Testing and adoption of bottom-up agricultural innovations to improve soil fertility in small holder farms in sub Saharan Africa: An interdisciplinary approach

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Abstract

Soil fertility is at stake at a global scale, putting pressure on food security, poverty alleviation and environmental protection, under scenarios of climate change that in most cases aggravate the threat. In sub-Saharan Africa, a combination of depleted soils and population growth adds particular pressure to smallholder farmers and society. Their capacity to innovate in a social, economic, political and cultural context is seen as decisive to reverse the trend of declining soil fertility. However, many technologies with a potential to protect, maintain and build up soil fertility are hardly used by small-scale farmers, triggering the urgent question on their reasoning not to do so. Exploring and understanding the constraints and complexity of the social systems interacting with the implied institutional dynamics are essential steps in designing appropriate agricultural innovations that are scalable and adoptable. The focus of the inter- and transdisciplinary approach applied in the project ORM4Soil (Organic Resource Management for Soil Fertility; www.orm4soil.net) lies at the heart of this project. We are combining qualitative and quantitative methods from agronomy, sociology and communication sciences in order to bring soil-fertility-enhancing-technologies and their adoption to the center of the decision-making process of farmers' as well as local and regional institutions. At local and regional innovation platforms, stakeholders from business, government, academia and farmer organizations are discussing the outcomes of agronomic trials and sociological research. We are expecting to create bridges between the needs and concerns of farmers, relevant segments of society and policymaking, with the new common goal to enhance soil fertility.

Keywords: Soil Fertility; sub-Saharan Africa; Innovation Adoption; Transdisciplinary Research; Innovation Platforms

Introduction

Low and declining soil fertility are among the major bottlenecks to the improvement of agricultural productivity and sustainability in sub-Saharan Africa (SSA) (Vanlauwe et al. 2017). Nutrient depletion at farm level is very common throughout the continent (Henao and Baanante 1999; Stoorvogel and Smaling 1990). Many soils are highly weathered and show high contents of low activity clay minerals with poor adsorption capacity. Around 25% of the soils are acidic (pH < 5); and the majority are low in soil organic carbon (SOC) (< 20-30 gkg^{-1}), resulting in important biophysical challenges such as low cation exchange and water holding capacity (Kolawole 2013).

In West Africa, long term experiments show a range between over 5% loss of SOM per year on sandy soils to around 2% on better textured soils (Bationo and Buerkert, 2001; Pieri, 1989). It is also estimated that per capita arable land in SSA has shrunk from 0.53 to 0.35 hectares between 1970 and 2000 (Place 2003), adding further pressure to invest in appropriate soil fertility management techniques.

This calls for urgent identification or development of agricultural innovations that are capable of improving soil fertility and can easily be adopted. The rate of adoption of a technology does not only depend on its physical performance but also on socio-economic and cultural factors (Kolawole, 2013; Glover et al., 2016). Within this challenging biophysical context, it is essential to understand the socio-cultural dynamics that determine farmer's perceptions and behaviors towards soil fertility management.

Social structure, norms, opinion leaders and communal authorities are highly influential in terms of how information and innovations disseminate (Rogers 2003). On a more tangible level, the low levels of education and illiteracy, frequently observed in SSA, seriously undermine farmers' ability to access, use and disseminate information and knowledge on agricultural innovations (Sanginga and Woomer 2009). For instance, it has been agreed that highly educated farmers are more likely to adopt agricultural innovations earlier than those who are relatively poorly educated (Basu et al. 2002).

The socio-economic status of the farmer co-determines the ability to invest resources and time in new techniques, as well as to take the inherent risk to change from the traditional technologies to new ones (Martey at al. 2013). This is also the case for other socio-economic factors such as household labour availability, the technology's profitability, market dynamics, land ownership and access to non-farm income (Boateng 2000; Mignouna et al. 2011; Martey at al. 2013). Access to quality information sources, such as a frequent interchange with extension officers and the existence of communication channels that speak the farmers' languages are also important in shaping farmers motivation and attitudes towards soil fertility management (Sousa et al. 2016). Local or regional social structures can help empower farmers to adopt soil fertility management techniques. For example, it has been shown that farmers belonging to a local organization have a higher chance of accessing information on SFM and adopt new techniques (Katungi 2006).

Considering the complexity of the social and biophysical systems surrounding soil dynamics and how they are the basis of terrestrial life, the need for increasing adoption of appropriate SFM techniques is evident, as poor soil management remains the single main factor for soil fertility decline (Tittonell et al. 2013).

In this paper we briefly describe the need for appropriate agricultural technologies and their real application and adoption, as well as the prevailing constraints for the dissemination and adoption of already existing ones. Finally, we address the chosen methodology and pathway to impact of the ORM4Soil project, and how a bottom-up and interdisciplinary approach may contribute to significantly overcome the system's hindrances to the improved adoption of appropriate SFM technologies in the studied contexts.

The need for improved adoption of appropriate technologies

The last decades of soil and soil fertility research and development in SSA saw a dramatic shift from an almost exclusive focus of recommendation programs on inorganic fertilizers in the 70s and 80s – inspired by the Asian green revolution – to a more integrated approach, with the use of more organic and low external input based systems (Vanlauwe et al. 2017). This shift was stimulated by early research showing the negative effects of the continuous use of inorganic fertilizers on soil acidity, nutrient leaching, nutrient deficiencies and SOC dynamics concluding that this technology alone was not appropriate to keep soil fertility levels and instead contributed to declining soil quality and fertility in the long-term (Juo and Lal 1977, van der Heide et al. 1985, Kotschi 2013). Even though, authors such as Vanlauwe and Giller (2006) claim the soil threat of degrading fertility caused by mineral fertilizers to be overestimated.

As a consequence, the following decades saw an increase in the testing and dissemination of soil management solutions that were rather based on organic inputs and system approaches. Among the new technologies was integrated soil fertility management (ISFM), seeking to include organic inputs such as animal manure and compost along inorganic fertilizers (Vanlauwe et al. 2010). The nutrient release from organic resources being more closely synchronized with plant uptake and showing residual effects on the following crops, besides promoting the build-up of SOC (Giller 1997).

Intercropping is another systemic approach that brings benefits related to diversification and the reduction of crop failure risk, as well as the optimization of the use of resources by the two different plants. In addition, the use of leguminous plants as an intercrop can add nitrogen to the soil for the direct benefit of the non-legume crop (Rusinamhodzi 2012). This technology has been tested in many African countries, using plants such as cowpeas or pigeon peas and an alternated spatial distribution of the crops, with positive results in terms of total crop yields, despite more labour input for weeding (Rusinamhodzi 2011).

Even though the first intercropping experiments used auxiliary crops, whose single contribution was their anticipated effect on soil fertility, research has since then turned the focus to species with dual or triple purposes – edible grain, fodder, N enrichment and even pest management – which have a higher adoptability among farmers (Vanlauwe 2017). One well studied case is the push-pull method, which intercrops cereals with an insect repellent plant, such as Desmodium, and an attractive trap plant, such as Napier grass (Fischler 2010).

If sufficient water is available, green manures– usually nitrogen fixing legumes – can be planted before or after harvesting the main crop, with its subsequent use as soil amendment, plowed into the soil (Cherr et al. 2006). However, according to the same author, the technology is only appropriate for the farmer if all benefits such as pest and weed control, nutrient capture, soil protection, SOM increase and use as fodder for cattle are accounted for.

Some small scale soil mobilization technologies, such as the indigenous Zaï technique and demi-lunes for water harvesting (Pasternak et al. 2009), can help combat erosion while promoting water and nutrient retention. When combined with the inorganic fertilizer micro-dose technique, these technologies can help improve yields while increasing nutrient use efficiency at a low cost (Fatondji et al. 2006).

Agroforestry is getting attention from research and development efforts since the 1980s, consisting of the integration of trees into cropping systems. The integration of trees into agricultural landscapes can generate several improvements in the soil as a habitat for soil organisms and also for crop growth (Barrios et al. 2012), but the loss of productive land and the competition to the crop plant for soil resources needs to be taken into account. Among the effects trees can have in agricultural systems are the build-up of SOM, soil cover, lower temperature fluctuations, increased moisture levels, lower erosion rates, increased biodiversity levels with consequences for organic pest management, among other ecosystem services (Barrios et al. 2012). But integrating trees in arable land often poses practical problems particularly for small-scale farmers under various ecological and socio-economic constraints.

However, despite the number of available approaches and decades of efforts in the research and development sectors towards testing, evaluating and disseminating different SFM technologies, these remain poorly adopted by farmers and frequently dependent on projects (Douthwaite et al. 2002). The disappointing rates of adoption of existing SFM techniques have thus deserved much academic research and attention (Sunding and Zilberman 2001, Pannell et al. 2006, Adolwa et al. 2012, Glover et al. 2016).

According to Tittonell (2014), most farmers in the SSA context do not have access, cannot afford or are unwilling to adopt modern agricultural technologies, which too often don't suit the reality of small scale farmers across the continent. The dependency of farmers and farms on societal factors remains poorly understood (Nicolay 2017), clouding the understanding of the adoption dynamics of promising technologies.

Efforts to correct this failure have resulted in another major shift within the agricultural research and development sector: the inclusion of farmers in the process of identifying and testing agricultural innovations (Adekunle and Fatunbi 2012). Such a bottom-up or participatory approach may promote adoption of agricultural innovations, facilitating the emergence of solutions that suit the farmers' realities better. Another aspect of this perspective shift was the inclusion of multi-stakeholders platforms in the process of validation and dissemination of the developed technologies (Nicolay 2016).

Despite these much needed shifts in the attitudes and perspectives from researchers and policy makers throughout the last decades, farmers struggle to adapt agricultural innovations to their farm situation. As other authors suggest (Ouédraogo et al. 2001, Sanginga and Woomer 2009), and as preliminary results from the ORM4Soil research process allow to confirm, adoption levels of even relatively simple techniques, which have been targeted by many projects such as composting, are still not widely adopted and remain largely unknown in many localities, suggesting that quality communication channels and efficient networks of knowledge and dissemination are still missing.

Communication matters: The relevance of quality communication and information sources

The role of communication and its impact on farmers' perceptions and behavior towards soil fertility management is an important aspect of innovation dissemination. In some rural contexts of SSA, the use of radio, farmer field days, extension services and in some cases even TV programs were considered the most accessible, reliable, informative and understandable communication channels (Adolwa et al. 2012, Nyambo and Ligate 2013).

Agricultural instruction videos for mobile phones have been shown to have potential in SSA's rural context, since most farmers use mobile phones that can read videos, which can be easily translated into farmers' languages and disseminated by farmers themselves via the Bluetooth technology (Sousa et al. 2016). Extension services are among the information sources most valued and trusted by farmers because they provide direct and continuous contact with experts and information about new technologies (Sousa et al. 2016). However, such services are very often insufficient, have poor quality or are absent in many regions (Nyareza and Dick 2012).

Kimaru-Muchai et al. (2013) argue that low adoption rates of soil fertility management techniques are due to inadequate mass communication channels for the dissemination of information. Fischler (2010), on the other hand, suggests that interpersonal communication is more effective than mass media in the adoption of farming innovations. As stated by Spurk et al. (2013), trust in information providers, type of content, its quality and mode of information (top-down or debating options) are the most relevant aspects to meet farmers' information needs for considering investments. Yet, the link between poor SFM technologies' adoption and the quality of existing communication channels remains poorly explored.

Many studies have focused on the frequency of contact with different information sources, such as radio, farmer field schools, extension services and others (Kimaru-Muchai et al. 2013, Adolwa et al.2012, Nyambo and Ligate 2013, Sousa et al. 2016), but few have addressed the effects of such information on the use of organic resource inputs to improve soil fertility. The ORM4Soil project seeks, among other goals, to find the best suited communication channels capable of efficiently disseminating SFM messages that are interesting, informative and comprehensible for farmers.

Using inter and transdisciplinarity to deal with a complex system: the case of ORM4Soil[1]

The complex nature of SSA's rural contexts, where i) local and national agricultural systems show defying biophysical and socio-cultural challenges, ii) improved adoption of appropriate SFM technologies are urgently needed and iii) a wide diversity of actors with contradicting interests constitute elements of the system required the use of inter- and transdisciplinary approaches in order to design effective intervention strategies.

The "Farmer-driven organic resource management to build soil fertility" project (ORM4Soil) seeks such an approach, aiming at improving soil fertility through a participatory and interdisciplinary

[1] www.orm4soil.net

methodology. This research and development process brings together farmers, researchers and other stakeholders in a joint effort to develop action plans and tools to reverse soil degradation and improve fertility by increasing adoption of appropriate SFM techniques and bringing more attention to the topic through novel knowledge.

Researchers and students from five countries (Mali, Ghana, Kenya, Zambia and Switzerland) representing three main disciplines – agronomic sciences, sociology/socio-economics/agro-economics and communication sciences – embarked on a six-year collaboration. To achieve this, an intercultural and interdisciplinary dialogue had to be built, with the necessary deconstruction of some discipline related language barriers and persisting stereotypes between different research fields.

The ongoing process of finding a common language across academic disciplines was met by the additional challenge of communicating and collaborating with non-academic actors, such as farmers, technicians and other stakeholders. This involves learning how to communicate scientific results and approaches in a non-scientific language with the involved actors. Despite the difficulties encountered in bringing such a diverse array of actors under the same framework, this has remained the core of the project and the engine behind its novel approach.

The process of bottom-up selection of agricultural innovations to be tested began with an exercise that was to be the first joint interdisciplinary activity between the different project members: a participatory rural appraisal (PRA). The PRA was conducted in two sites per country, allowing to cover a diversity of environmental and social rural contexts, where the final selected techniques were to be tested. Different participatory methods were used, meant to engage all participants and map the basic relationships and societal dynamics within the studied rural communities.

Towards the end of the PRA, a survey and participatory discussions with farmers allowed the selection of the ORM4Soil techniques to be tested in each site, later developed into experimental protocols by each national research team to be implemented in a total of 8 on-station and 120 on-farm trials. In Mali for example, farmers chose to test an agroforestry technique, the intercropping of cotton, maize and sorghum with *Gliricidia sepium* trees. In Ghana, farmers wanted to explore further the application rates and combinations of existing organic resources such as cow manure, compost, biochar and crop residues. In Kenya, the chosen techniques were different organic resources (including Tithonia, an abundant invasive plant) in combination with minimum and conventional tillage. In Zambia, on the other hand, farmers chose the techniques of alley cropping and other intercropping techniques with legumes and the improved version of a traditional type of green manure, locally known as *fundikila*.

Other interdisciplinary activities and initiatives were (or are now under the process of being) carried out along the project's research process, including innovation platforms, farmer field days and surveys before and after a communication campaign seeking to disseminate the results. An ongoing socio-economic research will include aspects such as profitability calculations for the most appropriate technologies being tested and focus group discussions capable of better capturing the social dynamics these innovations might face. Towards the end, an “endline survey” will help to assess the impact and efficiency of disseminating the lessons learned via various channels, and the extent of acquired knowledge and final uptake of adapted technologies.

The final results will be compiled in specific recommendations, brought not only to the relevant policy makers, but also to the main target population of the whole study, the farmers.

The ORM4Soil adoption model and pathway to improved adoption

Rogers (2003) identified five attributes of an innovation decisive for its adoptability: its relative advantage, its compatibility with the existing set-up at production and society level, its complexity and the way how to deal with it, its trialability before adopting it, and finally the observability of the innovation. Some agricultural adoption related studies identify agro-economic factors (Sunding and Zilberman 2001) as central to the decision to adopt a technology (in Rogers’ terms “relative advantage”), while other authors concentrate on communication channels (Adolwa et al 2012, Kimaru-Muchai et al 2013, Nyambo and Ligate 2013).

The work of Pannell et al. (2006) identified three main factors relevant for adopting agricultural innovations: i) the process of learning and experience about the innovation, ii) the characteristics of the farmers within their socio-economic environment and iii) the characteristics of the technology itself. Kuehne et al. (2017) have developed this framework further, generating the ADOPT (Adoption and Diffusion Outcome Prediction Tool) model.

The ADOPT model (Kuehne et al. 2017) asks the users 22 main questions related to i) characteristics of the technology that influence its relative advantage, ii) characteristics of the population influencing their perceptions of the relative advantage of the technology, iii) characteristics of the technology influencing the ease and speed of learning about it, and iv) characteristics of the potential adopters that influence their ability to learn about the practice. The 22 variables are then parameterized and defined algorithms are used to measure the expected adoption rate. The model is designed to contribute to the conceptual understanding of adoption related dynamics within the agricultural sector.

In the project, the ADOPT model for smallholders is seen as appropriate to help understand the complexity of adoption dynamics in the studied agricultural contexts. A new version, focussing on developing contexts and considering its specific characteristics, is being developed and the international ORM4Soil team and experience might provide relevant insights for it.

Pathway to impact: Paving the way towards improved adoption

The agronomic and sociological results coming from the project's research process at local level are brought into a continuous and dynamic interactive discussion centered on the innovation platforms (IP). These multi-stakeholder structures were set up in each of the eight project sites, and are expected not only to identify collectively the local constraints and opportunities around the topic of SFM technologies and build-up of soil fertility. They also to bring the lessons learned and the acquired knowledge to a wider dialogue and help paving the way to its practical implementation and scale up.

Insights from well-functioning IPs are vital to assess the adoptability and scale up potential of the tested technologies, since the diversity of actors can interlink cross-discipline information such as the likeliness of the technology to have good yields, to generate profit, to be easy to implement and to build-up soil fertility. Therefore, the IPs are also instrumental in producing messages from the outcomes of the project, which are being disseminated in the communication campaigns in the eight project sites.

The following scheme represents the timeline of ORM4Soil's pathway to impact, with the width of the triangle outlining the potential proportion of technology adopters along and beyond the project's lifetime.

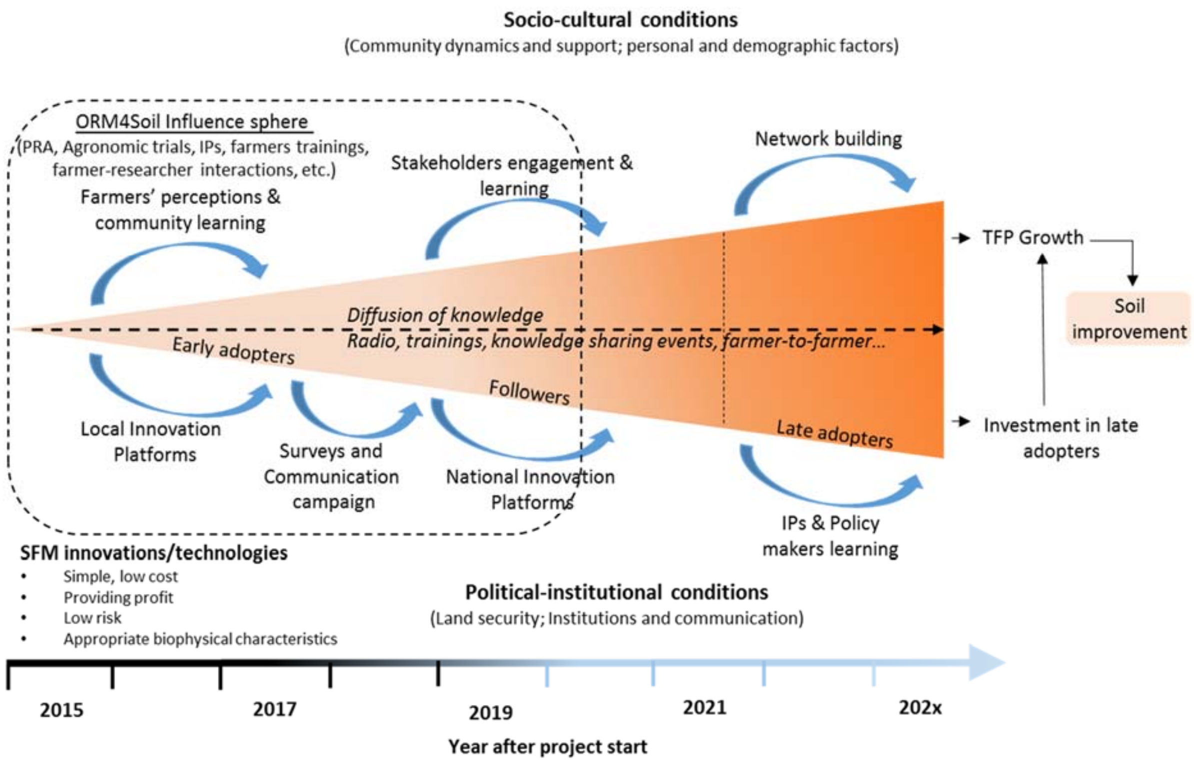

Fig. 1. Timeline of ORM4Soil's pathway to impact, paving the way to the improved adoption of appropriate SFM technologies.

Illustrating the potential growth of the project's technologies or its adoption rates, the left side of the scheme shows the little proportion of early adopters, still triggered by the project's activities and by the farmers directly engaged in the project. After the development and ripening of the IPs set up in the framework of ORM4Soil, as well as after the first wider diffusion of the project's messages and successfully tested technologies during the communication campaign, the proportion of adopters is expected to grow.

The communication campaign will engage radio and extension services, and will be complemented by farmer field days in order to show the practical results to a wider audience. The messages used for dissemination during the communication campaign will be produced by the coordinated efforts of each national team, joining cross discipline data and expertise, with the consultation of IPs for fine tuning.

The IPs are also meant to expand their range and reach the regional and hopefully national levels, seeking to influence policy and engage nation-wide stakeholders and their networks.

Bridges with other structures, such as small and medium enterprises (SME), extension services, governmental and non-governmental agencies working in the agricultural sector and other relevant stakeholders are expected to be built. Extension services in particular can prove instrumental in the ORM4Soil's strategy for dissemination of the produced messages.

As time goes by, the project's acquired knowledge and experience is expected to translate into action and behavioral change regarding the adoption of SFM technologies, hopefully reaching farmers outside of the eight project sites and contributing to fulfill the project's overall aim of building soil fertility and tackling food insecurity.

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