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Abstract summary

An experiment has been designed in the Highlands of Madagascar with the aim to produce multi-criteria indicators of performance of agroecological practices. In this experiment, different traditional and innovative practices were tested in field conditions with the assumption that practices that enhance soil biodiversity and soil ecological processes are the one that best promote plant production, yield and sustainability. Both ecological and agronomic performances were confronted with socio-economic performance defined by farmers in order to propose innovative practices adoptable by farmers.

A 2-year field experiment with 16 different practices, replicated 4 times, was designed in the Highlands of Madagascar with upland rice as the main crop. Many soil and plant parameters were measured: 73 parameters to describe soil biodiversity and soil ecological processes, 19 descriptors to measure rice production, nutrition and yield, and 8 socio-economic descriptors.

This study led to the production of a useful indicator allowing to evaluate an agroecological practice on the way it promotes soil health and especially soil biodiversity, crop yield and socio-economical requirements which are the main limits for practice adoption. We measured interesting relations between soil ecological descriptors and agronomic descriptors.

Keywords: Agroecological transition, soil health indicators, soil ecological processes

Introduction, scope and main objectives

Agroecological practices are usually designed following different principles. Some of them (Altieri, 1999) underline the need to increase soil biological activity. Other principles highlight the needs to cross indigenous and scientific knowledge, to be economically and environmentally sound, and based on local resources, to be socially and culturally acceptable, and to enhance farm productivity (Pretty, Toulmin and Williams, 2011). Agroecological transition is particularly important for smallholders in tropical regions where rural societies and food systems generally face many challenges.

Scientists generally recognize the need for an ecological intensification of agricultural production by increasing biodiversity and complexity in agrosystems, to rely more on natural functions, biotic interactions and ecological processes, and to amplify the services provided by living organisms (Altieri, 1995; Barrios, 2007). Generally, at field and farm levels, agroecological practices drive and optimize functional biodiversity aboveground, whereas soil (belowground) biodiversity and functions are rarely managed. The importance of soil functions in the performance of agroecological systems is widely recognized and their restoration appears necessary (Altieri, 1999; Barrios 2007; Brussaard, De Ruiter and Brown, 2007; Bardgett and van der Putten, 2014; Bender, Wagg and van der Heijden, 2016). Unfortunately, due to the complexity of soil functioning and the poor knowledge of its determinism, only little consideration is given to soil when designing agricultural systems. Four basic soil ecological functions are of interest when regarding plant functions: (i) soil organic matter dynamics, (ii) nutrient cycling, (iii) maintenance of soil structure, and (iv) pest regulation (Brussaard, De Ruiter and Brown, 2007; Kibblewhite, Ritz and Swift, 2008). These soil functions directly or indirectly affect plant functions (De Deyn, Raaijmakers and van der Putten, 2004) and are provided by the activity of soil organisms.

The SECuRE project, funded by Agropolis Foundation, aimed to enhance agrosystem services by intensifying soil ecological functions in rainfed rice cropping system in the Madagascar Highlands. The overall objective of the project was to provide Soil Function Restoration (SFR) practices based on local and scientific knowledges, to increase both agronomic, socio-economic and ecological performances of agroecological agrosystems in a tropical context. For this purpose, 16 innovative SFR (4 replications) have been tested following the 5 levers:

1. use original organic inputs with high agroecological performances such as vermicomposts;

2. combine existing organic and mineral inputs promoting plant functions;

3. increase soil heterogeneity by providing various coupled organo-mineral substrates in a stratified way;

4. inoculate mycorrhizae and earthworms (biofertilization) to enhance key soil functions;

5. use crop varieties that best respond to innovative SFR practices.

The impact of each SFR practice on agronomic, socio-economic and ecological performances of the agroecological rice system has been determined in field experiments in order to select those improving rice production, soil health and being easily applicable by small farmers. The objective was to develop, following a participatory and multi-actor approach, innovative indicators adapted to the local and accurate evaluation of SFR practices.

Methodology

SFR practices were experimented using a field trial located in a farm at the vicinity of Imerintsiatosika (20 km west from Antananarivo). In order to understand how each of the 16 practices tested impacted soil ecological functions, carried by soil biodiversity, as well as crop production and quality, several scientific analyses have been performed along the second cultural season, leading to a database of 19 agronomical and 73 soil descriptors. Among those, Biodiversity descriptors have been chosen to focus on the three ecological functional groups: (1) "decomposers" assessed using Biolog® Ecoplates, (2) "regulators" assessed by the number of taxa, the density and several indices reported to the soil nematofauna and (3) "engineers" assessed by the number of taxa, the biomass and density of macrofauna.

The methodology we followed can be visualized on Figure 1.

- descriptors were first selected on the basis of their correlation with one or more SFR conditions;
- mean values of selected descriptors over the four replicated blocks per SFR were homogenised;
- selected descriptors were aggregated into 5 classes for the ecological performance (biodiversity promotion, the soil physico-chemistry, C storage, nutrient cycling and pest regulation) and 4 classes for agronomical performance (plant growth, grain yield, grain quality and forage quality).

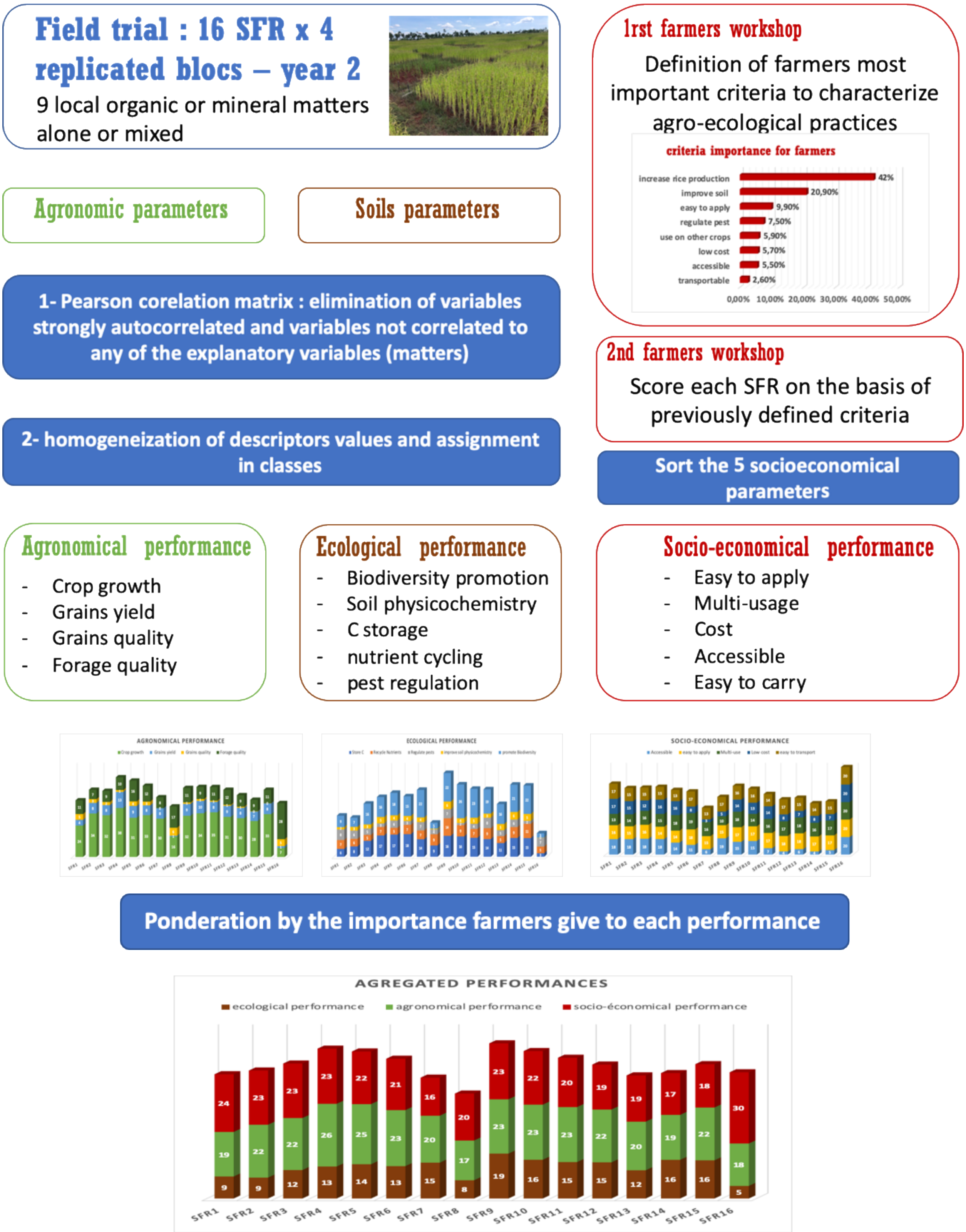

Figure 1: Diagram illustrating the methodological approach followed to generate the agro-ecological indicator, and the type of results obtained

To assess socio-economic performance, two farmers' workshops have been conducted. The first one aimed to identify and sort the main descriptors related to the farmer choice of fertilizers. Descriptors have been gathered into eight criteria, including 5 corresponding to socioeconomic, 2 to agronomic and 1 to ecological descriptors. Each criterion was weighted according to the frequency of citation by farmers. During the second workshop, farmers were invited to rate their perception for each SFR. Workshops were conducted with 7 groups of 5 farmers (2-3 men and 2-3 women). Notes rated for the 5 socio-economical descriptors were weighted by the importance of each criterium determined at the previous workshop and finally summed for each SFR, giving a percentage called socio-economic performance. Agronomical and ecological performances were adjusted by their respective coefficient of importance for farmers determined during the first workshop.

Results

SFR rating the lowest aggregated index is the one based on simple chemical fertilization with NPK (SFR8, Figure 1). This SFR rate at the lowest for each of the three dimensions of the index (ecological, agronomical and socio-economical), even lower than the negative control without any amendment (SFR16). After two years of culture, the mixing of different matters (SFR12 to SFR15, manure + compost + vermicomposts) did not show better results than the traditional cattle manure alone or associated with dolomite, and mixing matters is more constraining for farmers. But their high ecological performance suggests that their positive effect on soil biodiversity and ecological functions can increase with time.

Biodiversity promotion descriptors varied from 3 to 26 percent of the ecological performance. SFR16 showed the lowest value confirming the poor status of this practice. SFR 10 (manure + ashes and earthworm inoculation) best promoted soil biodiversity. From an agronomic point of view, it was as performant as SFR9 (manure + dolomite) but a little less appreciated by farmers. Biodiversity increased with the amount of organic fertilizers or with a mix between organic and mineral fertilizers, and depended on the matters. For example, the Biodiversity index was higher with lombricompost (SFR7) than with compost (SFR6). Lombricompost rated very low by farmers because they barely know this fertilizer in this area, while compost was promoted by the ONG AgriSud International.

When looking at the Pearson correlation matrix between classes and practices conditions, Biodiversity promotion was highly and positively correlated ($P<0.05$) to C storage (0.80), soil physico-chemistry improvement (0.74), crop growth (0.61) and grain yield (0.61) and nutrient recycling (0.56). Conversely, it was negatively correlated with grain quality (-0.81), and accessibility of fertilizers (-0.57). When looking at the practice conditions, Soil Biodiversity was mostly promoted by the quantity of C (0.86), N (0.88), S (0.73) amended as well as the amount of hemicellulose (0.59), cellulose (0.79) and lignin (0.78) of the amendment, and on the C/N of the amendment (0.54). It seems that mixing different matters also promotes soil biodiversity (0.54).

Discussion

This study led to the production of a useful indicator. While the final aggregated value provides an idea of the match between farmer expectations and ecological and agronomical performances, class composition can inform on the criterium to improve in order to increase the global notation.

The participatory approach we followed to develop the socio-economical part of this indicator instead of scientifically quantified parameters (real cost of fertilizers, distance to producers….), introduces the farmer perception into the evaluation. This allows for cross-cutting dialogue between farmers and researchers and help orientate future research in order to build technical solution along with actionable knowledge.

Our study showed that soil biodiversity is especially enhanced in practices with mixing different organic matters or mixing organic and mineral matters, and positively correlated to the amount of C, N, S in the amendments. This confirms previous studies showing the need to feed soil organisms with organic matters (Lavelle *et al.,* 2001). Another interesting result is the positive correlation between soil biodiversity, carbon storage and crop productivity. Nevertheless, the negative correlation between soil biodiversity with rice grain quality reinforces the need to continue improving practices so as to reach this important food function. More communication seems also to be required to improve the farmer perception of agronomic modalities promoting soil biodiversity.

Conclusions

This study led to the production of a useful indicator allowing to evaluate an agroecological practice on the way it promotes soil health and especially soil biodiversity, crop yield and socio-economical requirements which are the main limits for practice diffusion.

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