Catena 147 (2016) 755–763

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Sediment trapping with indigenous grass species showing differences in plant traits in northwest Ethiopia

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ARTICLE INFO

Article history:
Received 8 September 2015
Received in revised form 27 August 2016
Accepted 30 August 2016
Available online 7 September 2016

Keywords:
Soil conservation
Runoff
Sediment trapping efficacy
Key functional traits
Desho

ABSTRACT

Soil loss from an 8% sloping Teff field in north-western Ethiopia is significant (~70 t ha^{-1} yr^{-1}), and thus found to be an important source of sediment. Grass barriers showing sediment trapping efficacy (STE) are important measures in trapping sediment inside Teff fields and protecting downstream reservoirs and lakes from sedimentation. There are many indigenous grass species available that have the potential to act as sediment trapping measure when used in strips downstream of sloping crop fields. However, their STE and their key functional traits that determine their STE are not yet known. This negatively influence agricultural extension agents in disseminating conservation technology to farmers at larger scales. The indigenous grass species Desho (*Pennisetum pedicellatum*), Senbelet (*Hyparrhenia rufa*), Sebez (*Pennisetum schimpri*) and Akirma (*Eleusine floccifolia*) and one exotic species, Vetiver (*Vetiveria zizanioides*) were tested for two years (2013 and 2014) in 1.5 m wide strips below Teff fields at 8% slope in the Debre Mewi watershed, northwest Ethiopia. The average runoff during the study was 79, 64, 69, 71, 74 and 75 l m^{-2}, with 7.0, 1.7, 2.9, 3.6, 4.5 and 5.6 kg m^{-2} yr^{-1} of sediment from the Control, Desho, Vetiver, Senbelet, Akirma and Sebez treatments, respectively. Differences in key functional traits affected the STE of the different grass barriers. Desho with the highest tiller number and density, and the second highest root length (depth) showed better STE (76%) than the other grass species, Vetiver (59%), Senbelet (49%), Akirma (36%) and Sebez (20%). This indicates that grass barriers can be used as a soil conservation measure replacing the costly and more maintenance demanding physical structures like trenches and ridges. As a co-benefit, grass barriers provided important fresh biomass for livestock, thereby helping to reduce the feed shortage. Thus we conclude that indigenous grass species provided a practical means to reduce soil loss from Teff fields (up to 8% slope) in the northwest Ethiopia and can be easily adopted by farmers due to their combined soil conservation and feed value.

1. Introduction

Soil erosion by water is a global problem (Morgan, 2005), however, it is more severe in developing countries (Lal, 2001; Thomaz and Luiz, 2012), such as Ethiopia, where soil erosion of agricultural fields is leading to the loss of fertile top soil (Hurni, 1993; Zeleke, 2000) and significantly reducing crop yields (Hurni, 1993; Haileslassie et al., 2005). The problem is most critical in the Ethiopian highlands (> 1500 m a.s.l.) (FAO, 1986; Zeleke, 2000; Nyssen et al., 2004; Frankl et al., 2013) as 4% of the highlands is seriously eroded (Kruger et al., 1996). Plot scale measurements of soil loss in the cultivated fields of the Ethiopian highlands has been estimated to be 42 t ha^{-1} yr^{-1} (Hurni, 1987).

Recent and more location specific studies at watershed scale estimated sheet and rill erosion losses between 19 and 79 t ha^{-1} yr^{-1} at Chemoga watershed (Bewket and Sterk, 2003), and from 12.5 to 50 t ha^{-1} yr^{-1} at Debre Mewi Watershed (Mekonnen and Melesse, 2011). Amare et al. (2014) also found from 26 to 71 t ha^{-1} yr^{-1} at plot scale in Debre Mewi watershed. Erosive tropical rains, steep slopes, extensive deforestation for fuel wood collection, expansion of cultivation into steep land areas, overgrazing, long periods of inadapted agricultural practices and high population pressure are important causes of such high rates of soil erosion in the north-western Ethiopian highlands (Bewket, 2002; Nyssen et al., 2004; Amsalu et al., 2007; Mekonnen and Melesse, 2011; Mekonnen et al., 2015a).

To maintain sustainable crop cultivation about 75% of the highlands need soil conservation measures (FAO, 1986). The use of on-site sediment trapping measures can reduce soil loss by promoting sedimentation within farmers' fields (Verstraeten et al., 2006; Wanyama et al., 2012; Mekonnen et al., 2014). Vegetative measures, for example grass barriers, are among the on-site measures that play a significant role in trapping sediments from overland flow (Ritsema, 2003; Blanco-Canqui et al., 2004; McKergow et al., 2004; Stroosnijder, 2009;

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http://dx.doi.org/10.1016/j.catena.2016.08.036
0341-8162/

Wanyama et al., 2012). This is because of sediment filtration and deposition (Dillaha et al., 1989), upslope ponding (Meyer et al., 1995; Spaan et al., 2005), and decreased flow velocity and increased surface roughness, which decreases sediment transport capacity of surface runoff (Borin et al., 2005). Grass barriers also increase the efficacy of physical soil conservation structures in trapping sediment and reducing on-site soil loss when combined together (Rachman et al., 2008; Mekonnen et al., 2014) and are less expensive and less labour intensive to implement than physical structures such as trenches and ridges. As a co-benefit, grass barriers provide livestock with feed and this can play an important role in controlling free grazing, encouraging a cut and carry system for soil conservation and in the adoption of the measures (MoA, 2001; MOARD, 2010).

The sediment trapping efficacy (STE) of many grass species is well known. For example; Lemon grass (72–92%), Elephant grass (62–84%), Paspalum (65–88%) and Sugarcane (56–82%) in Uganda (Wanyama et al., 2012); Vetiver grass (65%) in Australia (McKergow et al., 2004); Brome grass (70–85%) (Robinson et al., 1996) and Switch grass (92%) (Lee et al., 2000) in the USA; Centipede grass (24–73%) in Japan (Shiono et al., 2007); Black rye (42–69%) in China (Pan et al., 2010) and Vetiver (62%) and Desho (43%) in the lowland part of Ethiopia (Welle et al., 2006). The STE of Desho grass was tested by Welle et al. (2006) in the lowland part of Ethiopia but not in the highlands where it performs best (MOARD, 2010). There are in fact many grass species that could potentially serve as vegetative barriers in the northwest Ethiopian highlands but have not been studied for their STE including locally used grass species Desho (*Pennisetum pedicellatum*), Senbelet (*Hyparrhenia rufa*), Sebez (*Pennisetum schimpri*) and Akirma (*Eleusine floccifolia*). Traditionally, these four grass species are being used by a majority of Ethiopian farmers by planting them on their lower field edges in 1–1.5 m wide strips.

Investigating the STE of these indigenous grass species in northwest Ethiopia will provide valuable information for local farmers, agricultural extension agents and researchers. To facilitate the extrapolation of results to other contexts and species, attention should be paid to key functional traits. Grass morphological characteristics such as number of tiller, density and root depth affect STE (Pearce et al., 1997; Abu-Zreig et al., 2004; Spaan et al., 2005; Montakhab and Yusuf, 2011; Burylo et al., 2012; Wanyama et al., 2012). Spaan et al. (2005) found that dense vegetation barriers promote sedimentation reducing flow velocity and building up backwater upslope. STE is influenced by the type and density (Abu-Zreig et al., 2004), and density and distribution (Montakhab and Yusuf, 2011) of the grass barrier. Plant roots increase the resistance of soils to erosion (Reubens et al., 2007) and help improve soil permeability, increasing soil infiltration and thus decreasing runoff volume, thereby promoting sedimentation. Furthermore, a plant with deep roots can access water deep below the surface, which increases infiltration and reduce runoff, thus increasing sedimentation (Ohare et al., 2016).

This study evaluated the STE of four indigenous grass species (Desho, Senbelet, Akirma and Sebez) and one exotic grass species (Vetiver), to determine the differences in plant traits, in northwest Ethiopia. The objectives were to (i) evaluate the STE of these grass species at the field level, and (ii) determine the differences in STE through the key functional traits of these grasses (root depth, tiller number and density). Finally, an assessment of the chance of adoption of these plants by farmers in northwest Ethiopia, based on social and economic considerations, is presented.

2. Materials and methods

2.1. Experimental site

The study was conducted over a two year period using experimental plots located at an elevation of 2300 m a.s.l., with an average slope of 8% (ranging from 7 to 9%), in the Debre Mewi watershed, in the upper Blue Nile Basin, northwest Ethiopia (327,865 m N and 1,256,370 m E; Adindan_UTM_Zone_37N; Fig. 1). The average annual rainfall over these two years was 1080 mm (1105 mm in 2013 and 1055 mm in 2014). About 80–90% of the rainfall falls in the main rainy season (*Kiremt*), which starts in June and extends to September, but is preceded and followed by one month of low and dispersed rains. Mean annual minimum and maximum temperatures of the site are 8.7 °C and 25.4 °C, respectively.

The Nitosol soil type present has a predominantly clay texture (Mekonnen and Melesse, 2011; Mekonnen et al., 2015b) containing 12% stoniness. According to Bationo et al. (2006), Nitosols are deep, well drained and red tropical soils with a clay-rich subsoil, characterized by good soil structure. They are in general considered to be fertile soils and are found in ~200 million ha worldwide, with more than half of all Nitosols present in tropical Africa, especially in the highlands (>1000 m) of Ethiopia, Kenya, Zaire and Cameron.

2.2. Field experiment

The experiment was conducted during the 2013 and 2014 seasons on a natural slope, which was treated similarly as the surrounding farmland (Fig. 2). Six runoff plots (6 m wide × 29.5 m: 177 m^2) were constructed according to the Soil Conservation Research Programme

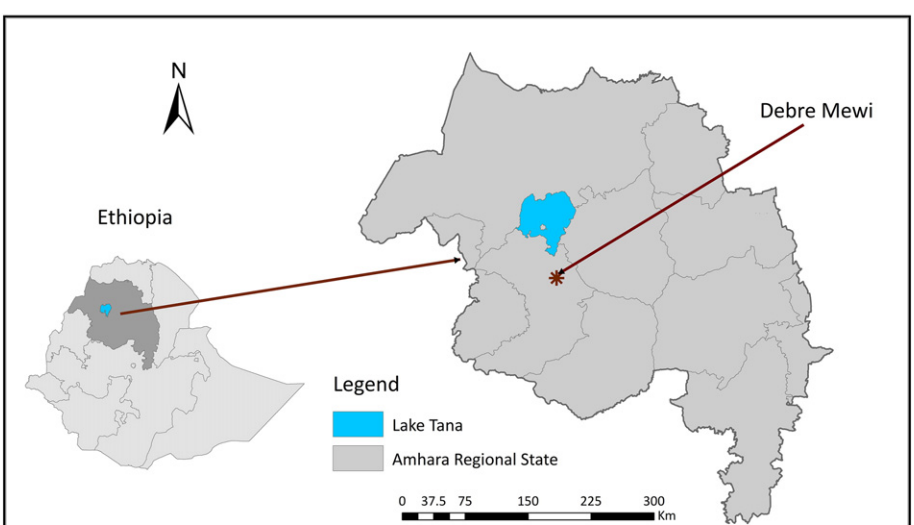

Fig. 1. The Debre Mewi watershed in Amhara Regional State of Ethiopia.