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INNOVATIVE SOIL FERTILITY MANAGEMENT BY STAKEHOLDER ENGAGEMENT IN THE CHÓKWÈ IRRIGATION SCHEME (MOZAMBIQUE)†

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ABSTRACT

Appropriate soil fertility management plays an important role in irrigated systems and can contribute to reducing the yield gap. To that end, abiotic, biotic, management and socio-economic factors need to be considered and participatory approaches need to be implemented to ensure the sustainability of the interventions.

Our objective is to analyse a participatory process conducted in the Chókwè Irrigation Scheme (Mozambique) to trigger agronomic innovation in soil fertility management.

Through a method combining interviews with 31 farmers, soil sampling and the organization of communities of practice we studied actual agrarian practices and farmers' knowledge about soil fertility management as well as the social and physical context. This information was the basis for selecting an association in order to promote the innovation process. A participatory planning of the innovation test was conducted. The whole process was evaluated by farmers. Adoption of the majority of the practices is limited mainly by factors related to the socio-economic status of farmers and not to the lack of knowledge. Farmers did not highly value the participatory process itself, but valued the learning-by-doing process and the collaboration with researchers. We consider that the approach increased collective learning and this process triggered the innovation dynamics.

KEY WORDS: soil fertility management; communities of practice; compost; innovation; Mozambique

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RÉSUMÉ

Une gestion appropriée de la fertilité des sols joue un rôle important dans les systèmes irrigués et peut contribuer à réduire l'écart de rendement. À cette fin, des facteurs abiotiques, biotiques, des facteurs de gestion et socio-économiques doivent être pris en considération et les approches participatives doivent être mises en œuvre pour assurer la durabilité des interventions.

Notre objectif est d'analyser un processus participatif conduit dans le périmètre irrigué de Chókwè (Mozambique) pour déclencher l'innovation agronomique en matière de gestion de la fertilité des sols.

Grâce à une méthodologie combinant des entretiens avec 31 agriculteurs, des analyses de sol et l'organisation de communautés de pratique, nous avons étudié les pratiques agraires en conditions réelles et les connaissances des agriculteurs sur la gestion de la fertilité des sols ainsi que le contexte social et physique. Cette information fut le matériau de base pour sélectionner une association afin de promouvoir le processus d'innovation. Une planification participative de l'essai de l'innovation a été réalisée. L'ensemble du processus a été évaluée par les agriculteurs. L'adoption de la majorité des pratiques est limitée principalement par des facteurs liés au statut socio-économique des agriculteurs et non au manque de connaissances. Les agriculteurs n'ont pas réellement apprécié le processus participatif en lui-même, mais ils ont apprécié le processus

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d'apprentissage par la pratique et la collaboration avec des chercheurs. Nous considérons que l'approche a augmenté l'apprentissage collectif et ce processus a déclenché la dynamique d'innovation.

MOTS CLÉS: gestion de la fertilité des sols; communautés de pratique; compost; innovation; Mozambique

INTRODUCTION

Local agricultural capacity is the basis of food security in sub-Saharan Africa, but it has performed below its potential as indicated in the *Africa Human Development Report 2012* of the United Nations Development Programme (UNDP) (2012) Since 1960, the increase in agricultural production in Africa is mainly due to the increase of the area cultivated, not to the improvement in yields (Henao and Baanante, 2006). Planting larger areas as a strategy for increasing production is susceptible to higher risk of crop failure and environmental degradation (Tittonell and Giller, 2013). The possibility of crop intensification is expressed by the concept of 'yield gap' defined as the difference between the potential yield (Y_p), which is the yield under ideal conditions (non-limiting water and nutrients and no biotic stress), and the average actual yield (Y_a) (George, 2014). Yield gaps in sub-Saharan Africa are large; for instance, Mueller *et al.* (2012) estimated that closing the yield gap of sub-Saharan Africa for maize and rice to Y_p requires an increase of the yield of 236 and 224% respectively.

From a purely biophysical point of view, irrigation, nutrients and climate are the main factors that limit potential yields. Nutrients can play an important role in yield gaps. In many parts of Africa, crop productivity in rain-fed farming systems is limited primarily by nutrient rather than water availability (Tittonell and Giller, 2013). However, irrigation is necessary to obtain the highest yields. In sub-Saharan Africa closing maize yield gaps to 50% of Y_p can be achieved by addressing primarily nutrient deficiencies, but attaining 75% of Y_p would require increasing both irrigated area and nutrients (Mueller *et al.*, 2012).

In irrigated systems where water limitation may be overcome, appropriate soil fertility management is even more important. Bado *et al.* (2010) showed in the Senegal River valley how irrigated rice yields declined when soil fertility was not appropriately managed. Another positive effect of good soil fertility management is that it can optimize water use. Organic fertilizers, for example, can increase the water-holding capacity of the soil (Mueller *et al.*, 2012). Adamtey *et al.* (2010) showed that compost improves soil hydraulic conductivity and that inorganic fertilizers or compost increase root volume and length. Ali *et al.* (2006) demonstrated how the addition of rice straw compost increased total yield and water-use efficiency. So soil management technologies can have a value in irrigated schemes, contributing to better water use and consequently reducing the demand for irrigation (Pereira *et al.*, 2003).

The purely biophysical perspective for closing yield gaps may lead to ineffective strategies for increasing crop productivity. In fact, yield gaps are influenced by four categories of constraints that need to be taken into account: abiotic, biotic, management and socio-economic factors (Waddington *et al.*, 2010). There is a lack of integrated studies about soil fertility management in African irrigated schemes that take into account all those factors affecting the yield gaps. There are many studies which focus on the nutrients–yield relationship (Bado *et al.*, 2010; Adamtey *et al.*, 2010; Murungu *et al.*, 2011; Krupnik *et al.*, 2012; Muzangwa *et al.*, 2012) or salinity (Ojo *et al.*, 2011; Sone *et al.*, 2011) among other topics, but there are few which take into account the biophysical and the socio-economic aspects at the same time.

Altieri (2002) recognizes that low productivity in traditional systems is affected mainly by social causes, which means that we need to take them into account when planning one of those interventions. In particular, aspects related to how to trigger the learning process that could increase the possibility of adoption of new techniques of soil fertility management are just as important as agronomic technical aspects.

Identifying the different categories of factors which influence yield gaps and promoting the learning process among stakeholders who participate in an innovation process require the adoption of people-centred innovation and learning approaches (Scoones *et al.*, 2009), as an alternative to the top-down transfer-of-technology approach that has failed in the context of subsistence agriculture. The failure has been attributed to not taking into account local participation and traditional knowledge and overestimating modern scientific knowledge (Altieri *et al.*, 2012). According to Scoones *et al.* (2009), farmers who were new technology recipients become active stakeholders in different stages of the innovation process. Multi-stakeholder processes are promoted and different types of knowledge of stakeholders are integrated into what we call a transdisciplinary process. Jahn *et al.* (2012) definition of transdisciplinarity introduces some important elements: (i) critical and self-reflexive research approach that relates societal and scientific problems; (ii) new knowledge is the result of integrating different kinds of knowledge; (iii) it wants to contribute to societal and scientific progress.

Farmers' learning seems to be inherently social (Nykvist, 2014). Therefore, promoting this social learning was a priority for us. Communities of practice (CoPs) were the mechanisms to trigger the innovation process in that social way. The CoPs, as defined by Wenger E. (http://wenger-trayner.com/theory/), are 'groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly'. The author points out three characteristics of the CoPs:

- *the domain*: membership implies a commitment and a shared competence in the domain that distinguishes members from other people;
- *the community*: this allows collective learning, promoting learning from the other members;
- *the practice*: members of the CoP are practitioners.

We promoted CoPs as a tool for innovation where the farmers may share their experiences, and scientists/technicians provide an input without adopting the top-down approach and consider the different dimensions of the limitations farmers face with the adoption of new techniques.

The objective of this paper is to analyse a participatory process to trigger agronomic innovation in soil fertility management conducted in the Chókwè Irrigation Scheme (Mozambique). The process is described and critically evaluated by farmers.

MATERIALS AND METHODS

Study site

Our study was carried out in the Chókwè Irrigation Scheme (Gaza province, Mozambique), in the Limpopo basin. The climate of Chówkè district is semi-arid, with an average rainfall of 620 mm mostly falling in the rainy season (October to April). Its location in the lower part of the Limpopo River Basin makes Chókwè vulnerable to extreme climatic events like floods and droughts. Average annual evapotranspiration calculated by the Penman–Monteith method is 1410 mm and the average annual temperature is 23.6 °C. The predominant soils in Chókwè come from Pleistocene marine sediments, with a subsoil that is often saline-sodic and fertile river plains.

The scheme was constructed by the Portuguese colonial government for rice production, and was the largest in the country with 25 000 ha under irrigation in 1987 (Bowen, 1989). The irrigated area decreased to 4000 ha due to a lack of investment, management problems and damage caused by periodic floods of the Limpopo River (Kajisa and Payongayong, 2011).

There are about 12 000 users in the scheme, cultivating in two cycles (data from HICEP, 2003 in Chilundo *et al.*, 2012). According to the Faculdade de Agronomia e Engenharia Florestal (FAEF, 2001) there are three types of farmers/farms in the scheme: smallholders who cultivate areas between 0.5 and 4 ha, medium-holders who cultivate areas between 4 and 20 ha and commercial farmers who cultivate areas bigger than 20 ha. According to Hidráulica do Chókwè E.P. (HICEP), the public company responsible for the irrigation scheme management, the predominant type of farmer in the scheme is the smallholder. During the rainy season they cultivate long-cycle cereals, mainly rice and maize, while in the dry season (from May to September) they cultivate mainly horticultural crops like tomato, onion, cabbage, salad, cucumber, pepper and different kinds of beans, as well as maize (FEWS NET, 2011).

Since 1997 the scheme has been managed by HICEP, who are also responsible for land attributions in the scheme (attribution of land use rights).

Conceptual framework

In Figure 1, we have illustrated the conceptual framework of the participatory approach for improving soil fertility management. Figure 1(a) illustrates a traditional top-down approach where technical diagnosis of soils and agrarian practices plus technical knowledge of technicians lead to the selection of an innovation. This innovation should be adopted later by farmers. Figure 1(b) shows a participatory approach, which is more complex, and where the role of scientists/technicians is to make an informed decision but also to collect information and present it to farmers and allow them to discuss the options and make decisions about what innovation to promote (Figure 1b).

In the transdisciplinary approach not only are the purely objective biophysical aspects important, but also the socio-economic context and farmers' perceptions and knowledge about the issue to be discussed (Figure 2). All these factors are interrelated and nourish dialogue and decision making in the CoP; at the same time the CoP also serves to provide information about each of the factors.

Stakeholders

Three associations from the Chókwè Irrigation Scheme were selected to participate in this study, in an attempt to represent the different typologies of farmers' groupings. Two of them, Muzumuia and 21 de Maio, are farmers' associations belonging to Mozambique´s National Peasants Union (UNAC). Aredonze is a water users' association that has some competence in managing secondary- and tertiary-level irrigation infrastructures. In Table I some characteristics of the associations are summarized.

Methods

In order to promote a transdisciplinary approach in the innovation process, we organized it in four parts and selected different tools for each part, as shown in Figure 3.

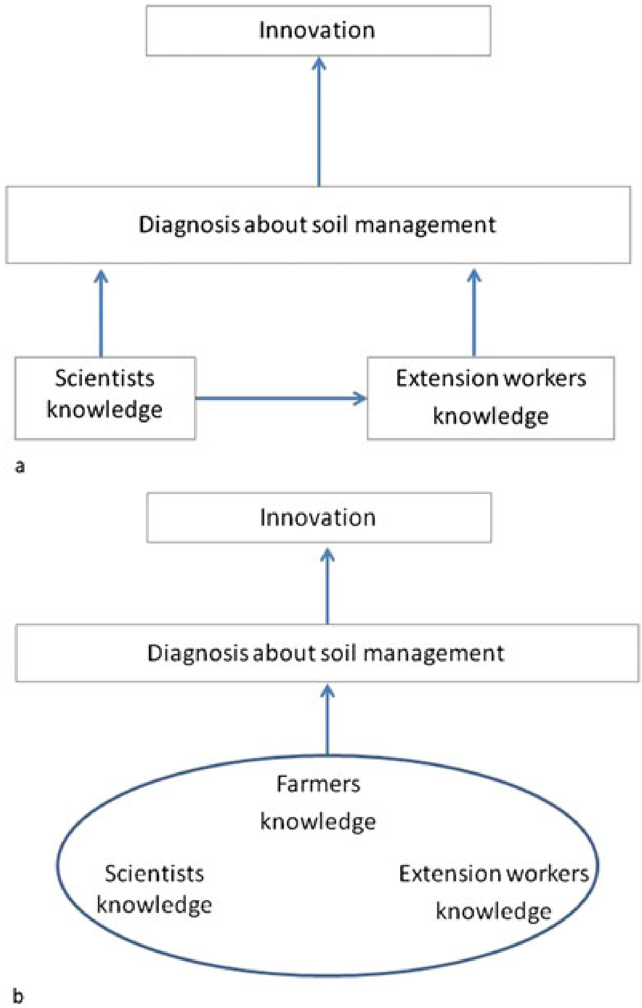

Figure 1. (a) Knowledge flow in Transfer of Technology approach to innovation (b) Knowledge flow in Transfer Transdisciplinary research approach to innovation

In this paper we present results of parts I, II and III, as part IV is still ongoing.

The diagnostic phase (part I) was designed to obtain information about the social context of the farmers, their knowledge about soil fertility management, to analyse their level of knowledge and application of seven practices for soil fertility management (legume inter-planting, manure, compost, crop residues, crop rotations, fallows and inorganic fertilizers) and their actual agrarian practices and the soil conditions. Three methods were selected to relate all these aspects:

- structured interviews with farmers. From 24 June to 2 August 2013 interviews were carried out with a random sample of 31 farmers, with an even distribution of this sample across the 3 associations (i.e. 10 per association). Interviews were conducted whenever possible in farmers' fields, in Portuguese or in Xangana (the local language) with translation into Portuguese. Trends of variation and associations between socio-economic variables and perceptions and strategies of soil fertility management were analysed through a multivariate analysis (multiple correspondence analysis). For this they were selected using the set of variables in Table II.
- soil sampling in the interviewed farmers' fields. One soil sample per plot of the interviewed farmers was taken, combining subsamples of the different parts of the plot. Each sample was taken at 0–20 cm. Soil sample analysis of the main physical–chemical properties: pH, texture, electrical conductivity of the 1 : 5 soil : water extract, available calcium (Ca), Olsen phosphorus (POlsen), available potassium (K), organic carbon (C), total nitrogen (TN) and the carbon/nitrogen ratio (C/N).
- Communities of Practice (CoPs). One CoP per association was organized, with a local and an international facilitator. CoPs were held directly on the field for 21 de Maio and Muzumuia. The CoPs for Aredonze were held at the association's office. Participation was open to all interested farmers, especially those who had participated in the interviews. The CoPs focused on assessing seven soil fertility management practices analysed during the interviews. Farmers discussed at a collective level the positive points and the negative points/difficulties in adopting each practice. The elements signalled by farmers were represented by pictures by the facilitators on a flipchart. In 21 de Maio and Aredonze a preliminary dialogue was conducted about possible innovative practices to be tested to increase soil fertility. For further information, see the method description in Sánchez-Reparaz (2013).

Taking into account all the results, the 21 de Maio association was chosen to conduct the innovation test because:

1. Its members identified an opportunity for innovation that could be supported by one of the partners of EAU4Food;
2. They are already a CoP;
3. From the socio-economic point of view they face economic and labour limitations that limit their access to inorganic fertilizers. There are locally available resources like rice straw that can improve soil fertility, reducing costs associated with soil fertility management;
4. They are part of Mozambique`s National Peasants Union (UNAC) which could be a platform for the diffusion of innovations.

The innovation test consists in preparing compost with rice straw and manure and applying it on a part of the association's collective plot to compare its effects on yield with

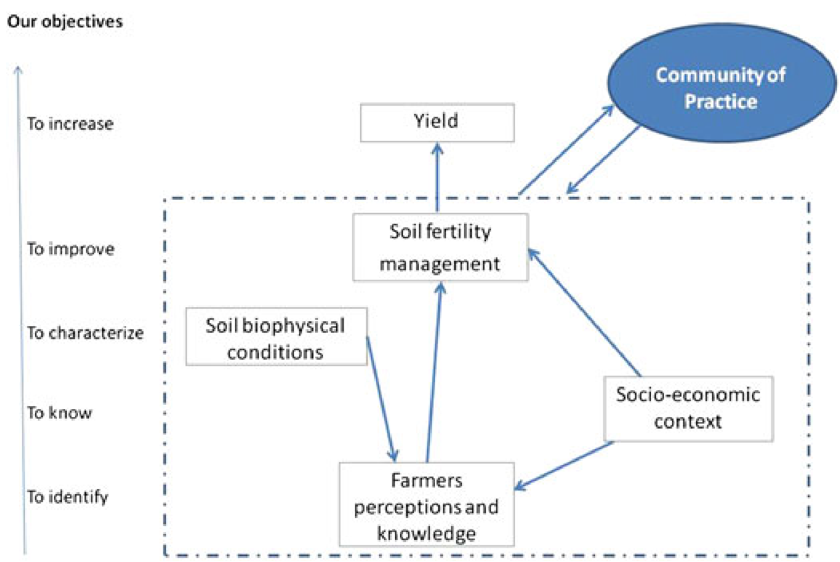

Figure 2. Interrelated aspects on a transdiciplinary approach to agronomic innovation

Table I. Some characteristics of the three associations studied

	21 de Maio	Muzumuia	Aredonze
Type of association	Farmers' association member of UNAC	Farmers' association member of UNAC	Water users' association
Creation date	1983	2004	2002
Total surface available (ha)	80	52	1200
Total surface cultivated (ha)	75	41 (from which 11.5 in non-irrigated land)	900
Surface cultivated per farmer (ha)	0.5–1	0.25–0.5	0.5–16
Number of members	87	46	352
% women	100	No data (majority men)	No data (majority men)
Collective surface (ha)	1 + 0.5 loaned	0.5 + possibility of having additional 0.5	No
Main crops	Rice, maize, beans and some horticultural crops	Maize, beans and horticultural crops	Rice and horticultural crops

Source: FAEF UEM (2011) and interviews with the associations' presidents (July 2013).

another part of the collective plot where the same crops are cultivated without compost. All the organizational aspects for compost preparation, assessment and application are a central part of the test.

The methodology to conduct the compost innovation test was designed by the scientific team and tested in CoPs in Montpellier (https://participmontpellier.wordpress.com/2014/04/14/test-dune-experimentation-agronomique-participative/). A participatory planning workshop was proposed to a group of farmers from the 21 de Maio association with the objective of explaining to farmers how to prepare compost. All the technical and organizational issues related to the innovation test were also decided in this workshop. After the workshop the compost pile was prepared by 21 de Maio farmers and researchers from the EAU4Food project in May 2014. It was turned by 21 de Maio farmers and they also monitored temperature and humidity.

Compost was applied (part III) on the collective plot of the 21 de Maio association in June 2015 over a surface of 0.125 ha, at a dose of 20 t ha^{-1}. Maize and beans were the crops selected by farmers to conduct the test. These crops were also established on another 0.125 ha without compost application in order to compare results.

In order to assess the impact of the participatory methodology and the potential of innovation uptake inside and outside of the association, 10 semi-structured interviews were carried out in June 2015, just in the final step of the innovation implementation. The interview was composed of 30 open-ended questions organized in two parts: the first part about the compost innovation process and the second

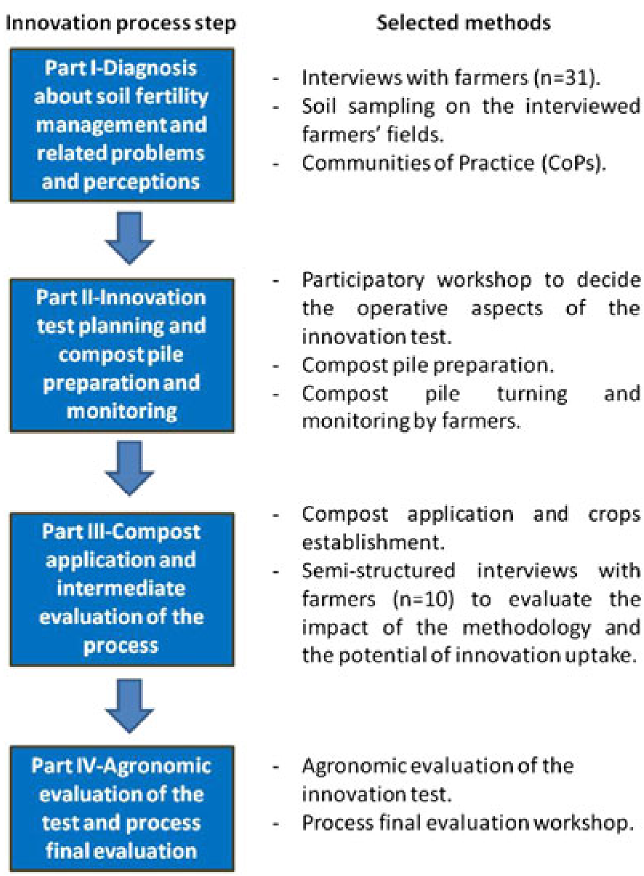

Figure 3. Overview of the innovation process and of selected methods

Table II. Variables selected from the interview for the MCA

Variables and groups of variables selected from the interview to analyse the relationships between them
Gender
Education level
Surface
Livestock owner
Harvest main destination (self-consumption, market)
Level of knowledge and application of the studied practices for soil fertility conservation
Best practice for soil fertility conservation
Perception of changes in soil fertility over the last years
Perception of salinity as a problem

about innovation networks inside the association. Interviews were conducted directly on the field in Xangana with translation into English.

RESULTS

Results are presented according to the different factors affecting yields as previously shown in Figure 3: soil fertility management, farmers' perceptions and knowledge, socio-economic context and soil biophysical conditions. The main results of CoPs are also presented.

Actual agrarian practices, farmers' knowledge and perceptions of soil fertility

As it it shown in Table III fallows, manure, crop residue incorporation and inorganic fertilizers were known about by more than 70% of the farmers interviewed. At an intermediate level of knowledge were crop rotation and legume inter-planting (50–70%). Compost was hardly known as a soil fertility technique (about 25%).

Per association, Aredonze is the one where farmers have a higher level of knowledge of the practices (95% of average knowledge per individual technique), while 21 de Maio and Muzumuia show some lower average knowledge (about 70%). However, knowledge is in general high, so it does not seem that at least nominal knowledge of the technique is a problem in the area.

There was an approximate equilibrium between the proportion of farmers supporting inorganic fertilizer as the best technique, organic fertilizing methods (crop residues and manure) and the combined use of both (Table IV), existing some preference for the inorganic fertilizers. Similarly, there is a balance between the perception of evolution of soil fertility as improving, degrading or stable. In both aspects there are apparent differences between associations but the sample size was too low to test for significant statistical difference.

The CoPs showed a group of practices that were not frequently applied (fallows, manure, legume inter-planting and compost) and the reasons why they were not often used, despite the fact that most were well known. Although the practice of fallows is well known among the farmers the areas they cultivate are too small and they need to use them continuously. The main problem in using manure is access, as many farmers do not have livestock, and there are difficulties in transporting and acquiring sufficient quantities for the area they want to cultivate. The more frequent crop combination for legume inter-planting is maize and beans, but the problem identified is that they consider that the yield for maize and beans is lower when inter-planted than when cultivated separately, possibly related to the fact that the two crops have different water needs. Compost is not well known by the farmers interviewed, and among the farmers that do know it the difficulties in adoption are the amount of labour and its technical complexity that takes time and work to prepare it and that it is feasible just to use it on small plots.

The positive points for using crop rotation are that it is good for preventing pests and diseases and helps the soil to be fertile. An important difficulty for adoption is that in some parts of the scheme soils need lots of time to dry out

Table III. Level of knowledge and application of the practices studied for soil fertility conservation (n = 31). Frequency of application is referred to those farmers who actually apply the technique, not the total farmer population

	High knowledge (known by +70% farmers)	Medium knowledge (50–70%)	Low knowledge (<50%)
Very frequently applied (+70%)	Crop residue incorporation Inorganic fertilizers	–	–
Frequently applied (50–70%)	Crop rotation	–	–
Not frequently applied (<50%)	Fallows Manure	Legume inter-planting	Compost

Table IV. Farmers' perceptions about soils and their management

		21 de Maio	Aredonze	Muzumuia	Total
		% farmers from the association	% farmers from the association	% of farmers from the association	% of farmers from the whole sample (n = 31)
Best practice for soil fertility conservation	Inorganic fertilizers	70	20	27	39
	Organic fertilizers: crop residue incorporation or manure	20	30	18	23
	Combination of both	10	40	37	30
Perception of evolution in soil fertility over recent years	Improvement	40	10	36	29
	Degradation	20	50	37	36
	No change	40	40	18	32
Perception of salinity as a problem	Yes	40	90	73	68
	No	60	10	27	32

after rice because of a poor drainage system and if they wait for the soil to dry they will be late for the other crops.

Crop residue incorporation and inorganic fertilizers are the most applied and known practices. Crop residue incorporation is considered a good source of organic matter for soil but the negative point is that it requires a lot of physical work if it is done manually or with animal traction. Inorganic fertilizers are seen as a good way of increasing production but the main difficulty in their adoption identified by the three associations is cost.

Table V shows a summary of the reasons enounced in the three CoPs for using/not using the practices studied.

The social and physical context of soil fertility management on Chókwè

The knowledge of techniques of soil fertility management, their degree of application and the results of CoPs are, at least in part, constrained by the physical and social context. We briefly reviewed these aspects. Detailed analyses are found in Sánchez-Reparaz (2013, 2014).

The physical–chemical analyses (see Table S1 on supplementary information at the end of the article) of the soils in the farms studied have, in general, acceptable conditions. The soils present medium to high values of nutrient concentration as well as good levels of organic matter, neutral pH, medium texture and a moderate electric conductivity, with minimal negative effects in general. In this respect, the scheme of Chókwè (or the areas of the farmers' association we researched) does not have, at the present, a clear severe fertility limitation.

An in-depth analysis of the structured interviews for farmers revealed some interesting characteristics that provide understanding of the attitudes toward soil fertility management in the area. Table VI shows the main conclusions that arise from the study of the relationships between the selected variables through multiple correspondence analysis (Sánchez-Reparaz, 2013).

Innovation test planning and compost pile preparation and monitoring

The CoP we organized in Montpellier before going out to the field was helpful in adapting the methodology designed for the planning workshop to real conditions through simulation.

Once in the field the planning workshop was important for promoting collective planning, learning and action.

Table V. Summary of positive and negative perceptions /perceived difficulties for adoption of soil fertility conservation practices: as agreed by participants of CoPs

Practice	Positive perceptions	Negative perceptions / perceived difficulties for adoption
Legume inter-planting	1. Optimizes small surfaces. 2. Good practice for soil nutrition. 3. Cheap.	1. Lower yield for maize and beans. 2. Weeding more difficult.
Rotation	1. Optimizes small surfaces. 2. Good practice for soil nutrition. 3. Way of preventing pests and diseases. 4. Cheap.	1. With no food crops they cannot afford the costs. 2. If no correct drainage, just possible to cultivate rice. 3.Lack of knowledge about how to do it.
Fallows	1. Cheap. 2. Good practice for soil nutrition.	1. Plots too small. Need continuous cultivation. 2. Practice not well perceived in the association.
Manure	1. Good practice for soil nutrition. 2. Positive for salinity control. 3. Cheap. 4. Synergy with urea, improves its effects.	1. Difficult access. 2. Limited quantity available. 3. Transport and time. 4-They are not used to using it. 5. Very work demanding. 6. Just feasible for small surfaces. 7. Slow effect. 8. Expensive application.
Residue incorporation	1. Good practice for soil nutrition.	1. Work demanding. 2. Time required for decomposition.
Compost	1. Direct preparation on the field, no transport required. 2. Prepared with local materials. 3. Need to use less chemical fertilizer. 4. Long-lasting effects. 5. Cheap.	1. Lack of knowledge about how to do it. 2. Just for small plots. 3. Difficulty, time and work to prepare it. 4. Slow effect. 5. Amount of materials needed.
Mineral (inorganic) fertilizers	1. Good results, increases production.	1. Cost.

Table VI. Related variables after MCA

Related variables after MCA	
Group 1	Group 1
Men.	Women
Medium holder farmers.	Smallholder farmers.
Primary education.	No studies.
Have access to more means of production than women.	More family responsibilities than men.
Production oriented to market.	More limited access to means of production than men.
Higher level of knowledge and application of the practices for soil fertility conservation than women.	Cultivating mainly for self-consumption.
More negative perception about soil fertility evolution related to salinity problem.	More positive perception about soil fertility evolution than men.
Preference for inorganic fertilizers.	Preference for combination of inorganic with organic practices.

Compost application and intermediate evaluation of the process

The intermediate process and innovation uptake prospects evaluation show that for only some of the farmers was the fact they were listened to by researchers important, and a few of them felt they contributed their experience to the project. The others did not pay much attention to the participatory methods deployed during workshops. What farmers appreciated the most was the practice component of the project. The fact that they prepared compost themselves, on their own field, and later were responsible for monitoring and turning gave them a strong sense of ownership. They also appreciated the participation of the external researcher in the physical work while preparing the compost.

However, the interviews showed that although participating farmers perceive the compost as a technique that was proposed to them by researchers, they took time inside the association to discuss their involvement in the project and collectively agreed it was in their interest.

In terms of future perspectives for compost adoption, implementing the CoP approach had a strong impact on both learning the technique and its dissemination. All farmers interviewed were confident that they knew how to produce compost without external guidance. They pointed out that the project, through its practice component, built an important capacity inside the association. They emphasized the fact that the compost technique was accepted by all association members (not only project participants) and were convinced that the test planned by the project would only strengthen this effect. The positive reception of the technique was partly due to the results of the small test that the farmers spontaneously conducted, applying the compost on one garden crop (courgette). The internal dynamics of the association, where farmers typically share all new knowledge with other members (an already established although unnamed CoP), helped the dissemination. In addition, as we found out, the compost technique as well as the results of the farmers' spontaneous test, was also presented to another association that expressed its interest in trying the technique.

We have already identified constraints related to the materials needed for compost preparation. First, farmers are reluctant to keep the rice residues unburned for too long, as, according to them, the residues attract rats to the field, which endangers the crops. Second, even if the association has the funds secured, buying manure is problematic, as animal owners believe that entering into possession of animal excrement gives that person power over those animals' reproduction, and fearing the consequences, refuse to sell. Despite these constraints, all the farmers declared they wanted to continue with composting in the future.

DISCUSSION AND CONCLUSIONS

Approaches to agricultural research and development have evolved over the last 50 years, from the transfer of technology approach where farmers had a passive role and the processes were single discipline driven to the more recent people-centred innovation and learning approaches where farmers are active stakeholders in the process and different disciplines and knowledge are integrated, from approaches centred on farmers and technologies to a wider systems perspective (Scoones *et al.*, 2009). In this study we implemented a participatory approach following the principles of CoPs. From the theoretical and ideal approach to its practical implementation there may be faults and weaknesses. We discuss the whole process to identify them and suggest future courses of action in participatory approaches.

Soil fertility management: not just a technical question

Do soils on Chókwé present soil fertility problems? Soil analyses show an acceptable status of the soils. In spite of this, intensive use in the coming years may produce a decrease in fertility and therefore pre-emptively implement correct soil fertility management at the right time. On the other hand, not presenting obvious fertility problems is not the same as saying that a general increase in nutrient levels would not increase crop productivity.

Farmers' perceptions about the evolution of soil fertility over recent years are diverse, with an equal distribution between improvement, degradation and no change. Per association, 21 de Maio and Muzumuia have a more positive vision than Aredonze. There is evidence (Sánchez-Reparaz, 2013) that perception about fertility evolution is related to the production objectives of the farmers and therefore more related to expectations than to objective crop yields. For instance, women are poorer and are producing for self-consumption or for local markets and do not consider decreasing soil fertility, while men producing for markets do have the idea of decreasing fertility. Nevertheless, on Aredonze large extensions were abandoned because of problems of salinity (pers. obs.), in spite of these lands not belonging to the farmers interviewed the context may influence their perception.

Our results show that soil fertility management and the adoption of innovations are conditioned not only by technical factors but also by the socio-economic context and by farmers' knowledge and perceptions. Farmers perceiving soil fertility decrease have a higher preference for inorganic fertilizers. In this sense, their socio-economic context, market objectives, etc. may be a barrier to adopting alternative, collectively led innovations. Therefore, after the diagnosis phase we chose to work innovation with the apparently more permeable groups that did not expect large and immediate increases in yields. The integral approach to the problem underlying participatory methods has the advantage of allowing one to judge what is the most feasible action to promote innovation, not only from a technical perspective, but also in a context of limited resources. As is shown in Table III, the main barrier does not seem to be knowledge but difficulties in implementation.

Sietz and Van Dijk (2015) identify household and farm characteristics as one of the main factors that affect the adoption of soil fertility conservation measures. Stakeholders' perceptions and behaviour constitute another important factor according to the authors, as if soil degradation is perceived as a problem the possibilities of adopting measures to control it increase. Murage *et al.* (2015) focus on the gender approach of farmers' perceptions about new technologies, as men and women play different roles in agriculture and this can affect their perceptions and therefore the adoption of new practices.

As indicated by Andersson and Gabrielsson (2012), collective action has the potential to overcome some of the limitations identified that can affect compost adoption in the future, as it is *a way of risk sharing and pooling of labour and other limited assets*. CoPs can be a platform to promote this collective action.

Contributions of the participatory approach and critical assessment of the process

According to the guidelines and best practices for stakeholder participation suggested by several authors (Reed, 2008; Hassenforder *et al.*, 2015) we identify some weak points of the process related to its initiation by researchers and not by farmers and to the lack of experienced facilitators. In this case, in a place where the previous experience in participatory approaches is non-existent it seems improbable that farmers will initiate the participatory process. Participation takes time but research projects have time constraints, making it necessary to adapt the level of participation to the project's life. For this reason, a participatory project should be formulated when a research institution has a previous relationship with farmers and if they identify a research need. EAU4FOOD, indeed, was conceived as a workbench for testing participatory approaches in different contexts. The next step should be the routine application of the methods incorporating the lessons learnt. In terms of facilitation, it is quite a new discipline and in some countries it is not easy to find qualified local facilitators.

As indicated by Dolinska *et al.* (2015, in preparation), the level of participation in the present case study according to the scale of participation adapted after Pretty (1995) can be considered as giving opinion in the diagnosis and definition of the research agenda, interactive participation in identifying the innovation to be tested and planning of the innovation test, and self organization in conducting the innovation test. This means that there was a progressive increase in the level of participation in the innovation process.

In terms of future perspectives, alternative ways of disseminating the composting innovation (the final objective) should adapt the technique to the specific conditions of farmers (use of other materials, smaller piles). The National Farmers' Union (UNAC) of which the 21 de Maio association is a member, could be an interesting platform to promote exchange and collective learning with other associations and could play a key role in diffusion of the innovation.

CoPs are a way of promoting collective learning and action and the fact that the 21 de Maio association is a self-organized CoP played an essential role in this innovation test. They also allowed a better knowledge of the social and bio-physical environment essential to design a site-specific innovation process. The fact of learning by doing, of sharing work with researchers and of applying compost on their own fields, made the difference.

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