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Soil carbon sequestration and erosion control potential of hedgerows and grass filter strips in sloping agricultural lands of eastern India

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ABSTRACT

Contour hedgerows and grass filter strips are important towards enhancing and sustaining productivity of sloping agricultural lands in medium to high rainfall regions. However, impact of such measures on erosion control, soil carbon sequestration and agronomic productivity have not been widely assessed for the small land holders in eastern India. Therefore, an on-farm study was conducted between 2001 and 2006 to evaluate the impact of the techniques on soil organic carbon (SOC) concentration and pool; losses of water, soil and nutrients; soil moisture storage and agronomic yield on arable lands of 2–5% slope. The study was taken in 5.95 ha area with six treatments and nine replications. Treatments consisted of two hedgerow species (*Gliricidia sepium* and *Indigofera teysmanni*) and a control, with or without grass filter strip (GFS) of a local species (*Saccharum* spp.). Using finger millet (*Eleusine coracana*) as the test crop, the hedgerow species were planted at 0.5 m × 0.5 m spacing in staggered double rows and the GFS in a single row at 0.3 m spacing. In general, Gliricidia + GFS was most conservation effective followed by Indigofera + GFS. It reduced runoff by 33% (10.7% runoff compared to 16.1% in control), soil loss by 35% (6.3 Mg ha^{-1} compared to 9.71 Mg ha^{-1} in control), and SOC loss through runoff by 50 kg ha^{-1} yr^{-1}. In addition, it resulted SOC build up at 0.352–1.354 Mg ha^{-1} yr^{-1} at three graded distance from hedgerows, out of which 0.352 Mg ha^{-1} yr^{-1} was sequestered due to soil reclamation and about 1.0 Mg ha^{-1} yr^{-1} was retained due to barrier effect. With higher soil moisture storage by 28–37 mm and 22–43 mm at 12 and 17 days of dry spell, respectively, the grain yield of finger millet increased by 49% from 952 kg ha^{-1} in control to 1413 kg ha^{-1} in Gliricidia + GFS treatment. Addition of GFS significantly reduced the losses of water runoff, soil and nutrients in all the treatments, and increased SOC stock by 0.38–1.0 Mg ha^{-1} in the 0.6 m soil profile. The GFS also improved soil moisture storage by 9–12 mm and 6–15 mm at 12 and 17 days of dry spell, respectively. As compared to the pre-treated initial, the SOC stock decreased by 60–112 kg ha^{-1} yr^{-1} in the control indicating on-going erosion process in unprotected lands. The study showed the C sink potential of erosion control measures in the sloping agricultural lands of eastern India.

1. Introduction

Decline in soil quality, depleting soil organic carbon (SOC) and degradation of land resources due to erosion are the major impediments for future global food security. The productivity of some lands has declined by 50% due to soil erosion and desertification. In South Asia, annual loss in productivity is estimated at 36 million tons of cereal by water erosion (Eswaran et al., 2001). Eroded lands left unprotected lead to further erosion on-site and have greater off-site impacts. On the other hand, rehabilitation of eroded lands with conservation measures not only reverses the process of soil degradation but also improves the soil quality and converts these lands to potential carbon sinks (Lal, 2008; Lenka et al., 2012).

In India, 146.82 million ha (about 45% of the land area) area is under various forms of land degradation (SoER - India, 2009). Degradation is particularly severe in regions with sloping and hilly terrains and those affected by unsustainable land management practices such as shifting cultivation. The sloping and hilly regions of eastern India, called e*astern ghats* region with a geographical area of 19.8 million ha (Sikka et al., 2000) is such an erosion prone zone, having characteristic link of poor lands with people's poverty. For instance, the share of good quality soil in Orissa is one of the lowest, merely 10.4% of the land area of the state (Kumar, 2011). It also happens to be the most backward state of India with 46.4% of the population below poverty line (Planning Commission, GoI, 2012).

Shifting cultivation is prevalent in the hill slopes of the region. However, reduction in restoration or fallow cycle from 15 to 20

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years to the current level of 2–3 years due to population pressure, resulted in reduced farm output and increased land denudation (Lenka et al., 2012). This shifted focus of the people to settled cultivation on the sloping and undulated uplands and medium lands, with average slope varying from 2 to 5% and characterized by coarse textured *Alfisols*. These lands are located downside the denuded hillocks and are the major alternatives for the predominantly subsistence agriculture practiced in this rainfed region of India. Low soil fertility and erosion due to overland flow from denuded hill slopes do not permit more than one crop per year and a crop yield of more than 1.0 Mg ha^{-1} in these lands. Finger millet (*Eleusine coracana* L.) is the most common crop and in lands with better fertility, upland rice (*Oryza sativa* L.) is grown. Left unprotected, these arable lands yield to high runoff, get eroded and further damages the downstream cultivated lands due to erosion and siltation. Putting these lands to conservation treatments can restore productivity through reduced soil and nutrient loss, increased soil moisture and soil organic carbon (SOC) storage and consequent improvement in soil quality.

Mechanical measures for controlling soil erosion are not affordable by individual farmers because of extreme poverty condition. On the contrary, vegetative measures involving hedgerows and grasses are cost-effective, durable and find people's acceptance in this region as they offer multiple benefits such as for fodder and fuel wood. They are effective in low to medium slope ranges of arable lands (Chunale, 2004; Dass et al., 2011). The species generally used are vegetative barriers of grass species or shrubs and their performance for soil and moisture conservation depends upon their hedge forming ability (Sharma et al., 2002). Hedgerow intercropping though initially developed to restore the fertility of degraded soils in the tropics has been adopted in other regions not only for soil amelioration, but also to provide additional products (e.g. fodder) and services (e.g. erosion control) (Albrecht and Kandji, 2003). Contour hedgerows are reported to promote the SOC storage because of a local effect under the hedge and also due to their anti-erosive effect (Walter et al., 2003). They are also effective in maintaining soil fertility and reducing the soil and nutrient losses in sloping lands (Lin et al., 2009; Tao et al., 2012; Xu et al., 2012). As the cultivated lands are scarce and fragmented, systems such as alley cropping are not popular in arable lands of the study region. The most acceptable measures are modification to field bunds through strengthening with vegetative measures with shrubs or grass species.

Management practices such as conservation tillage (Lal et al., 1999; Schlesinger, 2000) and erosion control measures can improve the SOC stock and net C sink potential of sloping arable lands. Keeping in view the finite C sink capacity of soil (Chung et al., 2010), eroded lands, if put under erosion control measures, can be potential C sinks. Certain soil management practices such as application of manures, fertilizers, irrigation of semi-arid and marginal lands for crop production, though increase the SOC status, are not net C sinks for CO_2 emission and do not contribute to the Kyoto Protocol because of the associated carbon costs (Schlesinger, 2000). Even the advantages of no-till system over conventional tillage for SOC sequestration is questioned in recent studies (Blanco-Canqui et al., 2011; Ogle et al., 2012). SOC build up may be higher where the land cover is fully changed to pasture or agroforestry (Saha et al., 2010; Lenka et al., 2012). But, subsistence farming as prevalent in the region, (Srivastava et al., 2004) may not permit pasture or agroforestry in agricultural lands used for growing food crops, even if they are eroded. On the other hand, keeping the land use unaltered, eroded lands can be treated with conservation measures to offset the on-site and off-site impacts on soil and environment.

Much of the studies on SOC storage and C sequestration in arable lands have focussed on tillage and residue management practices, but not on erosion control measures. Even, in majority of sequestration studies, the sampling depth is restricted to 30 cm or less (Baker et al., 2007), which gives an unclear picture about the effects of conservation tillage on C sequestration. On the contrary, erosion control measures apart from soil amelioration effect minimize the loss of C by reducing the runoff and soil loss, which should be counted while computing the net C sink benefits. However, impact of such measures on erosion control, soil carbon sequestration and agronomic productivity have not been widely assessed for the small land holders in eastern India. Thus, this study attempts to compare the net soil C sink potential of selected soil conservation treatments and their efficacy for retaining nutrients and moisture in the sloping arable lands of a sub-humid sub-tropical region of eastern India.

2. Materials and methods

2.1. Experimental site

The experiment was conducted in farmers' fields in a participatory research mode for 5 consecutive years during 2001–2005 in a micro-watershed located at Kokriguda village in Koraput district of Orissa, in the *eastern ghats* of India (Fig. 1). The selected watershed is a completely tribal village with illiterate (less than 10% literacy) and poor populace. The experiment site is located at 18° 45′ N latitude and 82°42′E longitude and at 910 m above mean sea level. The study area comes under sub-tropical and sub-humid type of climate, with annual mean maximum and minimum temperatures of 30.6 °C and 17.0 °C, respectively. Mean annual rainfall is 1373 mm, 80% of which is received during June–September. Soil type is predominantly red lateritic and acidic with pH around 6.0 and come under *udic paleustalfs* as per USDA soil classification.

2.2. Experimental treatments

The experimental treatments consisted of selected soil conservation systems on miniature field bunds of 0.15 m × 0.60 m (height × width) in 54 plots in farmers' fields with two hedgerow species – *Gliricidia sepium* and *Indigofera teysmanni* – integrated with or without filter strips of a local grass species – Sambuta (*Saccharum* spp.); a control and a sole grass filter species (GFS), taken in nine replicates in a randomized block design. Thus, the treatments were: (1) Gliricidia, (2) Gliricidia + GFS, (3) Indigofera, (4) Indigofera + GFS, (5) Control, (6) Sole GFS. The treatments covered 5.95 ha area, with average land slope of 2–5%. The minimum running length of the conservation system for each treatment was 10 m. The hedgerow species were planted at a spacing of 0.5 m × 0.5 m in staggered double rows and the grass filter species was planted in a single row at 0.3 m. A total of 1800 m bund length was planted with the selected treatment species during July 2001. A third hedgerow species, perennial arhar (*Cajanus cajan*) though was taken initially but was a failure due to its poor survival. Thus, from the year 2002, the treatments were continued with two hedge rows species and a grass species, as mentioned above, with a control and the monitoring of data such as runoff and soil loss started from 2002. A schematic presentation of the treatment lay out is given in Fig. 2.

2.3. Test crop

To compare the efficacy of conservation treatments on crop performance, a medium duration (105 days) finger millet crop (cv. Bhairabi) was taken at a row–row spacing of 0.2 m across the slope in the first week of July during the experiment period. As the experiment was conducted on a participatory on-farm research mode, the crop was sown direct seeded under rainfed conditions with nutrient and weed management practices followed by the local farmers. The