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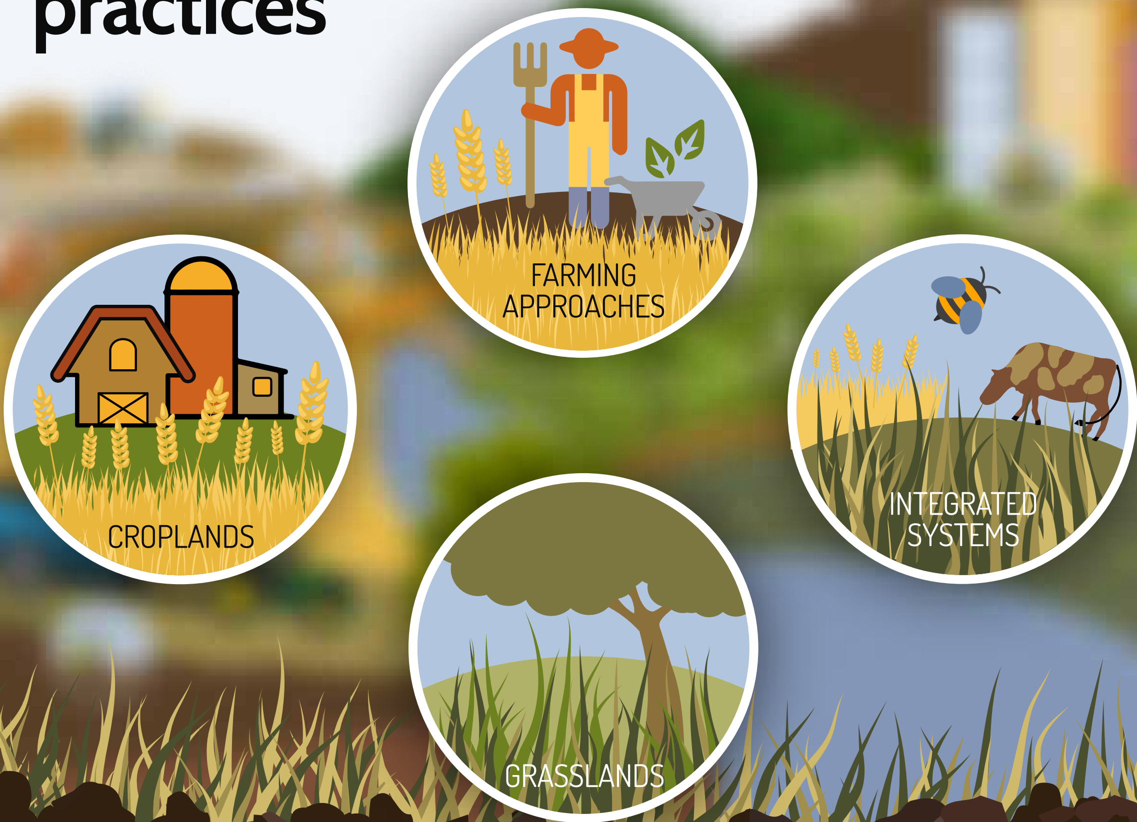
RECARBONIZING GLOBAL SOILS

A technical manual of recommended management practices

CASE STUDIES



CROPLAND, GRASSLAND, INTEGRATED SYSTEMS AND FARMING APPROACHES

itps INTERGOVERNMENTAL TECHNICAL PANEL ON SOILS

GLOBAL SOIL PARTNERSHIP

2. Agricultural practices for the restoration of soil ecological functions in Madagascar

Eric Blanchart[1], Laetitia Bernard[1], Jean Trap[1], Tantely Razafimbelo[2], Onja Ratsiatosika[2], Kanto Razanamalala[2], Patrice Autfray[3], Paulo Salgado[4], Sarah Audouin[5,6,7]

[1]Eco&Sols, Univ Montpellier, CIRAD, INRA, IRD, Montpellier SupAgro, Montpellier, France

[2]Laboratoire des Radio-Isotopes, University of Antananarivo, Antananarivo, Madagascar

[3]AIDA, Univ Montpellier, INRA, Montpellier SupAgro, CIRAD, Montpellier, France

[4]SELMET, Univ Montpellier, CIRAD, INRAe, Montpellier SupAgro, Montpellier, France

[5]Innovation, Univ Montpellier, CIRAD, INRA, Montpellier SupAgro, Montpellier, France

[6]CIRAD, UMR Innovation, Antsirabe, Madagascar

[7]Centre National de Recherche Appliquée au Développement Durable (FOFIFA), Antsirabe, Madagsacar

1. Related practices and hot-spot

Integrated soil fertility management, Organic fertilization (manure, (vermi) compost), Mineral fertilization Biofertilization, Earthworm inoculation

2. Description of the case study

With agroecology, great attention is now given to ecological processes occurring within agrosystems. Nevertheless, little attention has been given to soil ecological processes and the below-ground biodiversity in agricultural practices despite their recognized high potential to enhance ecosystem service delivery and promote multiple ecosystem functions simultaneously (Ratnadass, Blanchart and Lecomte, 2013; Clermont-Dauphin *et al.*, 2014; Blanchart *et al.*, 2020). Soil function restoration (SFR) is especially relevant for tropical smallholder farmers developing their crops on fragile and poor soils, with low available chemical inputs and under climate change. Restoring soil functions first requires restoring the abiotic environment or habitat and providing energy to soil biota. SFR practices gather (i) the use of original organic inputs with high agroecological performances such as vermicomposts, composts, improved manures, (ii) an efficient combination of organic and mineral inputs promoting plant functions, (iii) biofertilization (i.e. inoculation of soil-plant mutualists (such as earthworms, mycorrhizae, etc.) to restore some soil functions) and (iv) the use of crop varieties that respond efficiently to innovative SFR practices.

Understanding and managing the plant-soil interactions and feedbacks in agricultural transition is thus challenging. A key question is what agronomic interventions are required for successful restoration of soil functions in agroecological agrosystems? In Madagascar, different practices based on combined fertilization practices and co-designed with farmers have been tested in the frame of a project called SECuRE (Soil ECological function REstoration to enhance agrosystem services in rainfed rice cropping systems in agroecological transition, funded by Agropolis Fondation, 2017-2020). The agronomic, socio-economic and ecological performance of practices have been assessed through the measurements of many parameters and through knowledge exchange with farmers. A participatory approach has also been designed to help researchers to better understand farmers' perception and drivers for decisions regarding soil fertility and to help farmers to better understand the trial protocol and the results.

3. Context of the case study

The experiment was conducted in the Itasy region, Madagascar, near the city of Arivonimamo, 40 km West of Antananarivo (GPS coordinates: 19°03′14.3″S 47°15′24.5″E). The region is about 1 400 m above sea level. The relief is sloping with the presence of granite mountains and rock outcrops. The climate has two very distinct seasons: a hot and humid season from October to March and a cool, dry season from April to September. The region is characterized by a mean annual temperature of 18°C and a mean annual rainfall of 1 300 mm. The soils are red to brown ferrallitic strongly desaturated soils (i.e. Ferralsols in the FAO classification), with about 40 percent clay, 20 percent silt and 40 percent sand in the upper layer. They are rich in gibbsite. The iron and aluminum oxide contents are high (31.4 percent Fe_2O_3 and 28.2 percent Al_2O_3) while those of silica are low (10 percent SiO_2). The soil pH is in the range 4.7-5.1. Soil carbon contents are low (total C = 29 g/kg). Nutrient omission trials on rice growth have shown strong deficiencies in the decreasing order: phosphorus > calcium > magnesium > nitrogen (Raminoarison *et al.*, 2020). Phosphorus (P) is a major limiting nutrient because of the low content of soil organic matter (and consequently low organic P content) and the high P-sorption potential of soils.

The cultivated areas in the region are mainly concentrated in lowlands, which represent nearly half of cropped areas. The bottoms of slopes are also intensively cultivated (more than a quarter of the cultivated areas). Steep and weak slopes as well as the top flats represent a weaker area for cultivation in the region. Lowland rice (*Oryza sativa*) cultivation is the main crop. It is generally practiced in rotation with vegetable crops in the same year. Lowland areas are saturated due to permanent cropping. Currently rainfed cultivation of rice and other grains or tubers on upland soils (slopes) only represents a small proportion of cultivated areas. Nevertheless, due to the need to produce more of this staple crop, upland cultivation of rice faces many constraints such as a poor soil fertility, the presence of pests and pathogens, and high cost of fertilizers. Family farms present on average an area of 91 acres (70 percent lowland and 22 percent upland). This chapter deals with upland rice and not with lowland rice (including SRI, System of Rice Intensification).

4. Possibility of scaling up

In this experiment, we tested different types of amendments, fertilizers, beneficial organisms, in the form of combined management practices to improve soil ecological functions and plant response (production and yield). Organic, mineral and biological substrates were chosen in agreement with farmers, substrates being - more or less - available on farms or in the neighboring areas. This participatory approach and the generic characteristics of Ferralsols in the tropical regions make the results of this study easily transferable to other parts of the world, especially in West Africa, South America and South-East Asia. The main result of our study is that combining organic and mineral matter can increase soil ecological functions and the provision of several agrosystem services such as C sequestration, nutrient recycling, and plant growth, nutrition, yield and resistance to disease. All results are available on the website (in French) of the project (www.secure.mg). Dissemination of innovative sustainable practices to smallholder farmers will be co-constructed at the scale of Malagasy Highlands, and could be realized at a larger scale to improve food security and farmer livelihoods in sub-Saharan Africa where soil and farmers' constraints are similar to Malagasy Highlands: fragile and poor soils, low access to chemical fertilizers, small farms, etc.

5. Impact on soil organic carbon stocks

Soil carbon contents and stocks have been measured after two cropping seasons in our experiment (i.e. 2 years). Soil carbon content was measured for 24 samples per treatment with the Walkley-Black method, after air-drying of soil samples. Bulk density was measured with a cylinder of a known volume (10 cm depth) with 8 replicates per treatment; soil was oven-dried at 105 °C and weighed. Soil C stocks were calculated on a volume basis as follows:

$$\text{Soil C stock (tC/ha)} = \text{C content (g/kg)} \times \text{bulk density (t/m}^3\text{)} \times \text{d (layer thickness, m)} \times 10.$$

The baseline C stock was measured in the control (no fertilization) and was equal to 28.66 tC/ha (upper 0-10 cm). C stocks were also measured in 15 other practices differing in fertilization. Data are still unpublished while available on the SECuRE website (www.secure.mg). Tested practices are referred to SFR (Soil Function Restoration practices), from SFR1 to SFR16 (Table 5), with SFR16 being the negative control without fertilization. C storage was calculated as the difference between SFR and SFR16 (synchronic approach).

Table 5. Mean additional C storage (tC/ha/yr) for different treatments

More information on the practice	Additional C storage (tC/ha/yr)
SFR1: 3 t/ha cattle soil-mixed powder	0.25 ± 1.7
SFR2: 3 t/ha manure	0.99 ± 1.0
SFR3: 3 t/ha manure + 40 kg/ha NPK	1.18 ± 1.9
SFR4: 6 t/ha manure	1.30 ± 1.4
SFR5: 6 t/ha nitrogen-conserved manure	0.78 ± 2.1
SFR6: 6 t/ha compost	2.24 ± 3.2
SFR7: 6 t/ha vermicompost	1.15 ± 1.7
SFR8: 100 kg/ha NPK + 100 kg/ha urea	0.94 ± 2.9
SFR9: 6 t/ha manure + 500 kg/ha dolomite	0.23 ± 0.5
SFR10: 6 t/ha manure + 500 kg/ha ashes	0.86 ± 2.3
SFR11: 6 t/ha manure + 500 kg/ha hyperphosphate	0.93 ± 2.2
SFR12: 2 t/ha manure + 2 t/ha compost + 2 t/ha vermicompost	0.97 ± 1.7
SFR13: 2 t/ha manure + 2 t/ha compost + 2 t/ha vermicompost + 500 kg/ha ashes	0.80 ± 2.1
SFR14: 2 t/ha manure + 2 t/ha compost + 2 t/ha vermicompost + 500 kg/ha hyperphosphate	0.71 ± 2.4
SFR15: 2 t/ha manure + 2 t/ha compost + 2 t/ha vermicompost + 500 kg/ha guano	1.11 ± 2.3

Calculated as a difference with the control treatment without fertilization in the 2-year experiment

Results show that the C storage potential is very variable and more important for high inputs of compost (SFR6, 6 t/ha) with mean additional C storage above 2 tC/ha/yr. High inputs of manure (SFR4) and vermicompost (SFR7) are also potentially interesting for C storage (above 1 tC/ha/yr) along for the complex fertilization with guano (SFR15).

6. Other benefits of the practice

6.1. Improvement of soil properties

Physical properties

In our experiment, there was no change in bulk density after 2 years with values around 1.06 g/cm^3. Aggregation (dry sieving) changed a little with some SFR showing an increase in the percentage of macroaggregates compared to the negative control (41.5 percent): 47.5 percent in SFR11, 47.0 percent in SFR6, 46.5 percent in SFR5, 46.0 percent in SFR10, 45.7 percent in SFR13.

Chemical properties

Total soil N content (0-10 cm) strongly increased in many SFR practices, compared to SFR16 (1.55 g/kg): up to 1.83 in SFR6 and around 1.7 for SFR4, SFR5, SFR7, SFR14. Available (extracted with resin) P also increased in all SFR compared to SFR16 (1.04 mg/kg): up to 4.69 in SFR15, 3.8 in SFR11, and around 2.7 in SFR12, SFR13, SFR14.

Biological properties

Microbial biomass, assessed by microbial P content, increased in all SFR, especially in SFR6, SFR4, SFR5, SFR7, SFR12, and SFR13. Soil macrofauna and nematodes were also strongly affected by fertilization: nematode density (in 250 g of soil) was 388 individuals for SFR16 and higher for all SFR especially in SFR10 (1 190), SFR6 (1 432) and SFR15 (1 692). Bacterial-feeding nematodes were especially abundant in SFR9 and SFR10.

6.2 Minimization of threats to soil functions

Table 6. Soil threats

Soil threats	
Soil erosion	Soil losses generally decreased with increase in SOC (Blanchart *et al.*, 2006).
Nutrient imbalance and cycles	Yes, see above for total soil N and exchangeable P
Soil acidification	pH increased with organic fertilization: pH was low in the negative SFR16 and the positive control SFR8; it increased in all other SFR (especially 6-7-9-11-12)
Soil biodiversity loss	See above for macrofauna and nematofauna. We also investigated microbial functions (Ecoplates), tea bags, and bait lamina
Soil compaction	Yes, see bulk density above

6.3 Increases in production (e.g. food/fuel/feed/timber)

Crop yield at the end of the second year of the experiment showed important differences between SFR practices. As expected, yield was very low in the negative control (SFR16) 0.04 t/ha, in the mineral fertilization practice (SFR8) 0.75 t/ha, and in the poor cattle powder (SFR1) 1.03 t/ha. For all other practices, yield exceeded 2 t/ha and exceeded 3 t/ha in SFR4 (highest value 3.59 t/ha), SFR9 and SFR10.

6.4 Mitigation of and adaptation to climate change

NA

6.5 Socio-economic benefits

Two participatory farmers' workshops allowed to evaluate the farmers' perception of the tested practices. Farmers considered 8 main criteria to evaluate the amendments used in the experiment: cost, transport, accessibility, expected effects on soil quality, on rice production, on other crops, on pests, and easiness of spreading. Such diversity of criteria indicates that farmer's decisions are multifaceted, based on economic issues but also on labor-related and agronomic and ecological issues. A rough economic analysis considering the cost of amendments compared to the rice yield for each SFR shows that manure remains the most interesting amendment (relatively high yield and a low cost of manure). The mixing of manure with ashes (SFR10) also gives a high ratio. Due to the high cost of vermicompost sold in the area, all SFR integrating vermicompost presents a relative low ratio despite the high yield measured. This suggests the need to support and train farmers so as they are able to produce vermicompost by themselves so as to increase the amount at local scale and lower the price.

7. Recommendations before implementing the practice

Local availability of organic matters in the area (cattle soil-mixed powder, manure, other biomass needed to elaborate compost and vermicompost) is one of the main limitations. Implementation of new practices based on the use of organic matters would benefit from technical, economic and institutional support. Such support can take the form of a network of skilled farmers, extensionists and advisors, support by decentralized agricultural State agencies, able to produce and sell a high amount of compost or vermicompost and to disseminate exchange experiences and advice to other farmers in the area.

8. Potential barriers for adoption

Table 7. Potential barriers to adoption

Barrier	YES/NO	
Biophysical	Yes	Need of organic matter to produce compost or vermicompost.
Social	Yes	Trade-off to be made regarding the time and labor needed for organic fertilizer preparation (compost, vermicompost), allocation of the biomass (cattle feeding, compost, even selling of biomass), the cost and the results on agronomic (rice production) and soil ecological issues.
Economic	Yes	Poor farmers from the Highlands in Madagascar have very low access to fertilizers, and even for the poorest, to manure.
Institutional	Yes	Extension and advisory services for farmers are crucial to support technical change. Thus, service providers such as decentralized public organizations, farmer organizations or NGOs must be coordinated to provide accessible, relevant, timely and affordable advice for farmers. In an innovation perspective, technical support is therefore not sufficient, other services must be considered: capacity building, access to market and to credit, support for networking and institutional support for scaling up (Faure *et al.*, 2019).
Legal	Yes and No	Land tenure is highly complex in Madagascar, because of traditional rights intertwined with public rights. However organic fertilizers are easily accepted by the local population because it does not question land transmission (contrary to tree plantations for agroforestry practices).
Knowledge	Yes	Exchanges of knowledge between scientists and farmers are crucial for the adoption of such practices. Local NGOs transfer knowledge to help farmers producing compost of vermicomposts by themselves.
Other: choice of the research model	Yes	The design of the research intervention is highly influential on the use of the research outputs and hence on the biophysical and societal impacts (Faure *et al.*, 2018). Participatory research approach has been chosen in order to bridge researchers' and farmers' knowledge: inclusion of farmers' practices into the trials, identification of farmers' descriptors, matching farmers and researcher's evaluation regarding the performance of the SFR tested, and discussion of the trade-off accordingly. Other research models imply multi-stakeholders' commitment: co-design of innovation, support for the innovation process, and promotion of open innovation.

Photos

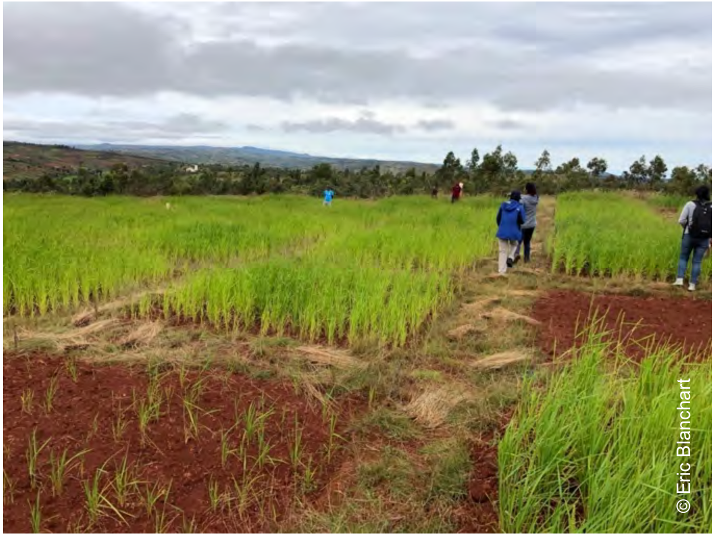


Photo 4. Field experiment at Arivonimamo, Highlands, Madagascar

Sixteen practices have been co-designed to restore Soil Ecological Function (SFR), with 4 replicates. At the bottom left, we can see SFR8 (practice with mineral fertilization only) showing that mineral fertilization with NPK cannot eliminate deficiencies (Ca, Mg). On the right side we can see SFR16 (negative control without fertilization) and the quasi absence of production. Other SFR combined different types of organic matters and mineral matters.

Photo 5. Preliminary meeting with farmers to exchange knowledge on fertilization and sustainable practices (2018)

This meeting aimed at identifying amendments used by farmers (frequency, availability, cost…) and at collecting their perception (indicators) of soil quality, rice growth, efficacity of amendments.

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