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Effectiveness of sustainable land management measures in West Usambara highlands, Tanzania

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ABSTRACT

Soil erosion is a serious problem that affects food security and social livelihoods in the highlands of East Africa. Sustainable land management (SLM) measures have been widely promoted to reduce erosion and increase crop yield, but the adoption of SLM measures has remained low. In order to understand the contribution of bio-physical factors on adoption, this study was carried out to (i) determine the biophysical conditions of fields with SLM measures; (ii) assess the impact of different SLM measures on soil degradation; and (iii) determine the effects of SLM measures on crop productivity. The study was conducted in Lushoto District, north-eastern Tanzania. Sixty fields with five different SLM categories were studied. The five SLM categories ranged from no intervention at all (SLM 5 — control plots), to excellent land and crop management, including well-constructed bench terraces and application of farmyard manure (SLM 1). SLM 2 also has terraces, but the management is not as good as for SLM 1. SLM 3 has some poorly maintained terraces or grass trips, while SLM 4 has only poorly maintained grass strips. The bio-physical properties of the fields were determined, and measurements of meteorology, soil properties, soil erosion and crop yield were carried out during the period October 2009–June 2011. The results showed that the better SLM categories (SLM 1 and SLM 2) are preferentially implemented on less steep slopes, and they do stabilize the slope and reduce soil losses by water erosion significantly. The use of high amounts of farmyard manure (>6.0 ton ha^{-1} y^{-1}) on the terraces of SLM 1 and SLM 2 category fields resulted in a 3 to 4 times higher yield of maize compared to the control plots (SLM 5), while yield of beans increased 6 to 7 times compared to the control plots. Despite the use of farmyard manure on better managed fields, no significant improvements of soil fertility were found. This is probably because the amounts applied are too small to allow build-up of soil nutrients.

1. Introduction

The East African highlands occupy only one quarter of the collective area of Burundi, Ethiopia, Kenya, Rwanda, Tanzania, and Uganda, but are home to more than 50% of their combined population (Kassie et al., 2010; Nyssen et al., 2009). The agro-socio-ecological importance of these highlands is their adequate water, reliable precipitation, good soils, rich vegetation cover and minimal occurrence of malaria. This favorable rating has drawn in many people to settle and exploit natural resources, leading to high population densities of sometimes more than 300 people per km^2. Unfortunately, the growing population coupled with poor resource-use practices have resulted in widespread land degradation problems, which now contribute to the agricultural crisis in the East African highlands. Land degradation in highland agro-ecosystems has been reported from Kenya (Gachene et al., 1997), Rwanda (Byiringiro, 1995) and Tanzania (Tenge, 2005).

The West Usambara highlands in Tanzania are one of the East African Highland zones that suffer from land degradation (Conte, 2004). They consist of crystalline block mountains which are part of the Eastern Arc Mountains located in north-eastern Tanzania. Massive land degradation in this region began with the introduction of commercial crops and establishment of related estates (Johansson, 2001). Within a few years of establishing crop plantations and introduction of commercial crops, serious soil erosion from both plantations and new cash crop fields was reported. Not just commercial land use activities suffered from soil degradation. Also, the many smallholder farmers who cultivate small plots (<1 ha) on steep slopes to grow food crops experience problems of soil erosion (Tenge, 2005).

Numerous soil conservation schemes since the 1930s were implemented in the West Usambara highlands to reverse soil degradation though many of them failed because of being implemented by coercion (Maddox, 2006). On the other hand, even schemes which were

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implemented through a participatory manner have also reported a dismal adoption of the advocated technologies (German et al., 2010), which suggests that problems may not be purely methodological. Other studies have also indicated adoption of technologies to be constrained by socio-economic conditions (Matata et al., 2010), policy issues (Marenya et al., 2012), institutional issues (Komakech and van der Zaag, 2011) and biophysical conditions (Mbilinyi et al., 2007).

Sustainable land management (SLM) measures are described as "a system of technologies and/or planning that aims to integrate ecological with socio-economic and political principles in the management of land for agricultural and other purposes to achieve intra- and intergenerational equity" (Hurni, 1997). In this study, SLM means technologies which farmers implement in their fields as a package to improve farming conditions. During a reconnaissance survey, SLM measures which farmers in the West Usambara highlands use to combat land degradation were found to include: tree planting; bench terraces; *fanya juu* terraces; contour grass strips; cut-off drains; application of livestock manure; application of good agricultural husbandry (use of high quality seeds, following extension advice in their agricultural enterprises); mulching; crop rotation; use of compost; livestock keeping (a source of manure); and use of fertilizer (for good crop cover and yields). Typically, the SLM technologies consisted of a few of these measures as a package. However, only five percent of farmers in the survey had adopted such SLM packages (Wickama and Nyanga, 2009).

A number of studies have indicated that farmers' choices of SLM measures are essentially a socio-economic decision (Mascarenhas, 2000; Tenge et al., 2007). Yet, for technologies to improve natural resource management, the difficulty in adopting them is reported to be rooted in their location-specificity such that one cannot generalize (Lee, 2005). One issue that has not been addressed extensively in the SLM adoption discussion is how the local biophysical factors impact on the effectiveness of certain SLM types (Lefroy et al., 2000). For instance, in the West Usambara highlands, it is generally recommended to adopt certain soil conservation measures depending on the slope steepness. It is assumed that slope steepness is the principal determinant of the effectiveness of the soil conservation measures. Yet, adoption of the advocated measures has been little perhaps because other biophysical conditions (soil type, field size, cropping system, agro-meteorology, etc.) play an important role as well. If relationships between biophysical conditions and SLM effectiveness exist, this could explain, at least partly, why adoption is not always logical to a farmer.

Experience from India indicates that profitability of natural resource investments was observed to depend on factors like the natural fertility of soils, topography, climate and the length of the growing period (Shiferaw et al., 2009). In the United States, it was also reported that adoption of farm technologies depended on such factors like farm size, farmer demographics, soil quality, urban influences, farmer status of indebtedness, and location (Isgin et al., 2008). It should be noted that soil quality, farm size and location are biophysical factors. Earlier, it had been observed that a close relationship exists between soil fertility, land quality, rainfall and other local/regional biophysical factors to the adoption and diffusion patterns of conservation tillage, Integrated Pest Management (IPM) and fertilizer application (Aldy et al., 1998). It has also been reported that biophysical factors featured prominently in the adoption of IPM, agro-forestry, and soil conservation technologies among Central American farmers (Ramirez and Shultz, 2000). In Ethiopia, it has been reported that slope and farm size were important factors considered by farmers before constructing soil conservation measures such as terraces in their fields (Ketema and Bauer, 2012).

In view of the above, it may be assumed that biophysical factors are important for both the performance and the effectiveness of SLM measures, but it is not sufficiently known which specific biophysical factors are dominant in influencing effectiveness of such SLM-measures. Hence, studying the effectiveness of SLM measures across different biophysical conditions can increase our knowledge on the relation between biophysical factors and SLM effectiveness. Such knowledge may assist in promoting effective SLM measures that successfully reduce soil degradation in areas with similar biophysical conditions. Therefore, the aim of this study was to determine the effectiveness of the SLM measures as practiced by local farmers in the West Usambara highlands in relation to biophysical conditions. Specifically the study addressed the following objectives:

1. Determine the biophysical conditions of fields where SLM measures have been adopted;
2. Assess the extent to which the different SLM measures reduce soil degradation;
3. Establish the impact of SLM measures on crop productivity in relation to the different biophysical conditions.

2. Materials and methods

2.1. Description of the study area

The West Usambara highlands are located in northeastern Tanzania, between latitudes 4° 23′ to 5° 08′ South and longitudes 38° 05′ to 38° 40′ East. They rise from the surrounding plains at 600 m to 2300 m above sea level (Pfeiffer, 1990). The study was conducted in Lushoto District, Tanga region, which covers approximately 70% of the West Usambara highlands. The topography of Lushoto District is mountainous and highly dissected in some parts. The parent materials from which the soils are derived are metamorphic rocks like gneisses, schist and other forms of granulites (Geological Survey of Tanganyika, 1963). Soils are generally deep (>1 m), and the major soil types in Lushoto District are Humic, Haplic and Chromic Acrisols, Luvisols and Lixisols for most of the mountainous uplands. Fluvisols with some pockets of Gleysols dominate the valley bottoms (Meliyo et al., 2001).

Lushoto District has an area of approximately 3500 km^2 and a population density of 134 people per km^2, making it one of the most densely populated districts in Tanzania (Mascarenhas, 2000). Lushoto has a number of protected natural forests in which most of the naturally occurring vegetation is found. Approximately 2000 km^2 of the district is used for arable crop production (Mowo et al., 2002). The district grows tea, coffee, maize, banana, beans, sugarcane, and a number of temperate fruits. Lushoto is dominated by smallholder, low input subsistence type of land use. Landholdings have shrunk to 1 ha or less per household. The most intensive cultivation takes place in the valley bottoms (representing 10% of the entire landscape) where high-value vegetables are grown.

Temperatures in Lushoto District can range from 0 °C at night to a maximum exceeding 25 °C during the day. There are two major rainfall seasons, the long rains ("masika") which start around mid-March and last to the end of June, and the short rains ("vuli") which start in October and last till the end of December. The short rains account for 25% of the total rainfall being received on these highlands and are less reliable than the long rains, but they are the most important for growing annual crops like maize and beans. These crops require temperatures higher than 20 °C that actually occur during the period of October to March (Mascarenhas, 2000).

In terms of spatial rainfall distribution, there is a gradient of rainfall decrease from east to west and from south to north of the mountains. The annual amount of precipitation depends on the agro-ecological zone (AEZ), of which there are four in Lushoto District (Fig. 1) (De Pauw, 1984). The study was conducted in the AEZs E12 and E2. Zone E12 is a high altitude zone located in the northwestern flanks of the district. The zone is characterized by high altitudes (1200–2000 masl) with relatively low temperatures (16 °C). Zone E2 is characterized by moderate altitude (800–1800 masl), with average daily temperatures of 20 °C or more and is mostly found in the central and eastern flanks of the district. Levels of precipitations in zones E12 and E2 are about 800–1000 mm per year (De Pauw, 1984).

In both AEZs, two villages with contrasting levels of adoption of SLM measures were selected for a detailed study. The villages of Shashui