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Short- and medium-term impact of manual tillage and no-tillage with mulching on banana roots and yields in banana-bean intercropping systems in the East African Highlands

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ABSTRACT

Banana-bean intercropping systems are common in the bimodal rainfall areas of the East African Highlands and are characterized by low banana productivity. In these systems, the soil is tilled manually twice a year before bean planting with potentially damaging effects to the shallow banana root system. No-tillage with mulching (NT + M) may constitute an interesting alternative to conventional manual tillage (CMT) to avoid such root damage and improve banana productivity. The objectives of this study were therefore (i) to assess tillage-induced damage to the banana rooting system and its subsequent recovery, and (ii) to evaluate the impact of three NT + M systems vs. CMT on banana root distribution and banana bunch weight. At two sites in the D.R. Congo, the cord root length density (RLD) and fresh weight (FW) were monitored monthly in the top 0.2 m of the soil over a 5 to 6-month period following manual tillage, and compared with NT + M plots. Immediately after tillage and on average over the two sites, cord RLD and FW in the top 0.1 m of the soil were reduced on average to 15% and 16%, respectively, of the levels observed under NT + M. At 0.3 m from the rhizome, cord roots needed 2–4 months to recover to a level similar to the one observed prior to tillage. On average over the two sites, direct root damage by tillage caused the loss of 47% and 63% of the RLD and FW observed in NT + M plots, respectively. The remaining rooting deficit (38% of RLD and 21% of FW) was hypothesized to originate from differences in root growth conditions unrelated to immediate mechanical root damage. There was no evidence that the mechanical damage of roots by tillage affected banana growth in the short term. The medium-term effect of CMT and NT + M treatments was evaluated at three sites (two in D.R. Congo and one in Rwanda) 30 months after banana planting. At two sites out of three, root density profiles indicated lower rooting densities in the top 0.1 m of the soil in CMT plots compared with NT + M plots. Banana bunch weight was consistently lower in CMT plots compared with NT + M plots. Compared with NT + M, CMT appears to affect banana rooting and bunch weight in the medium term under the pedo-climatic conditions of the East African Highlands. No-tillage with mulching may constitute an alternative to manual tillage to enhance the sustainability of these systems but its impact on the whole intercropping system's productivity must be verified.

1. Introduction

In the East African Highlands (Uganda, Rwanda, Burundi, eastern D.R. Congo, north-western Tanzania and western Kenya), bananas are an essential commodity for 30 million people (Karamura et al., 1998). The East African Highland Bananas (*Musa AAA-EA*) dominate banana production. They are predominantly grown on small-holder farms, occupy 30% of the land (van Asten et al., 2004) and supply on average between 16% and 31% of the population's calorie requirement (Abele et al., 2007). Bananas are also an important source of income for farmers, transporters, traders and processors of banana and banana by-products (Karamura and Karamura, 1994; Eledu et al., 2004; Jagwe et al., 2008).

Two main banana-based cropping systems can be identified in small-holder agriculture in the East African Highlands: sole cropping of bananas, and intercropping systems. Bananas are frequently intercropped with annual crops, of which bush beans (*Phaseolus vulgaris*) are the most common (Dowiya et al., 2009). Before planting of the beans, the entire space in between banana plants is tilled

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manually using a hand hoe to prepare the seedbed. This is done bi-annually (approx. September and February) in Rwanda, Burundi, D.R. Congo and Uganda. The soil is typically tilled to a depth of 0.15–0.2 m (Dowiya et al., 2009), up to 10 cm from the banana mat. All residues present at the soil surface are generally taken off the field to facilitate tillage. This soil management practice is henceforth referred to as conventional manual tillage (CMT).

In banana-bean intercropping systems, tillage is clearly directed at the bean and not at the banana. Indeed, sole banana crops are not tilled, and weed control is achieved through (self-) mulching supplemented with occasional superficial weeding. According to the farmers, tillage in banana–bean intercropping systems favors the beans' performance, presumably by reducing competition with weeds and by providingfavorable seedbed conditions. Tillage may also reduce below ground competition with banana roots for water and nutrients, bananas having been shown to be more competitive than beans in the intercropping system (Wortmann et al., 1992). By improving the contact between the soil matrix and organic residues, tillage may also accelerate organic matter decomposition (Balesdent et al., 2000), thereby liberating additional nutrients for crop production.

Besides these positive effects, tillage may also have a number of negative effects. Tillage has been associated with low soil organic matter (SOM) contents (Lal and Kimble, 1997). Decreased SOM content may lead to reduced aggregate stability, increased surface sealing and hence an increased risk of runoff and soil erosion (Glenn and Welker, 1989; Gosai et al., 2009). When surface mulch is present, which is always the case in banana sole cropping in smallholder farms, banana plots are not prone to erosion. However, the removal of the mulch and frequent tillage in CMT may strongly enhance the risk of runoff and erosion (Rishirumuhirwa, 1993; Le Roux et al., 2005). The removal of crop residues prior to tillage will also enhance nutrient depletion, and accelerate soil degradation.

When carried out in established banana plantations rather than prior to banana planting, tillage may also damage the banana rooting system, as reported for other perennial crops (e.g., Lipecki and Berbec, 1997). Indeed, bananas are known to have a shallow root system, with about 45–85% of the root mass in the top 0.3 m (Blomme, 2000; Draye et al., 2005; Robinson and Galán Saúco, 2010). Hence, the bi-annual tillage is likely to repeatedly damage an important fraction of the banana root system in the most nutrient-rich topsoil. This practice, which is akin to shallow root pruning, may reduce the plants' ability for water and nutrient uptake, which is especially relevant in much of the banana producing areas of eastern Africa given the generally low fertility soils (Delvaux, 1995; van Asten et al., 2004) and sub-optimal rainfall conditions (rainfall < 2000 mm yr^{-1} and not well distributed throughout the year; Robinson and Galán Saúco, 2010; van Asten et al., 2011). Robinson and Alberts (1989) reported that up to 80% of water taken up by bananas originated from the top 0.3 m of the soil, highlighting the functional importance of roots in the topsoil. Root injury by tillage may possibly also increase the risk of plant root infection. Furthermore, regeneration of the rooting system following tillage-induced damage will also require additional resources on behalf of the plant and may restrict plant productivity, as reported for other plants (Schroth, 1999). Many studies have documented significant positive correlations between bunch weight (or banana yield) and below ground biomass for banana plants (e.g., Lassoudière, 1978; Serrano and Marín, 1998; McIntyre et al., 2000; Blomme et al., 2002), implying that any decrease in root biomass may lead to decreased production. Furthermore, the vigor of the main pseudostem strongly determines the vigor of suckers (Blomme, 2000), such that better root systems leading to more vigorous main pseudostems would lead to more vigorous suckers. Having more vigorous suckers is an advantage, as this reduces the duration between two successive banana harvests from the same mat, and hence could increase plantation productivity per unit space and time (Blomme, 2000).

As early as in the beginning of the 20th century, Higgins (1904) noted that the replacement of banana roots damaged by tillage "must make very considerable demands upon the stores of food in the corm". He thus advised that "plowing should not be done at a time when all the supplies of stored food are required for the developing of the flower-bud or of the fruit". This recommendation is still being issued by some researchers today (Robinson and Galán Saúco, 2010; Lassoudière, 2012). However, it seems to be based more on common sense (in view of the shallow banana rooting system) than on actual scientific evidence of direct negative impacts of tillage on the banana rooting system and banana productivity. Like Higgins (1904) and Lassoudière (2012) recently acknowledged that the practice of tillage in existing banana plantations remains a debated issue.

No-tillage with mulching (NT + M) has been much promoted as an alternative to conventional tillage in many temperate and tropical cropping systems. Benefits of NT systems include preserving soil structure; savings of time, energy and water; water erosion control; and maintaining biological activity and diversity (Derpsch et al., 2010). In addition, NT avoids disturbing the rooting system of perennial crops. Mulching with organic residue provides weed control (Lipecki and Berbec, 1997), stimulates soil biological activity, helps maintain SOM levels and conserve water, supplies nutrients, and further contributes to improving soil physical and physico-chemical properties (Erenstein, 2002). By helping maintain more favorable moisture conditions, mulching may also favor denser root exploration near the soil surface. NT + M may thus constitute an interesting alternative to CMT in banana-bean intercropping systems.

Hence, the objectives of this study were two-fold: (i) to assess the short-term, tillage-induced damage to the rooting system of East African Highland banana plants and its subsequent recovery, and (ii) to evaluate the impact of NT + M systems vs. CMT on banana root parameters, plant growth and banana bunch weight.

2. Materials and methods

Two types of experiments were carried out. (1) Field experiments at two different locations specifically aiming at evaluating banana rooting dynamics over a 5–6-month period following tillage. These are further referred to as 'banana root growth experiments'. (2) Field experiments at three different locations aiming at assessing the effect of CMT and three different NT + M soil management practices on banana root distribution. These are further referred to as 'NT + M experiments'.

2.1. Study sites

Banana root growth experiments were carried out at two locations: (1) at Kabamba (South-Kivu, D.R. Congo) in three long-established (>30 years), small-holder banana plantations, and (2) at Mulungu (South Kivu), in selected treatments of the NT + M experiment described below.

The NT + M experiments were carried out at three sites, namely at Mulungu and Walungu (South Kivu), and Rubona (Rwanda). At Mulungu and Rubona, the researcher-managed experiments were carried out on the research stations of the national research institutions (Institut National pour l'Etude et la Recherche Agronomiques and Institut des Sciences Agronomiques du Rwanda, respectively). At Walungu, the researcher-managed experiment was laid out in a farmer's field. In the previous season, the land had been grown with sweet potato at Mulungu, and an association of annual crops (sorghum, taro, sweet potato, bean) at Walungu and Rubona.