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Mulching as a strategy to improve soil properties and reduce soil erodibility in coffee farming systems of Rwanda

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ABSTRACT

In Rwanda, mulch is applied in coffee fields to control soil erosion. The objective of this paper is to quantify the effects of different types of mulch on soil properties and soil erodibility in coffee farming systems in three different agro-ecological zones of the highlands of Rwanda. The treatments consisted of five mulching systems (T1: *Cympobogon spp.*; T2: *Panicum spp.*; T3: *Cympobogon* spp. and *Panicum spp.*; T4: *Eucalyptus* spp. and *Cympobogon spp.*; T5: mixed residues) and control (un-mulched coffee - T6). The mulching systems were selected in coffee plantations to which the same mulch material had been applied annually at an average rate of 15–21 t mulch ha^{-1} for at least three consecutive years before we started field experiments in 2007. We tested the effects from 2007 to 2008 on two soil types. A factorial two-way ANOVA was used to assess the effects of the application of different mulch types on the soil organic carbon, bulk density, wet aggregate stability, and soil erodibility at each site. The application of mulch significantly reduced the bulk density and soil erodibility ($P < 0.001$) and significantly increased the soil organic carbon and wet aggregate stability ($P < 0.001$), mainly at Kibirizi and Karongi. In addition, the effects of the interactions between the type of mulch and type of soil were site specific ($P < 0.001$). Low bulk densities and soil erodibility as well as high soil organic carbon and wet aggregate stability values were observed mainly in response to the application of a mixture of mulches, particularly T4 and T5 at rates of above 17 t ha^{-1}. The maximum erodibility values coincided with the lowest values of soil organic carbon and wet aggregate stability and the highest bulk density. In addition, soil erodibility was also affected by soil texture; high sand and very fine sand fractions increased the vulnerability of soils to erosion. Mulching demonstrated positive effects on soil properties and soil erodibility, but the effects were site specific, depending on the agro-ecological conditions of the study sites and the types of mulch used.

1. Introduction

The reduction of soil erodibility in arable lands is important to maintain long-term agricultural productivity and sustainability (Lal et al., 2000; Svoray and Ben-said, 2009). Mulching is known to play an important role in erosion control (Adekalu et al., 2006; Blavet et al., 2009; Poesen and Lavee, 1991; Smets et al., 2008). The application of crop residue mulches can contribute to improve the soil fertility and soil properties that affect crop productivity (Jordán et al., 2010; Mulumba and Lal, 2008). The mulching of agricultural lands increases the content of soil organic matter (Duiker and Lal, 1999; Saroa and Lal, 2003) that helps to improve soil aggregation (Mulumba and Lal, 2008), and hence positively affects soil porosity, which improves water infiltration, reduces runoff and controls soil erosion (Edwards et al., 2000; Jordán et al., 2010; McGregor et al., 1990; Mulumba and Lal, 2008; Rees et al., 2002; Roose and Ndayizigiye, 1997). When straw mulching was used on erosion plots over a 3-year experiment, soil losses decreased by 49% (Edwards et al., 2000). The effectiveness of mulch depends on the amount of mulch applied (Mulumba and Lal, 2008), slope gradient, soil type, land use, soil management practices, and rainfall erosivity (Poesen and Lavee, 1991; Smets et al., 2008).

In the mountainous landscape of Rwanda, where most coffee is grown, mulching is adopted as a strategy to control soil erosion and possibly reverse soil fertility depletion. Most coffee plots are located between the 25–35% slope category. In the highlands, coffee is often cultivated on steep slopes above 55% (Nzeyimana et al., 2014), where it faces serious problems, including soil erosion and the loss of soil fertility. As a perennial crop, coffee should protect the soil against erosion

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better than an annual crop because of its year-round soil cover (Hartemink, 2006). This characteristic is expressed by its low C-value in the Revised Universal Soil Loss Equation (Renard et al., 1997). With limited mineral and organic inputs, the density of coffee trees in Rwanda is low with <2500 trees ha^{-1}, which limits the soil cover, and part of the field is vulnerable to soil erosion. Furthermore, the distance from home to the coffee plots that are scattered on the hilly steep slopes reduces soil management practices, such as mulching, and influences the soil erodibility (Nzeyimana et al., 2013). Some coffee fields are intercropped with beans, soybeans or taro because of land scarcity and land pressure, which may increase the soil loss and decrease the soil fertility. Physical structures, such as radical terraces, slow-forming terraces and *anti*-erosion ditches, are mostly used in Rwanda to control soil erosion on annual crop fields (Bizoza and de Graaf, 2012). In Rwandan coffee farming, mulching is practiced to protect the surface soil from soil particle detachment and the continuous loss of soil nutrients. With 20 Mg ha^{-1} y^{-1} of mulch in coffee plantations in Rwanda, erosion is reduced by up to 0.1–1 Mg ha^{-1} y^{-1} (Roose and Ndayizigiye, 1997). Studies in Colombia, Venezuela and Indonesia on runoff plots measured soil losses ranging from 0.2 to 8.9 Mg ha^{-1} y^{-1} in established coffee plantations (Iijima et al., 2003).

The data on the effectiveness of different types of mulch in controlling erosion and increasing soil nutrients are scarce in the different agro-ecological zones of Rwanda highland conditions. The objective of the present study is to quantify the effects of different mulching systems on soil properties and soil erodibility in coffee farming systems in three different agro-ecological zones of the highlands of Rwanda.

2. Materials and methods

2.1. Site description

The study sites were located in the Kibirizi sector of the Nyamagabe District in the Southern Province, the Ruli sector of the Gakenke District in the Northern Province, and the Gishyita-Mubuga sectors of the Karongi District in the Western Province (Fig. 1). The three sites are located in different agro-ecological zones (AEZ). Kibirizi is located at the Congo-Nile Watershed Divide AEZ, with altitudes varying between 1900 and 2500 m a.s.l.; the annual minimum and maximum temperatures average between 14 and 24 °C, and the annual rainfall averages between 1300 and 2000 mm with 273 days of rainfall. The soils are dominated by clay, loam and sandy loam soils derived from schistose materials; they are acidic, and their nutrient availability is poor. They are mostly classified as Ultisols, Inceptisols and Entisols according to Soil Taxonomy (Birasa et al., 1990). The Ruli site is located at the Central Plateau and granitic ridges, and its elevation varies between 1900 and 2300 m a.s.l.; the annual temperatures vary between 16 and 29 °C, and the annual rainfall varies between 1100 and 1500 mm with 243 days of rainfall. The soils are dominated by sandy clay loam and clay loam soils developed from granitic material and are mainly classified as Inceptisols, Ultisols and Alfisols. The Karongi site is located at the Lake Kivu border, and the soils are dominated by sandy clay loam, clay loam and sandy loam soils derived from shales and granites. The soils are mainly classified as Inceptisols and Ultisols according to the Soil Taxonomy. Except for the abrupt slopes that are strongly eroded, the level of soil fertility is moderate. The altitude varies between 1500

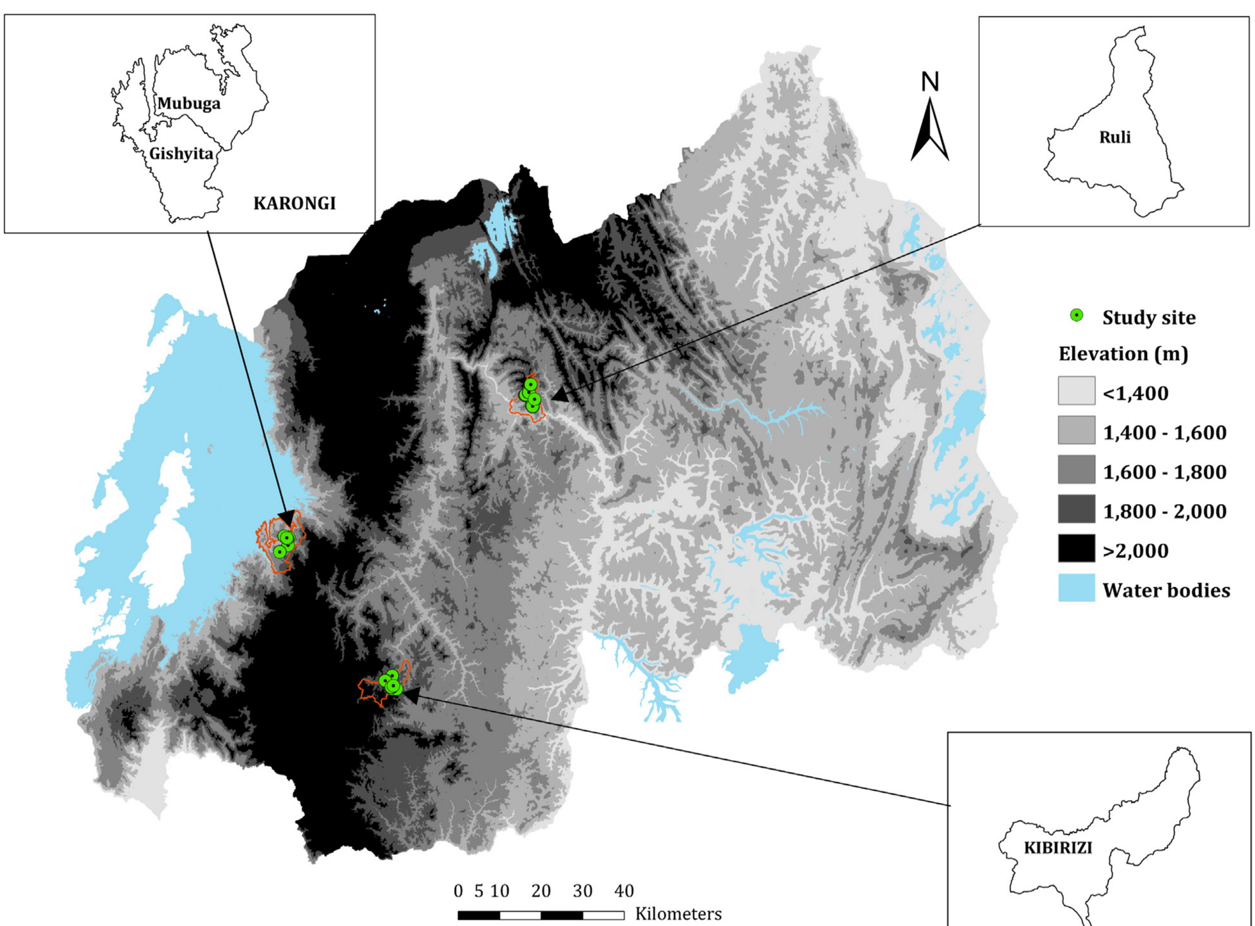

Fig. 1. The elevation map of Rwanda with the locations of the three study sites (Kibirizi, Ruli, and Karongi).