradation. This has posed a serious threat to the food, economic and livelihood securities of the people as agriculture employs 65% of the total work force (Anonymous 2003a) of this region. Poor crop production and the lack of employment opportunities have resulted in 71.97% of the population of the study region living below poverty line (Anonymous 2003b).

This hilly region has a sloping and undulating topography. Rainfed uplands consisting of red soils with medium to high erodibility (Chaudhary et al. 1999) and low fertility constitute a largest chunk of the cultivable lands. The slope of such lands varies from 2 to 15%. Topographically, the uplands are located just downside the denuded and shifting cultivation ravaged hillocks. Due to high and intense rainfall (about 1,500 mm year$^{-1}$) and no or very sparse vegetation, a large amount of runoff is generated on hillocks, which severely erode the downside cultivated lands (silt production rate 2.07–8.96 ha-m per 100 sq km), and thus, jeopardizing the sustainability of crop productivity and ecological balance (Sudhishri et al. 2003). These uplands are not provided even with field bunds. Such lands are farmed for growing the staple food crops like finger millet (*Eleusine coracana* (L.) Gaertn.) and upland rice (*Oryza sativa* L.) during rainy season (mid June to mid October). The productivity of these crops is less than 1 Mg ha$^{-1}$ (Dass et al. 2009) due to land degradation and low soil fertility resulting from the heavy water erosion, lack of irrigation and meager input use. This scenario calls up for conserving the rain-water, protecting sloping uplands from erosion, and enhancing and maintaining the crop productivity.

Mechanical measures help in minimizing erosion and controlling the localized runoff by reducing the length and/or degree of slope and dissipating the energy of flowing water (Sharda et al. 2002). Further, Ranade et al. (1995) reported that both mechanical and vegetative barriers were effective on mild slopes in reducing the runoff by 18–24%. Among the mechanical measures, bunding is commonly recommended for controlling soil erosion and conserving moisture in the arable land having 1–6% slope (Singh et al. 1990). Such mechanical measures, however, may not withstand a typical sandy or sandy loam soil because of breaching of the bunds due to pressure from the runoff water. Moreover, these are cost-intensive. Live-bunds or vegetative barriers are the alternative biological measures, which have been shown to effectively conserve soil and water by moderating the surface runoff and allowing the increased infiltration time (Krishnagowda et al. 1990). A review of the available literature indicates that world-over, vegetative barriers are used in the form of narrow filter-strips (also called as grass barriers) and filter-strips. The grass barriers are narrow strips (approximately 1.2 m wide) of tall, erect, stiff-stemmed, native perennial grasses planted on the contours to reduce the sediment yield, retard and disperse the runoff and facilitate benching of the slopes. Whereas, the vegetative filter-strips are typically much wider (more than 5 m) established between field borders and water ways (Blanco-Canqul et al. 2004) to protect land and reduce pollution in the water bodies (Srivastava et al. 1998). In India, vegetative barriers are mostly used in the form of narrow strips (few rows) to control erosion. Perennial grasses are also planted on the field or contour bunds and the risers of terraces in single or double rows. These grasses, in addition to providing strength and stability to the bunds or terraces, produce biomass which is used as fodder for animals or as thatching material. The role of vegetative barriers in soil and water conservation has been reported by various workers. Prasad et al. (2005) reported that on a 1% slope in a medium black soil at Kota, Rajasthan (India), the grass barriers reduced runoff by 5.7–6.5% from sorghum plots and 6.3–6.8% from soyabean plots with the corresponding reduction in the soil loss ranging from 0.76 to 1.03 Mg ha$^{-1}$ and 0.68 to 0.76 Mg ha$^{-1}$, respectively. At the International Crops Research Institute for Semi-Arid Tropics, Patancheru, Andhra Pradesh (India), vetiver reduced runoff by 57% and soil loss by over 80% (Rao et al. 1993). In the south Konkan coastal zone of Maharashtra (India), the vegetative barrier of lemongrass (*Cymbopogon citratus*) and Citronella grass (*Cymbopogon martini*), and graded bund with vetiver hedge decreased runoff by 55.5, 50.2 and 65.4% and soil loss by 5.94, 4.88 and 7.07 Mg ha$^{-1}$, respectively, over the control plot (Mane et al. 2009). In Kenya, napier grass (*Pennisetum purpureum*) reduced the amount of runoff and sediment loss by 54 and 92% and vetiver by 12 and 48%, respectively, over control (Owino and Gretzmacher 2002). Among the ten grass species evaluated in the shallow lateritic soils of Kolhapur, Maharashtra, India, *Pennisetum hohenackeri* was ranked the first for having the highest value of soil binding factor (516.51 kg cm$^{-2}$), better survival (76.5%) and better percentage of water stable aggregates (48.12% up to >0.25 mm and mean weight diameter 0.616 mm) as reported by Chunale (2004). However, the performance of vegetative barriers for soil and moisture conservation is governed by their hedge forming ability (Sharma et al. 2002).

Acceptance of vegetative barriers to the farmers can be enhanced, if, the species selected offer multiple benefits like conservation of rainwater, reduction in the soil erosion, and improvement in the crop yield and income (Katyal and Hegde 1994). Moreover, additional income from the sale of root or shoot biomass would compensate the farmers for the area lost under vegetative barriers (Mittal et al. 2002). Vetiver (*Vetiveria zizanioides*), initially, promoted as a promising grass species as vegetative barrier by the World Bank, was not found universally effective and acceptable to the farmers. It considerably failed in the dry zones because of the long dry summers (climatic conditions), damage caused to its roots by termites and rodents, and for the want of high level of management that is difficult to apply under the prevailing conditions of small and marginal farmers (Prakash et al. 1999). Non-availability of planting material locally, wider spreading growth and degeneration of clumps are the other important constraints limiting the adoptability of vetiver grass barrier. In India, a local grass, *sambuta* (*Saccharum* spp.) growing voluntarily in uplands as well as in waterlogged soils, was found to be as competent as vetiver in reducing the runoff and soil loss when planted on the miniature earthen bunds at a horizontal distance of 10 m on an 11% slope (Sudhishri et al. 2008). Whereas, the performance of vetiver in terms of its own growth and reduction in runoff and soil loss was inferior to that of local grasses in the semiarid region with deep vertisol soils in Karnataka, India (Ramajayam et al. 2007). In the sub-humid conditions of Doon valley and Shiwaliks, India too, the performance of vetiver barrier was outwitted by the grass species of local importance (Sharda et al. 2006). Sharma et al. (1991) observed that under farmers' field, the vetiver clumps were not adequate in thickness to make a good barrier with numerous gaps visible even after 4 years period and the plants could not grow beyond 15 cm. Another vegetative barrier, lemongrass, performed equally well as vetiver in the vertisols receiving 1,000 mm annual rainfall (Gupta 1993; Subudhi and Senapati 1996). At Koraput (Orissa), India, lemongrass barrier planted on the contour bunds (top width and height 0.3 m each, bottom width 0.6 m) with a continuous trench (0.45 m deep and 0.3 m wide with equalizers at a 3 m interval) on the upslope side, retained 41.4 Mg ha$^{-1}$ of sediment, and thereby conserved 236 kg ha$^{-1}$ organic C, 8.0 kg ha$^{-1}$ available N, 0.5 kg ha$^{-1}$ available P, and 7.1 kg ha$^{-1}$ available K (Dass et al. 2006). These vegetative barriers may behave differently under on-farm conditions where resource constrained farmers may not afford the level of management that researchers provide in the on-station experiments. Planting techniques may have influence on the survivability, growth and hedge forming ability of the vegetative barriers, which determine their resource conservation efficacy. Survivability and the fodder yield of vegetative barriers were considerably higher when planted on the contour bunds with 'V' ditch (V-shaped trench) compared to the contour bunds without 'V' ditch (Sharma et al. 2002). With this backdrop, the present investigation was carried out to study: (1) the impact of vegetative barriers on runoff, soil and nutrient losses, soil fertility, moisture retention and crop yield, (2) the interaction between the vegetative barriers and the test crop (finger millet), and (3) the biophysical growth of vegetative barriers.

## Materials and methods

### The study site

On-farm experiments on 60 experimental plots were set and monitored for the years 2002, 2003 and 2004 for hydrological parameters and 2001–2005 for crop yield and other biophysical parameters, at the Kokriguda model watershed (80° 50′ 0″ to 80° 51′ 30″ E, 18° 39′ 50″ to 18° 42′ 30″ N and 880–1,329 m above mean sea level), in district Koraput (Orissa), India. Soil of the study site was a red lateritic *Udic Paleustalfs* with sandy loam texture (sand 64.5%, silt 19.3% and clay 16.2%). The surface soil (0–15 cm) had organic C content of 0.38%, available N 186.5 kg ha$^{-1}$, available P 6.0 kg ha$^{-1}$, available K 294.6 kg ha$^{-1}$ and a pH of 6.4. Permeability and electrical conductivity of the soil was 2.80 cm h$^{-1}$ and 62.8 μS cm$^{-1}$, respectively. The slope of the experimental plots was 5%.

### The experimental treatments and crop management

Each experimental unit (plot) was 8 m wide and 60 m long with two cross bunds at a horizontal distance of 20 m. Figure 1 shows the installation of vegetative barriers along with bunds/trenches/*berms* and the runoff gauging devices in the experimental plots. Each experimental plot was bounded on all sides by a well compacted earthen bund and a shallow drainage channel to prevent the influences from outside. At the lower end of the plot, a galvanized iron (GI) plate was placed along the bund and compacted with a hard soil to obstruct the runoff. At the center of this reinforced bund, a multi-slot divisor having five slots was installed. The spout of the multi-slot divisor was connected to a 1 × 1 × 1 m runoff collection tank constructed with bricks and mortar. Six runoff plots (one replication) having similar properties were provided with multi-slot divisors and runoff collection tanks. The grasses were planted in double rows staggered (row to row and plant to plant spacing 0.3 m) on bunds (base width 0.45 m, top width 0.3 m, height 0.3 m) or *berms* (0.3 m wide space between trench and bund) at a vertical interval of 1 m. On a 5% slope, 1 m vertical interval is equivalent to a horizontal distance of 20 m. A continuous trench (width 0.3 m, depth 0.45 m) with equalizers at a 2 m interval was constructed on the upstream side (upper side) of the bund. In fact, the bunds were formed out of the earth excavated from digging of the trench. The experiment had six treatments consisting of the combinations of three vegetative barriers (*sambuta*, vetiver and lemongrass) and two planting methodologies (bund planting and *berm* planting). The treatments were set in a randomized complete block design replicated in 10 farmers' fields. Thus, the total number of experimental units (plots) was 60. Adjoining fields of the farmers without any vegetative barrier or bund were considered as the control plots for recording the yield, soil fertility and moisture content changes.

The test crop, finger millet (cv. Bhairabi) was sown in rows 20 cm apart across the slope in the first week of July every year. The first row of finger millet was sown at a distance of 10 cm from the bund/*berm*. The crop management practices like tillage, nutrient supply, weed control and pest control were done as per the farmers' practices. Land was ploughed thrice before sowing using the wooden local plough having single tine protected with an iron cap. The depth of ploughing was 15 cm. The crop was grown under rainfed conditions and was supplied with 25 kg ha$^{-1}$ each of urea and diammonium phosphate and 2 Mg ha$^{-1}$ farmyard manure. Weeds were controlled by one manual hand weeding at 30-day stage of crop.

### Data collection

#### *Analysis of runoff, soil nutrient and moisture characteristics*

For the runoff and soil loss studies, daily rainfall data were collected from the nearby rain-gauge installed at the Block Office, Semiliguda, district Koraput (Orissa), India. A total of 760, 585, 717, 771 and 1,096 mm rainfall was received in 43, 37, 49, 48 and 66 rainy days during the crop season of 2001, 2002,

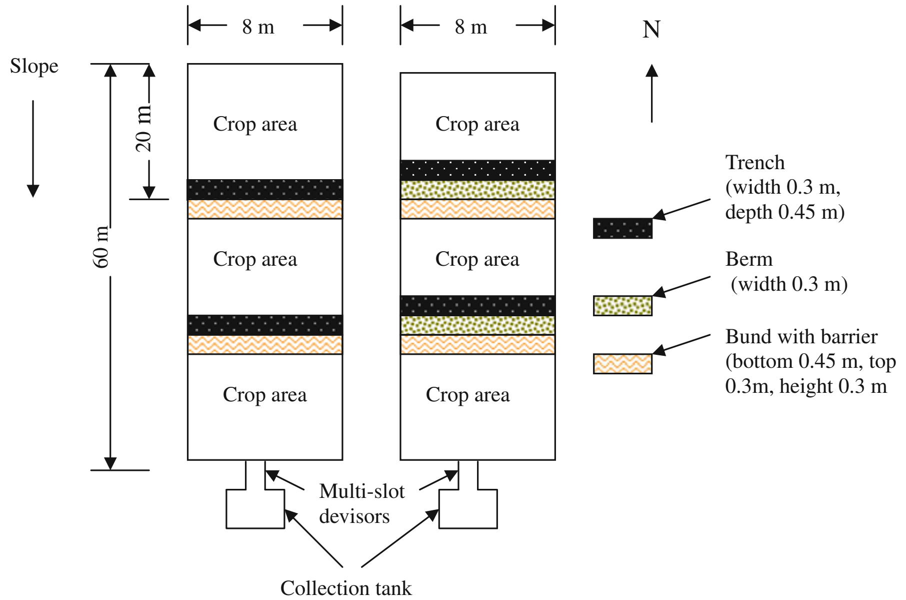


**Fig. 1** Sketch of two runoff plots with vegetative barriers and runoff gauging device

2003, 2004 and 2005, respectively (Figs. 1, 2). Runoff from the experimental plots was measured daily by measuring the depth of water collected in the runoff collection-tanks. To determine the soil and nutrient losses, runoff samples were taken after thoroughly churning the runoff with a rod, in one litre capacity glass bottles. For every observation, two samples were collected from each tank. These samples were stored in a refrigerator at a temperature of 4°C for 24–48 h in order to allow the suspended sediments to settle down at the bottom of the bottles. To determine the weight of soil eroded, sediment yield from runoff sample in one of the two bottles was dried in oven at 105°C till the constant weight was obtained and then weighed using an electronic balance.

Organic C, and available N, P and K contents in the runoff sediment were determined by using the wet

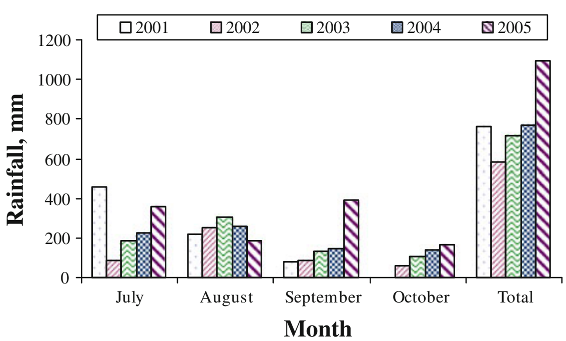


**Fig. 2** Monthly rainfall during crop season

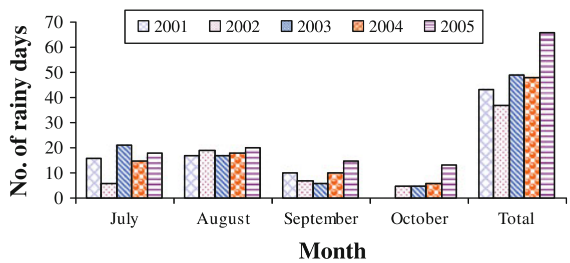


**Fig. 3** Number of rainy days during crop season

digestion method (Walkley and Black 1934); Alkaline $KMnO_4$ method (Subbaih and Asija 1956); Bray's P–I method (Bray and Kurtz 1945) and $NH_4OAc$ method (Hanway and Heidel 1952), respectively. At completion of the experiment, soil samples were collected from 0–15 cm layer and analyzed to study the impact of various conservation systems on the soil fertility. Moisture content of the surface soil (0–15 cm depth) at 0.5, 1.0 and 2 m distances from the bund both on upstream and downstream sides and at the centre of the plot (mid point between two consecutive bunds) was measured by gravimetric method.

*Finger millet (test crop) yield*

To determine the direct effect of vegetative barriers on the performance of associated crop (finger millet), yield was recorded at graded distances from the vegetative barriers. For this purpose, crop from the first 1 m wide horizontal strip consisting of five rows near the bund/trench, the second 1 m wide strip consisting of the next five rows and the third 1 m wide strip at the mid of the area between two successive bunds, was harvested separately. Although the length of these horizontal strips (parallel to the vegetative barriers) of the crop was 8 m (as width of experimental plots was 8 m), the net length of each strip was 7 m only because crop up to 0.5 m distance at both the ends of the strips was ignored. Crop from different strips (1 m × 7 m) was harvested and threshed separately and the weight of grains was recorded. Crop from the remaining area of the experimental plot, excluding 0.5 m border area on all the sides, was also harvested separately and weight of grains recorded. Grain weight from different strips and rest of the area (excluding borders) was accumulated to arrive at yield per plot or per ha. The yield variations at the graded distances from the vegetative barriers were calculated with respect to the average yield of the entire plot.

### *Growth performance of vegetative barriers*

To compare the growth performance of the three vegetative barriers (*sambuta*, vetiver and lemongrass), the morphological parameters like mortality, plant height, and thickness of clump, shoot diameter and inter-clump space coverage were measured for five sampled plants from each row of the vegetative barriers. These growth parameters were recorded in the last week of October after the harvest of finger millet. The vegetative barriers were cut at a height of 0.3 m from the ground in the first week of June during all the study years. To study the rooting behaviour, all the grasses were planted in the separate plots (2 × 2 m) adjacent to the experimental plots. Three clumps of each vegetative barrier were uprooted from these plots in the last week of October. Root portion was separated from the shoots and washed with water. The fresh roots were immersed in a graduated cylinder partially filled with water; the rise in the water level due to immersion of roots was noted as volume of the roots. Roots were then put in a brown paper, dried at 80°C in oven till the constant weight was obtained and weight of dry roots was recorded.

### *Statistical analysis of data*

Data on the hydrological parameter, viz., runoff, and soil and nutrient losses, were recorded from one replication only. Thus, the data (observations) pertaining to these parameters for each treatment were purposely divided into three groups. For any of the hydrological parameters, average value of the recorded observations falling in the first group was considered as the first replication, the second group as the second replication and the third group as the third replication. In this way each treatment had three replications of observations on hydrological parameters. Then statistical analysis of these data and the data on soil fertility, soil moisture content, crop yield and the growth characteristics of the vegetative barriers recorded form all the ten replications, was carried out as per the ANOVA procedures of randomized complete block design. Differences between individual means were compared at 5% level of probability.

## Results and discussion

### Influence of vegetative barriers on erosion and soil nutrient status

#### *Runoff and soil loss*

Lowest average runoff (8.1%) and soil loss (4.0 Mg $ha^{-1}$) were observed in the *sambuta* + trench-cum-bund followed by vetiver + trench-cum-bund treatment (runoff 9.77%, soil loss 12.95 Mg $ha^{-1}$). The lemongrass barrier, owing to its significantly lower survival, lower number of slips $clump^{-1}$, small clump size (clump girth), larger gaps between successive clumps and poor root growth, allowed significantly higher runoff than *sambuta* and vetiver. Whereas, significantly higher values of aboveground growth parameters coupled with better root proliferations in *sambuta* and vetiver resulted in significantly lower runoff and soil loss (Table 1). However, the longer and thicker roots with significantly higher dry weight and volume for *sambuta* had likely made the soil profile between and near the rows of this barrier more porous and permeable resulting in the greater channeling and infiltration of runoff obstructed and retained on the upstream side of the barrier into the soil. This, in turn, might have caused the reduction in runoff and soil loss from the *sambuta* treated plot compared to vetiver treated plot. The runoff and soil conservation effects of all the vegetative barriers were significantly augmented by bund planting over *berm* planting due to better growth characteristics of the barriers under former planting methodology. Owino and Gretzmacher (2002) reported a strong correlation between the growth of grass barriers and the runoff, soil loss and sediment deposition. Sudhishri et al. (2008) reported comparable runoff and soil loss from runoff plots having *sambuta* (runoff 9.48%, soil loss 4.39 Mg ha$^{-1}$) and vetiver (8.84%, soil loss 4.04 Mg ha$^{-1}$) barriers on an 11% sloping upland of Orissa, India. In the sub- humid conditions of Doon valley (the lower western Himalayas), India, Sharda et al. (2006) reported better conservation effect of *Panicum maximum* (runoff 32.5%, soil loss 6.2 Mg ha$^{-1}$) over vetiver (runoff 33.9%, soil loss 6.6 Mg ha$^{-1}$).

*Nutrient loss*

The highest organic C (102.07 kg ha$^{-1}$) loss was observed with lemongrass under *berm* planting, while the lowest (50.02 kg ha$^{-1}$) with *sambuta* under bund planting (Table 2). Bund- planted grass barriers proved significantly better in arresting the loss of organic C compared to *berm*-planted barriers. Nitrogen, the most important plant nutrient, is prone to losses by leaching with surface and sub-surface runoff, and causes the pollution of water in streams, reservoirs or tanks. *Sambuta* with 2.49 kg ha$^{-1}$ and vetiver with 2.81 kg ha$^{-1}$ N loss under bund planting were the most effective conservers of soil and applied N. The growth and hedge forming ability of the *berm*-planted barriers were relatively inferior, which permitted higher amounts of runoff and soil loss. The higher magnitude of soil loss was responsible for greater losses of organic C and N under *berm* planting than under bund planting of the barriers. Loss of available P was negligible and was not influenced significantly by the conservation measures. *Sambuta* under bund planting (0.17 kg ha$^{-1}$) was, however, the greatest protector of P followed by vetiver under the same planting methodology. Like nitrogen, K is readily soluble in water and prone to high losses along with runoff. In this study, the loss of available K from the bund planted *sambuta* plot was the lowest (1.56 kg ha$^{-1}$) closely followed by the bund planted vetiver plot (1.77 kg ha$^{-1}$), while the highest loss of available K (3.24 kg ha$^{-1}$) was recorded from the plots treated with *berm* planted lemongrass barrier (Table 2). Lower loss of organic C, and available N, P and K from the bund planted *sambuta*/vetiver plots is attributed to the lower amounts of runoff and soil loss from these plots. On the contrary, larger amount of runoff and soil loss from the lemongrass treated plot were responsible for the higher losses of soil nutrients. Lower loss of available P compared to available N and K is due to its low solubility and mobility, and high fixation to soil particles under acidic soils of the study region. In the southern region of Maharashtra, India, Bhanavase et al. (2007) also reported higher losses of N (3.04–5.72 kg ha$^{-1}$) compared to P (0.36–0.63 kg ha$^{-1}$) and K (0.24–0.51 kg ha$^{-1}$) under various grass barriers. Owino and Gretzmacher (2002) reported mean rate of N and P loss from vetiver grass treatments as 10.8 and 2.3 kg ha$^{-1}$ year$^{-1}$, and from napier grass as 6.3 and 1.17 kg ha$^{-1}$ year$^{-1}$, respectively.

**Table 1** Effect of vegetative barriers on runoff and soil loss

| Treatments | Runoff (%) | | | | Soil loss (Mg ha$^{-1}$) | | | |
|---|---|---|---|---|---|---|---|---|
| | 2002 | 2003 | 2004 | Average | 2002 | 2003 | 2004 | Average |
| *Sambuta* + bund | 7.83 | 8.26 | 8.10 | 8.06 | 3.69 | 4.30 | 4.10 | 4.03 |
| *Sambuta* + *berm* | 10.50 | 11.42 | 11.22 | 11.04 | 4.95 | 5.32 | 5.23 | 5.16 |
| Vetiver + bund | 8.96 | 10.44 | 9.90 | 9.77 | 3.9 | 4.87 | 4.74 | 4.49 |
| Vetiver + *berm* | 12.50 | 13.26 | 13.14 | 12.95 | 6.8 | 7.52 | 7.42 | 7.24 |
| Lemongrass + bund | 10.78 | 12.35 | 12.23 | 11.78 | 5.18 | 6.01 | 6.21 | 5.80 |
| Lemongrass + *berm* | 13.67 | 15.54 | 14.80 | 14.67 | 7.5 | 8.58 | 8.70 | 8.26 |
| LSD (0.05) | 1.10 | 2.10 | 1.75 | 1.68 | 0.42 | 0.55 | 0.52 | 0.65 |

**Table 2** Effect of vegetative barriers and planting methodologies on nutrient loss (kg $ha^{-1}$)

| Treatments | Organic C | | | | Available N | | | | Available P | | | | Available K | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species/year | 2002 | 2003 | 2004 | Ave. | 2002 | 2003 | 2004 | Ave. | 2002 | 2003 | 2004 | Ave. | 2002 | 2003 | 2004 | Ave. |
| *Sambuta* + bund | 41.33 | 54.61 | 54.12 | 50.02 | 2.14 | 2.64 | 2.69 | 2.49 | 0.15 | 0.19 | 0.19 | 0.17 | 1.34 | 1.66 | 1.69 | 1.56 |
| *Sambuta* + *berm* | 55.94 | 68.10 | 69.16 | 64.40 | 2.89 | 3.29 | 3.45 | 3.21 | 0.20 | 0.23 | 0.23 | 0.22 | 1.81 | 2.06 | 2.16 | 2.01 |
| Vetiver + bund | 43.68 | 62.34 | 62.98 | 56.33 | 2.27 | 3.00 | 3.14 | 2.81 | 0.15 | 0.21 | 0.22 | 0.20 | 1.43 | 1.91 | 1.97 | 1.77 |
| Vetiver + *berm* | 77.52 | 96.26 | 97.68 | 90.49 | 3.95 | 4.67 | 4.92 | 4.52 | 0.26 | 0.33 | 0.34 | 0.31 | 2.52 | 2.96 | 3.09 | 2.85 |
| Lemongrass + bund | 59.57 | 76.93 | 81.22 | 72.57 | 2.98 | 3.71 | 4.11 | 3.60 | 0.20 | 0.26 | 0.29 | 0.25 | 1.86 | 2.34 | 2.57 | 2.26 |
| Lemongrass + *berm* | 83.25 | 108.11 | 114.84 | 102.07 | 4.38 | 5.34 | 5.81 | 5.17 | 0.29 | 0.38 | 0.41 | 0.36 | 2.72 | 3.34 | 3.65 | 3.24 |
| LSD (0.05%) | 12.65 | 13.24 | 15.00 | 13.85 | 0.12 | 0.30 | 0.32 | 0.29 | NS | NS | NS | NS | 0.10 | 0.24 | 0.27 | 0.20 |

Ave. is average

*Soil fertility status*

Vegetative barriers significantly improved the soil fertility over the control plots (Table 3), which is the reflection of soil, nutrients and water conservation effects of the vegetative barriers. The highest organic C build-up (0.49%) was recorded from the *sambuta* treated plots which was significantly higher than the vetiver, lemongrass and control plots. Available K status was also the highest under *sambuta* treated plots (378.13 kg $ha^{-1}$) which was 26.9, 39.7 and 62.9% higher than the vetiver, lemongrass and control plots, respectively. Significantly higher organic C and K status in *sambuta* treated plots is attributed to the lowest loss of soil and nutrients. Vegetative barriers significantly improved the available P over the control plot; however, vegetative barriers did not differ significantly with one another. This might be due to a similar loss of P through runoff from these barriers, inherently low initial status of soil and fixation of applied or conserved P in the acidic red soils. Overall, *sambuta* proved to be the best arrester of nutrient loss. This finding demonstrates that the nutrient status of a soil can be improved by preventing their loss by water erosion using vegetative barriers. However, there was no significant change in the pH and electrical conductivity (EC) between control and vegetative barrier plots. Vegetative barriers are basically meant for conservation of nutrients and water. When the soil under study is inherently low in soluble salts concentration (even expressed in micro-simens $cm^{-1}$ level), the impact of different conservation treatments might not have been expressed in EC parameter. When the treatments were not significantly different in terms of EC, it is also expected that significantly different levels of soluble salts might not have been deposited in the vegetative barrier treated plots, which might be the reason for non-significant differences among different treatments for pH also.

## Effect of vegetative barriers on soil moisture and crop yield

*Soil moisture retention*

Soil moisture content measured by gravimetric method three days after rainfall at the most critical stage of the test crop (flowering), was the highest

**Table 3** Effect of vegetative barriers on soil fertility (0–15 cm depth) after 5 years of experimentation

| Vegetative barriers | Organic C (%) | Available P (Kg $ha^{-1}$) | Available K (Kg $ha^{-1}$) | pH | EC (micro-simens $cm^{-1}$) |
|---|---|---|---|---|---|
| *Sambuta* | 0.49 | 5.90 | 378.13 | 6.91 | 64.04 |
| Vetiver | 0.40 | 6.25 | 297.97 | 6.95 | 62.52 |
| Lemongrass | 0.40 | 5.84 | 270.74 | 6.87 | 80.67 |
| Control | 0.34 | 4.88 | 232.17 | 6.80 | 60.24 |
| LSD (0.05%) | 0.05 | 0.67 | 51.20 | NS | NS |

(range 17.1–19.1%) near the vegetative barriers and decreased with increasing distance from the barriers or bunds/trenches. On an average, the soil moisture content (17.9%) recorded at 0.5 m distance from the bund/trench was 4.7, 14.0 and 20.1% higher than at 1 and 2 m distance from the bund/trench and at the centre (mid point between two successive bunds) of the plot area, respectively. This could be due to a greater impounding and infiltration of runoff water and shading effect of vegetative barriers near the bunds. *Sambuta*, vetiver and lemongrass barrier treated plots retained 26.6, 22.7 and 15.3%, higher moisture, respectively, over the control plots (13.5%). Among the vegetative barriers, the *sambuta* treated plots (17.1%) had the highest moisture content which was, however, similar to vetiver plots (16.57%), but significantly higher than the control (13.5%) and lemongrass (15.56%) plots. The higher moisture content exhibited by the *sambuta* treated plots is due to greater conservation and infiltration of rain/runoff water into the soil. Patil et al. (1995) observed 16% higher soil moisture in the sorghum cropped plots when provided with vetiver barrier as compared to control.

*Test crop yield*

Vegetative barriers negatively influenced the yield of finger millet (test crop) from 1 m wide strip near the barrier both on the upstream (upper side of the bund or barrier in a sloping land) and the downstream sides (lower side of bund or barrier in a sloping land) (Fig. 1), compared to overall average yield from the entire plot (Table 4). This reduction in yield was larger on the upstream side due to temporary water logging or excess soil moisture during the rainy periods and the shading effect of barriers due to the sun facing orientation of the experimental plots. On the upstream side, lemongrass with bund planting caused the largest (44%) reduction in yield, which was significantly higher than the yield reductions owed to *sambuta* under any planting methodology and vetiver under *berm* planting. Likewise, there were yield reductions in 1 m strip on the downstream side of the vegetative barriers, but the level of overall reduction in yield was 12% less. Sudhishri et al. (2008) have reported a negative effect of *sambuta* and vetiver barriers on the finger millet yield up to 0.9 and 1.08 m, respectively, and of a comparatively taller and robust hill broom grass (*Thysanolaena maxima*) up to 1.38 m distance from the bund/barrier.

The negative impact of grass barriers on the crop yield was compensated and rather exceeded by a positive effect in the next 1 m wide strip (crop area between 1 and 2 m distances from the barrier) on both sides of the barriers, the central 1 m strip and by the crop area between second 1 m strip and central strip of the plot. The yield from the plot area (excluding the nearby 1 m wide strip on both sides the barriers) was 1.57–1.68 times greater than the yield from 1 m strip near the barrier on up and down stream sides. The gain in yield on the down stream side was larger than on upstream side might be due to beneficial effect of runoff water infiltrated into the soil on upstream side. *Sambuta* with *berm* planting resulted in the highest increase in yield at the second 1 m strip from the barriers on both upstream (21.1%) and downstream (33.3%) side. This was significantly higher than vetiver under any planting methodology on upstream side and with bund planting on downstream side, and lemongrass under any planting methodology on any side of the bund (Table 4). This could be due to a better runoff and soil conservation and less shading effect of *sambuta* than the other two barriers.

All the vegetative barriers increased the overall yield of finger millet considerably over the control

**Table 4** Yield gain and loss at graded distance from the vegetative barriers after five years of planting

| Treatments | Per cent yield loss or gain with respect to entire plot yield | | | | | |
|---|---|---|---|---|---|---|
| | Upstream side | | | Down stream side | | |
| | 1 m | 2 m | Centre | 1 m | 2 m | Centre |
| *Sambuta* + bund | −40 | 20.5 | 5.7 | −29.4 | 31.6 | 18.2 |
| *Sambuta* + *berm* | −39 | 21.1 | 4.2 | −27.5 | 33.3 | 17.7 |
| Vetiver + bund | −42 | 17.4 | 5.1 | −30.2 | 29.1 | 17.5 |
| Vetiver + *berm* | −41 | 18.2 | 4.7 | −28.6 | 31.5 | 16.5 |
| Lemongrass + bund | −44 | 15.9 | 4.5 | −32.8 | 25.8 | 16.3 |
| Lemongrass + *berm* | −41 | 17.5 | 4.0 | −29.5 | 27.5 | 16.0 |
| LSD (0.05%) | 3.24 | 2.15 | NS | 2.45 | 2.95 | NS |

during all the study years (Fig. 4). The yield from *sambuta* and vetiver treated plots was higher than the lemongrass treated plots by 13.2 and 11.9%, respectively. Significantly lower runoff, soil and nutrient losses and higher soil moisture content produced by the *sambuta* and vetiver barriers are the reasons for higher yield of finger millet under these barriers. The yield advantage accrued from the vegetative barriers over the control plots varied from 18.0% for lemongrass to 33.6% for *sambuta*. The crop yield, in general, was the highest during the year 2003 followed by the year 2004 due to a higher and well distributed rainfall of 715 and 771 mm occurring in 49 and 48 rainy days, respectively (Figs. 2, 3). The lowest crop yield was obtained during the year 2002 as it was a drought year with 585 mm rainfall occurring in 37 days. Doolette and Smyle (1990) reported that establishment of vetiver hedge in a contour cultivated field delayed the soil's wilting point by 14 days, and thereby, increased the finger millet yield by 57% over the control (0.79 Mg $ha^{-1}$). Mane et al. (2009) observed 25.9 and 5.43%, respectively, higher finger millet yields with lemongrass barrier and bund + vetiver barrier over the control (0.83 Mg $ha^{-1}$) in a lateritic hilly region.

*Biophysical performance of vegetative barriers*

Survival of grass barriers was, in general, better under *berm* planting than under bund planting (Table 5). However, *sambuta*, being a hardier and stress tolerant species showed significantly higher survival under bund planting over *berm* planting. Survival (about 84%) of *sambuta* and vetiver under bund planting was alike. Although lemongrass showed a poor survival rate, the survived plants grew the tallest.

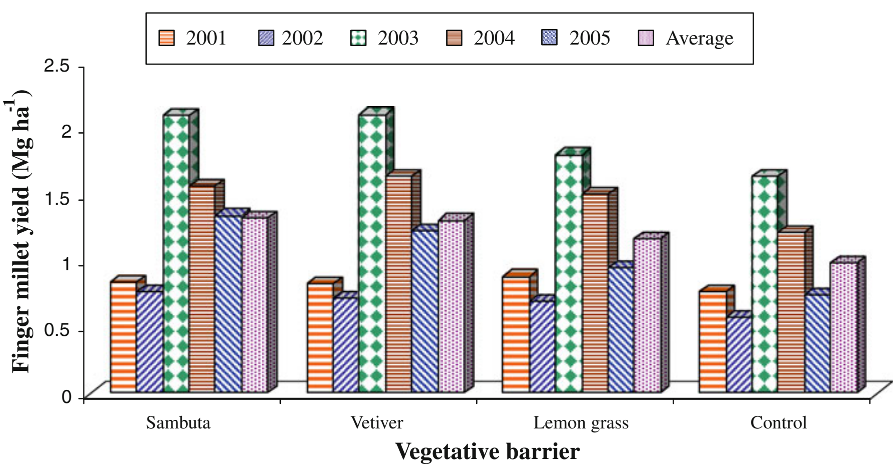


**Fig. 4** Effect of vegetative barriers on finger millet yield

**Table 5** Growth parameters of vegetative barrier species after 5 years of planting

| Treatment | Survival (%) | Height (cm) | Slips clump$^{-1}$ | Clump girth (cm) | Inter clump space covered (%) | Average root length (cm) | Dry root weight (g clump$^{-1}$) | Root volume (cc clump$^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| *Sambuta* + bund | 83.64 | 129.6 | 139.7 | 94.5 | 93.5 | 67.5 | 57.54 | 164.1 |
| *Sambuta* + *berm* | 75.91 | 121.8 | 124.4 | 82.7 | 93.0 | 62.0 | 51.36 | 148.7 |
| Vetiver + bund | 84.29 | 135.0 | 151 | 98.6 | 97.4 | 58.7 | 48.35 | 136.5 |
| Vetiver + *berm* | 85.24 | 130.2 | 131.4 | 87.0 | 96.5 | 52.3 | 42.62 | 122.8 |
| Lemongrass + bund | 34.74 | 159.1 | 68.9 | 50.8 | 48.6 | 39.8 | 28.41 | 62.6 |
| Lemongrass + *berm* | 40.50 | 154.5 | 64.8 | 42.8 | 49.2 | 34.2 | 23.85 | 49.8 |
| LSD (0.05%) | 1.55 | 3.5 | 14.6 | 6.7 | 25.32 | 5.82 | 5.34 | 13.85 |

On the other hand, the *sambuta* plants were the shortest, and thus, exerted the lowest shading effect on the finger millet crop. Bund planting significantly increased the plant height for all the barriers over *berm* planting. Highest number of slips clump$^{-1}$ and clump girth were produced by vetiver under bund planting which were, however, similar to bund planted *sambuta* and significantly higher than rest of the treatments. As a result of better growth, inter-clump space coverage was significantly larger in vetiver and *sambuta* than lemon grass.

Root growth in terms of average length, dry weight and volume was significantly superior in *sambuta* than other two barriers. Bund planting favoured the root growth, which is revealed by the significantly higher dry root weight and root volume under bund planting method. The variations in above- and below-ground growth parameters of the vegetative barriers might be due the genetic variability in these barriers. Moreover, the deep root system with average root length of 0.65 m for *sambuta* and 0.56 m for vetiver could have enabled these barriers to aptly withstand moisture stress and dry weather conditions particularly during the spring and summer periods by absorbing moisture and nutrients from the deeper soil layers. Such characteristics of *sambuta* and vetiver contributed to their better growth compared to thin and shallow rooted lemongrass (root length 0.37 m).

A significant improvement in the growth of vegetative barriers by bund planting is due likely to its better aeration effects than the naturally compacted *berms* and greater availability of sunlight during the crop period (rainy months). On the other hand, the lower parts of *berm* planted grass barriers suffered from the shading effect of the associated crop.

## Conclusion

Results of this on-farm study clearly demonstrate that the vegetative barriers in combination with small trench-cum-bund can be used for reducing the runoff, soil and nutrient losses, building up soil fertility, and enhancing soil moisture retention and crop yield. The obvious yield loss in the short distances from the barrier can be overcome by the yield gains from the remaining area of the plot. The benefits of vegetative barriers in terms of resource conservation make these barriers a suitable conservation technology to prevent water erosion and impart natural sustainability to the production potential of land for a long-term. Among the three grass barriers under study, *sambuta* (a local grass) barrier proved more effective than vetiver and lemongrass in the sub-humid region having predominance of red lateritic soils. This barrier in combination with a trench-cum-bund resulted in significantly less runoff, soil and nutrient losses and produced higher crop yield compared to other two barriers. After 5 years of establishment of barriers, organic C, available P and K status of the soil was the highest in the *sambuta* treated plots. Aboveground growth (erect plant type with less lateral spread of foliage) and root characteristics were also favourable with this barrier. Thus, the *sambuta* barrier with trench-cum bund is rated as the best conservation technology for treating and sustaining the productivity of the sloping uplands and medium lands of the sub-humid southern Orissa, adjoining states and other similar parts of India and the world. Vetiver also showed tremendously higher potential than lemongrass for resource conservation and increasing the crop productivity, and hence could be considered as the second best option under the sub-humid conditions. Lemongrass failed to compete with *sambuta* or vetiver in farmers' field. Other implications of this technology are the reduction in the sedimentation and pollution of water in streams and reservoirs. A large scale implementation of such measures in the catchments would reduce the flood hazards too.

Government of India in its watershed development programme is emphasizing the use of low-cost bioengineering measures for soil and water conservation. Trench-cum-bund planted with vegetative barriers offers an inexpensive, feasible and durable bioengineering measure. This technology has been adopted by the farmers of Kokriguda watershed (Orissa). Gradually, this technology is being adopted in other watersheds of the study region as well as adjacent states. However, farmers prefer *sambuta* grass barrier as it is erect growing, available locally and has a wider adaptability besides being conservation effective. Although performance of vetiver is also good, it has relatively spreading growth and involves transport cost which makes it relatively less attractive against *sambuta*. Thus, *sambuta* planted on bund with a trench on its upstream side is recommended for the conservation and bioremediation of the cultivated lands.

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