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Watershed management to enhance rainwater conservation and crop yields in semiarid environments—A case study at Hamelmalo Agricultural College, Anseba region of Eritrea

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ABSTRACT

Rainwater conservation on watershed basis is key to controlling land degradation and ensuring sustainable high yields in Eritrea, which has only 17.2% land potentially available for agriculture. Study was undertaken in 4.29 ha watershed (slope <1–33%) at Hamelmalo with a mission to store entire rainwater as soil water through adoption of soil conservation measures. Measurements were made of slope, runoff, soil loss, gullies and basic soil properties. Based on slope, watershed land was divided into block A (1.32 ha; slope ≤1%), block B (0.89 ha; slope >12–33%) and block C (2.08 ha; slope >1–12%). Runoff was measured for 2 years from 30 m^2 plots on 3, 6 and 9% slopes using a 10 slot runoff divisor placed at the outlet. Soil loss was determined by drying part of the storm runoff. About 80–90% of the rainfall exceeding 20 mm was being lost as runoff from 9% slope. Weighted average runoff from the watershed was 66% of the rainfall, which reduced to zero after development. Soil loss was 42.4 t ha^{-1} $year^{-1}$ on 3% slope and 268.6 t ha^{-1} $year^{-1}$ on 9% slope. Soil was stony loamy sand in block A, gravelly loamy sand in block B and gravelly sandy loam in block C. Bunding was done in block A (≤1% slope), ridging in block B (>12–33% slope) and broad base conservation bench terracing in block C (>1–12% slope). Runoff storage canal was constructed along foot of the block B land to intercept runoff. Soil bunds, terraces with shoulder bunds and runoff storage canals were most effective in rainwater conservation. Ridges in block B were unstable. After development, land in block A upgraded to capability class III, block B to class V and block C to class I, subject to availability of irrigations. Maximum water holding capacity of soils was 0.378 m^3 m^{-3} in block A, 0.389 m^3 m^{-3} in block B and 0.45 m^3 m^{-3} in block C. Soil profile in 2 m depth could thus accommodate about 756 mm rainwater in block A, 778 mm in block B and 900 mm in block C. This is more than peak rainfall in the last 90 years. Watershed development prevented further land degradation and raised average yield of sorghum (*Sorghum bicolor* L.) from <600 kg ha^{-1} on farmer's fields to 1930 kg ha^{-1} in block A and 3818 kg ha^{-1} in block C. Net return from sorghum crop was USD 13997 in the first year as against a total expenditure of USD 18,400 on watershed development.

1. Introduction

Rainwater conservation on watershed basis is a promising way to control soil erosion and achieve sustainable high yields in semiarid environments (Heathcote, 1998; Juel, 2001). It is of the utmost importance in Eritrea (Juel, 2001), which is not endowed with perennial rivers, springs or artesian wells. About 39% of the land area in Eritrea is arid, 37% semiarid and about 24% sub-humid (MOA, 2005). Of the total area, only 17.2% could be potentially used for agriculture in valleys surrounded by degraded hills or along ephemeral rivers and their tributaries criss-crossing the area. Almost all agricultural watersheds in the country are thus associated with non-agricultural degraded hilly lands. Proportion of non-agricultural land is relatively more in Anseba region, which is semiarid and farmers depend on agro-pastoral farming (MOA, 2005). The agricultural lands are often undulating with slopes ranging from less than 2 to more than 33%. Sorghum (*Sorghum bicolor* L.) is a major crop of the region, planted on existing field slopes without adoption of soil conservation measures. Farmers depend more on animal production than cereals due to average annual yields of 0.2–0.6 t ha^{-1} in the last 10 years (FAO, 2005; MOA, 2005). Low crop

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yields have been credited to poor soil quality and low and erratic rainfall (MOA, 2005). <!–

More than 90% agricultural land in Eritrea is degraded due to severe sheet and gully erosion leaving rocks and stone pieces outcropping in a large proportion of the land surface (Haile et al., 1998; MOA, 2005; Tripathi and Ogbazghi, 2010). Threshold retention of rainfall in the catchments has been low due to high slopes, poor vegetation, compact stony surface as a result of raindrop impact, repeated trampling by grazing animals and erosion (Frasier, 1980; Rockstrom et al., 2002; MOA, 2005; Isaac, 2008; Rockstrom et al., 2008). Land degradation is further aggravated by conventional practice of 3 ploughings before planting sorghum and another about 20–25 days later in the standing crop (Isaac, 2008; Temesgen et al., 2008). Whereas potential storage capacity of soils was sufficient to store entire rainwater in the root zone, about 70–90% of the annual rainfall was being lost as runoff from non-agricultural lands and 65–70% from agricultural lands under the conventional farming practices (Tripathi and Ogbazghi, 2010). Levelling and bunding alone to conserve rainwater in the root zone raised rainfed sorghum yields to 2.8 t ha^{-1} on cultivated fields at Hamelmalo Agricultural College (Isaac, 2008).

Temesgen et al. (2008) reported that traditional practice of tillage 3–4 times during the season in Ethiopian highlands facilitated conservation of 25–35% of rainwater. Almost 100% rainwater infiltration was only possible in level and well bunded fields covered 100% by plant residue mulch (Derpsch, 2000; Rockstrom and Falkenmark, 2000; Derpsch, 2003; Bolliger et al., 2006; Isaac, 2008; Temesgen et al., 2008). *In-situ* rainwater harvesting and local runoff storage canals and ponds have shown significant influence on agriculture in semiarid regions of the world (Boers and Ben-Asher, 1982; Tripathi and Singh, 1993; Rockstrom et al., 2002; Amlesom, 2005; MOA, 2005).

Runoff from non-agricultural lands, which is also rich in nutrients and soil colloidal fractions, if stored or diverted at least partly into agricultural fields can serve as extra rainwater and nutrients for crop use at affordable costs (Elwell and Stocking, 1988; Blevins and Frye, 1993; Tripathi and Ogbazghi, 2010). Surface runoff could be controlled to infiltrate *in-situ* and become soil water through adoption of soil conservation measures. The crop yields in Eritrea are thus limited not only by low and erratic rainfall but also by poor rainwater management.

Whereas feasibility of investments in big reservoirs to harness runoff for crop production in Eritrea is questionable (Mehari, 2005), it is undoubtedly cost-effective to conserve rainwater *in-situ* at least in agricultural watersheds involving few to many smallholder farmer's fields and upscale from the successful pilot studies (Juel, 2001). Rockstrom et al. (2002) also made similar observations and emphasized efficient rainwater harvesting for high yields in semiarid environments. Unless crop yields are guaranteed through management and technology demonstrations on large to small farms, Eritrean farmers are hesitant to adopt soil conservation measures (MOA, 2005). No such efforts were made in Eritrea in the past and authors are not aware of any effort to demonstrate harvesting of entire rainwater as soil water in north eastern sub Saharan Africa. The Hamelmalo Agricultural College in Anseba region of Eritrea adopted 4.29 ha hilly watershed (slope <1–33%) in 2008 to demonstrate benefits from watershed development to farmers and researchers. The watershed land was severely eroded forming deep and wide irregular gullies sheltering wild animals (Tripathi and Ogbazghi, 2010). Soils of the watershed are alluvium deposits brought by Anseba River and its tributaries from hilly terrains. Such soils are highly responsive to fertilizers and irrigations (Karlen et al., 2001; Tripathi et al., 2005). However, they proved unproductive due to uncontrolled erosion as a result of poor management. The objective of this study was to determine severity of runoff and soil loss and evaluate rainwater conservation measures and land use in terms of their effectiveness in controlling soil erosion and storing entire rainwater as soil water for sustainable high yields under rainfed farming in semiarid Hamelmalo.

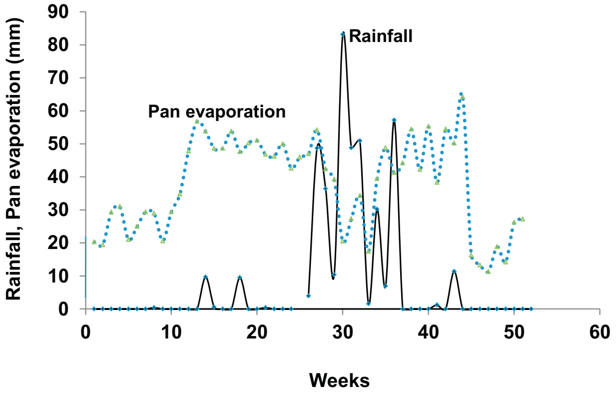

Fig. 1. Weekly total rainfall and pan evaporation at Hamelmalo in 2009.

2. Materials and methods

2.1. Description of the watershed

The selected watershed was 4.29 ha at Hamelmalo Agricultural College (15°52′20.6″N and 38°27′57.6″E at 1280 m above MSL) in the semiarid region of Eritrea. Annual rainfall in the past seven years ranged from 370 to 663.1 mm with a mean of 488 mm. As shown in Fig. 1, monsoon commences at Hamelmalo by the fourth week of June and ends by the second week of September and accounts for more than 90% of the total annual rainfall. Highest rainfall occurred in July. Average annual pan evaporation was 1931 mm, which was about 4 times the average annual rainfall. Highest mean monthly temperature occurred during May (35.7 °C) and lowest in January (11.1 °C).

Based on slope, the watershed was broadly divided into three blocks *viz*, block A in the upper portion (1.32 ha on slope ≤1%), block B in the middle portion (0.89 ha on slope >12–33%) and block C in the lower portion (2.08 ha on slope >1–12%). Before adoption, land was open to free grazing and was sparsely vegetated with wild grasses, thorny shrubs and trees comprising of *Acacia* and *Zizyphus* species. Severe sheet and gully erosion exposed gravels and stones that covered about 70–90% of the land surface in block A, 60–80% in block B and about 20–30% in block C (Table 1). $CaCO_3$ concretions were visible in block B. Three distinct 4–6 m deep and 15–30 m wide gullies were formed in blocks B and C together with many smaller gullies joining into larger ones. Dominant vegetations were *Acacia tortilis, Acacia seyal, Acacia nubica* and *Acacia senegal* followed by *Zizyphus spina christi*, *Balanites aegyptiaca* and *Adansonia digitata*.

2.2. Measurement of watershed characteristics

2.2.1. Surface features and physicochemical properties

The watershed land was surveyed using theodolite along with GPS to determine slope, contour lines, boundary area and map delineating the terraces (Fig. 2). Surface features such as gravel and stone percentages, vegetation characteristics, erosion conditions and texture were studied in 400 m^2 grids. Five soil profiles of surface dimension 1.5 m × 1.5 m and depth 2 m were dug at representative locations to study soil depth, physicochemical properties, and horizon differentiations. Two profiles were dug each in block A and block B and three in block C. Soil properties determined were texture, pH, EC, available nitrogen (N), extractable phosphorous (P), exchangeable potassium (K), bulk density, field capacity