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Impacts of some upland rice-based cropping systems on soil macrofauna abundance and diversity and black beetle damage to rice

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A B S T R A C T

Black beetles (BB: *Heteronychus* spp.: Coleoptera, Scarabaeidae) are serious constraints to upland rice production in the Madagascar central highlands. From 2002 to 2007 we compared the effects of two soil management and two fertilization modalities in an upland rice-based cropping system on soil macrofauna abundance, diversity and BB damage to rice crops and yield. This cropping system involved a 2-year rotation of upland rice the first year, followed by common bean the second year, with oat as a relay crop under both conventional tillage (CT) and no-tillage soil management (NT), each under both organic (OF) and mineral fertilization (MF). All four modalities (CT-OF; CT-MF; NT-OF and NT-MF) were managed under two plant protection levels (seed dressing with imidacloprid + thiram *vs* no seed dressing). Herbivorous/detritivorous beetles were the most abundant soil biota, respectively representing more than two-thirds and half of all macrofauna at the outset of the experiment and 4 years later, with the BB *Heteronychus arator rugifrons* (Fairmaire) being the dominant pest species (herbivore). The Shannon diversity index was reduced significantly between the beginning and the end of the experiment 4 years later, while it was only marginally affected by soil management, fertilization and seed dressing regimes at both sampling dates. Throughout the study period, seed dressing resulted in a significant reduction in BB damage, and in a significantly higher rice grain yield as compared to control. NT management did not enable seed dressing discontinuation based on grain yield and BB damage level after 3 and 4 years of this practice, respectively. In this respect, CT-MF management ranked best in the absence of seed dressing. The reasons for the poor performance of NT management in the studied cropping system as compared to the same strategy used in other systems reported in earlier studies are discussed.

1. Introduction

In Madagascar, the growing demand for rice and the resulting increased pressure on inundated lands has promoted upland rainfed rice cultivation on hill slopes. This type of agriculture cannot meet both sustainability and high yield objectives if conventional tillage is used due to the increased water erosion risk (Douzet et al., 2010). Conservation agriculture (CA) cropping systems, based on no tillage (NT) and permanent soil cover with dead or live mulch, have broadened the prospects for upland rice cropping (Bruelle et al., 2015).

Conservation agriculture reduces water erosion while improving the soil water balance and has hence been successfully adopted on large-scale mechanized farms, especially in America, Australia and Latin America (Scopel et al., 2005; Bolliger et al., 2006; Triplett and Dick, 2008). However, the CA adoption rate by smallholder farmers in sub-Saharan Africa is variable, but generally low (Ito et al., 2007; Giller et al., 2009).

The impacts on crop pests of curtailing tillage and keeping the soil surface covered are not as well documented as the above-mentioned effects on soil erosion and water balance (Ratnadass et al., 2006). For instance, attacks by dynastid beetle larvae

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(white grubs) and adults (black beetles), particularly *Heteronychus* spp., represent a major constraint to upland rice cropping, particularly in the central highlands of Vakinankaratra region (Randriamanantsoa et al., 2010). Depending on the environment, CA management can either aggravate or reduce damage as compared to conventional tillage (CT) (Ratnadass et al., 2006, 2013).

Heteronychus spp. are major crop pests worldwide, particularly *H. licas* and *H. arator*, which infest sugarcane, maize and potato crops and cultivated pastures (e.g. Abdallah et al., 2016; Conlong and Ganeshan, 2016; Frew et al., 2016). In Madagascar, however, mainly endemic species attack graminaceaous crops (namely sugarcane, maize and rice) (Paulian, 1954), while *H. arator rugifrons* is the most damaging species on upland cereal crops in the Vakinankaratra region (Randriamanantsoa et al., 2010). In this region, we showed that seed treatment with Gaucho® T45 WS (35% imidacloprid, 10% thiram) at 5 g/kg seed resulted in a significant reduction in black beetle damage and a significant increase in yield under both mulch-covered and bare-ploughed soil management systems (Randriamanantsoa and Ratnadass, 2005). However, the economic cost and environmental impact of the seed dressing technique has yet to be documented (Ratnadass et al., 2012a), thus warranting research in view of eliminating seed dressing in some cropping systems. From 2002 to 2007, under seed dressing with imidacloprid + thiram *vs* no seed dressing conditions, we therefore compared soil macrofauna abundance and diversity, as well as black beetle damage to rice crops and yield, in an upland rice-based rotation conducted under both CT and NT management with two levels of fertilization.

2. Materials and methods

2.1. Research site

A long-term experiment comparing CA with conventional farming systems has been underway since 2002 (Ratnadass et al., 2008; Rakotoarisoa et al., 2010; Dusserre et al., 2012) at Andranomanelatra (19°47′ S, 47°06′ E, 1640 m a.s.l.) in the highlands of Vakinankaratra region in Madagascar. This area is under a tropical highland climate with 1460 mm average annual rainfall, while the soil has been characterized as a ferralsol (Razafimbelo et al., 2006) according to the FAO classification (FAO, 2006). The study was set up on a piece of land that had for 10 years been under fallow dominated by grass (*Bozaka* = *Aristida* sp.), which was mown or directly grazed by neighboring farmers' cattle following many years of continuous wheat cropping.

2.2. Experimental design and crop management

As part of the long-term experiment, a 2-year rotation of upland rice (*Oryza sativa* L.) the first year, followed by common bean (*Phaseolus vulgaris* L.) the second year was evaluated under both CT and NT soil management conditions.

Management of this crop rotation has been described elsewhere (Sester et al., 2014). Oat (*Avena sativa* L.) was sown after the common bean crop was harvested. In the CT system, most of the rotation crop residue was removed, whereas in the NT system, rotation crop residue mulch was left on the soil surface. Under both soil management regimes, two fertilization modalities were used: 'OF' (corresponding to the conventional fertilization level used by farmers), organic fertilizer (cattle manure at 5 t/ha); and 'MF' (corresponding to the fertilization level recommended by the Malagasy National Center of Applied Research and Rural Development (FOFIFA)), organic fertilizer plus NPK mineral fertilizer (11% N, 22% P_2O_5, 16% K_2O) at 300 kg/ha, dolomite ($CaMg(CO_3)_2$) at 500 kg/ha, cattle manure at 5 t/ha and two top dressings with urea (46% N) at 50 kg/ha applied 30 and 70 days after sowing.

The FOFIFA 154 rice cultivar was used the first 2 years (2002–03 = t0 and 2003–04 = t0 + 1), but since it turned out to be too susceptible to blast disease under the local conditions (Sester et al., 2014), it was replaced by the partially resistant FOFIFA 161 cultivar the last 3 years (from to 2004–05 = t0 + 2 to 2006–07 = t0 + 4). All operations were conducted manually, including plowing in CT plots, using the Malagasy traditional *angady* spade. A split-plot experimental design with four replications was used, with the two soil management regimes as main plots, and the two fertilization modalities as subplots.

The experimental plot dimensions were 10 m × 15 m. Six to eight rice seeds were hand sown in hills spaced 0.20 m × 0.20 m apart (25 hills/m^2). From the beginning of the experiment, seeds sown in a 5 m-broad strip were not dressed, unlike seeds used in the rest of the plots, which had undergone a seed-dressing treatment (Gaucho®: 35% imidacloprid + 10% thiram at 2.5 g/kg of seeds) for protection against insects and fungi. In 2006, seed dressing was stopped on a new 5 m strip adjacent to the treated strip (Fig. 1). The first three blocks were located on a flat part so to minimize effects of run-off from seed-dressed strips on non-dressed strips. Otherwise, strips on the fourth block, where the slope was steeper, were oriented parallel to the slope, also with the aim of minimizing such effects.

2.3. Observations

In the first year (2002–03 = t0) and last year (2006–07 = t0 + 4), all above- and below-ground macrofauna were counted using the Tropical Soil Biodiversity and Fertility (TSBF) procedure, involving digging of 25 × 25 × 30 cm deep soil monoliths (Anderson and Ingram, 1993), in both "always treated" and "never treated" parts of the plots. These monoliths were respectively located 2.5 m from the bottom and left edges of the strips at t0, and 2.5 m from the bottom and right edges of the strips at t0 + 4 (Fig. 1). These data allowed calculation of macrofauna abundance (number of collected individuals per surface unit), and diversity (Shannon index, H': Shannon, 1948).

The Shannon index takes the number of taxa (families or groups of families) encountered into account (Biaggini et al., 2007). Its value is calculated by the following formula:

$$H' = -\sum pi \log_2 pi \quad (1)$$

with $i = 1$ to s, where pi = the probability of meeting a taxon i on a plot and s = the total number of taxa encountered on the plot.

Specimens of white grubs (scarab beetle larvae) collected the first year from all systems were preserved in vials filled with 70% ethanol, and were *a posteriori* mostly identified to the species level using the taxonomic key of Randriamanantsoa et al. (2010).

Other observations were conducted yearly, except in 2004 (t0 + 2), on quadrats of 96 hills (3.84 m^2) located both at the center of the untreated strip (10 m × 5 m) and, by symmetry, on the treated (10 m × 10 m) part of the plot (Fig. 1). Soil pest damage was assessed in 2003 (t0 + 1), 2005 (t0 + 3) and 2006 (t0 + 4) on rice at the tillering stage by using the 1–5 rating scale, as described elsewhere (Ratnadass et al., 2012b), namely: 1 = 0–20%; 2 = 21–40%; 3 = 41–60%; 4 = 61–80%; 5 = 81–100% damage, including complete absence of tillers. In 2006, damage data were also recorded on a quadrat located in the new untreated strip (10 m × 5 m). Grains from quadrats in treated and untreated strips were harvested separately and then sun-dried and weighed at t0 + 1 and t0 + 3.