The challenge of improving soil fertility in yam cropping systems of West Africa: a review

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Submitted to Journal:
Frontiers in Plant Science

Specialty Section:
Agroecology and Land Use Systems

Article type:
Mini Review Article

Manuscript ID:
304872

Received on:
22 Aug 2017

Frontiers website link:
www.frontiersin.org

Conflict of interest statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest

Author contribution statement

EF led the review and all co-authors made substantial contributions to the conception, development and revision of this review during the various workshops of the YAMSY project. All coauthors approved the final version and agreed to be accountable for all aspects of this work.

Keywords

Dioscorea spp, soil fertility, interdisciplinarity, transdisciplinarity, Innovation Platforms

Abstract

Word count: 248

Yam (Dioscorea spp) is a tuber crop grown throughout the tropics for food security, income generation, and traditional medicine. This crop has also a high cultural value for some of the groups growing it. Most of the production comes from West Africa where the increased demand of the past has been covered by enlarging cultivated surfaces while the mean yield remained around 10 t tuber ha-1, which is only 20% of the yield potential. In West Africa, yam is traditionally cultivated without input as the first crop after a long-term fallow as it is considered to require a high soil fertility. African soils, however, are more and more degraded. The aims of this review were to introduce yam as an orphan crop, show the importance of soil fertility for yam production, discuss the potential of integrated soil fertility management, highlight the challenge for adoption of innovations in yam systems, present the concept of innovation platforms to foster collaborative innovation design and provide recommendations for future research. This review shows that the development of acceptable soil management innovations for yam requires research to be conducted in interdisciplinary teams including natural and social sciences and in a transdisciplinary manner involving relevant actors from problem identification, to the co-design of innovations and their evaluation. Finally, this research should be conducted in diverse biophysical and socio-economic settings to develop generic rules on soil/plant relationships in yam as affected by soil management and on how to adjust the innovation supply to specific contexts.

Funding statement

This work has been done during the YAMSYS project (www.yamsys.org) funded by the food security module of the Swiss Programme for Research on Global Issues for Development (www.r4d.ch) (SNF project number: 400540_152017 / 1).

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Running title: Soil Fertility Management in Yam (5 words, max allowed 5 words)

Keywords: 8 words (max 8 words)

Number of words in the abstract: 248 (max allowed 250)

Number of words in the main body of the text: 2999 (max allowed 3000)

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Abstract

Yam (*Dioscorea* spp) is a tuber crop grown throughout the tropics for food security, income generation, and traditional medicine. This crop has also a high cultural value for some of the groups growing it. Most of the production comes from West Africa where the increased demand of the past has been covered by enlarging cultivated surfaces while the mean yield remained around 10 t tuber ha^{-1}, which is only 20% of the yield potential. In West Africa, yam is traditionally cultivated without input as the first crop after a long-term fallow as it is considered to require a high soil fertility. African soils, however, are more and more degraded. The aims of this review were to introduce yam as an orphan crop, show the importance of soil fertility for yam production, discuss the potential of integrated soil fertility management, highlight the challenge for adoption of innovations in yam systems, present the concept of innovation platforms to foster collaborative innovation design and provide recommendations for future research. This review shows that the development of acceptable soil management innovations for yam requires research to be conducted in interdisciplinary teams including natural and social sciences and in a transdisciplinary manner involving relevant actors from problem identification, to the co-design of innovations and their evaluation. Finally, this research

should be conducted in diverse biophysical and socio-economic settings to develop generic rules on soil/plant relationships in yam as affected by soil management and on how to adjust the innovation supply to specific contexts.

1 Introduction

Yam (*Dioscorea* spp) is a tuber crop grown by smallholders throughout the tropics (Andres *et al.,* 2017). The most important species are *D. alata* (greater or water yam), *D. rotundata* (white guinea yam), and D. *cayenensis* (yellow guinea yam) (Arnau *et al.,* 2010). Besides being a staple consumed by 155 million people, yam is grown as a cash crop and a medicinal plant (Lebot, 2009; Sangakkara and Frossard, 2014) and has a high cultural value for some of the groups growing it (Coursey, 1981). Despite its importance, yam remains an orphan crop (Kennedy, 2003; Naylor *et al.,* 2004). As an illustration, the number of publications on yam (*Dioscorea* spp) listed in the Web of Science since 1970 amounted to 12’700 in June 2017 which can be compared to the 280’000 publications listed for the same period on maize (*Zea mays*).

West Africa produced 62 million tons of tuber (91% of world production) in 2014 (FAOSTAT, 2016). There yam is a staple for at least 60 million of people (Asiedu and Sartie, 2010). In the past, the increased tuber demand was achieved by enlarging cultivated surfaces from 0.9 million ha in 1961 to 7.0 million ha in 2014. In the meantime mean tuber yield increased only from 7.8 t ha^{-1} in 1961 to 8.8 t ha^{-1} (FAOSTAT, 2016), whereas the yield potential is probably higher than 50 t tuber ha^{-1} (Lebot, 2009). The yam belt of West Africa spans from the humid forest to the northern Guinean savanna (Asiedu and Sartie, 2010). In the humid forest yam is cultivated for food security intercropped with other staple crops, whereas in the savanna, yam is also a cash crop, making it important for income generation. In the savanna, yam may also be cultivated in pure culture (Ndabalishye, 1995). Yam is traditionally planted as the first crop, after a long fallow as it is considered to be demanding in terms of soil fertility (Diby *et al.,* 2011; O’Sullivan *et al.,* 2008). In the following years, the field is cultivated with other staple crops (maize, cassava, groundnuts, cowpea or rice) and/or perennial crops such as cocoa (*Theobroma cacao*) in the humid forest, cashew (*Anacardium occidentale*) in the derived savanna zone and shea tree (*Vitellaria paradoxa*) in the northern Guinean savanna. Yam is usually grown without any external input using own tubers as planting material (so called yam seed). In areas where land is scarce, farmers grow yam after only a year of fallow or without fallow (Maliki *et al.,* 2012a and 2012b). The main constraints of yam production are: bad quality yam seed, the large proportion of harvest used as yam seed, lack of improved cultivars, need for staking, weeds, pests and disease, low tuber storability, limited water availability, low soil fertility and inadequate plant nutrition (Abdoulaye *et al.,* 2014). Other factors that limit production are the limited land available, complex and un-transparent markets and lack of processed products (Abdoulaye *et al.,* 2014). Given the rapid population growth, the high proportion of population living with a very low income, the large surfaces of degraded land and the rapid on-going climate change in Sub Saharan Africa (Montanarella *et al.,* 2016; FAO, 2017); it becomes urgent for research to deliver feasible and efficient options to sustainably increase yam productivity.

The aims of this review were to show the importance of soil fertility for yam, discuss the potential of integrated soil fertility management for this crop, highlight the challenge for adoption of innovations in yam, present the concept of innovation platforms as a tool to develop collaboration between actors for designing innovations in yam and provide recommendations for future research.

2 Importance of soil fertility for yam production

The importance of soil fertility for yam has been exemplified by Diby *et al.* (2011) who showed that tuber yields of improved cultivars of *D. alata* and *D. rotundata* grown after a fallow, under the same conditions and the same climate were 1.5 higher in a “forest” soil containing more clay and organic matter and having a higher pH than in a close by “savanna” soil. However, assessing the effect of soil properties on yam production by comparing results of different field experiments is often difficult as many factors, often not reported, affect tuber yield. These are weather conditions, cultivar, yam seed quality, seed weight, planting density, planting date, weeds, diseases and pests (Cornet *et al.,* 2014 and 2016; Rodriguez-Montero *et al.,* 2001). Some fertilization trials conducted with yam showed positive impacts of N, P and K inputs on tuber yields (responsive soils), while other trials did not show any impact of nutrient additions (non-responsive soils) (O’Sullivan *et al.,* 2008). This suggests that responsive soils were not able to release sufficient nutrients to cover plant needs, while other factors limited yam response in non-responsive soils. These other soil-related problems can be the low organic matter content linked to the slash and burn practice (Nwaga *et al.,* 2010) and the intensive soil preparation for preparing mounds in which seeds are planted, the change in arbuscular mycorrhizal population and the accumulation of pest and diseases during cultivation (Coyne *et al.,* 2005; Tchabi *et al.,* 2008 and 2009). Low soil organic matter content can lead to low water infiltration and to soil structural degradation impairing root and tuber growth. Finally, water erosion can damage soil surface before it becomes fully covered with vegetation.

Dansi *et al.* (2013) and Lebot (2009) report that producers perceive soil fertility decline as a key constraint for yam production. A recent global survey conducted by Abdoulaye *et al.* (2014) among yam experts classified the topic “Improving soil fertility (micronutrients, fertilizer, organic matter)” as the second most important topic to be addressed in research preceded by “Improving shelf life of yam tubers”. Although soil fertility degradation and inadequate plant nutrition are recognized problems (Asadu *et al.,* 2013), little has been done to address them. In the first conference on yam held in 2013, only 7 presentations dealt with these issues (Abdoulaye *et al.,* 2013; Asadu *et al.,* 2013; Dansi *et al.,* 2013; Ennin *et al.,* 2013; Lawal *et al.,* 2013; Maniyam *et al.,* 2013; Tournebize *et al.,* 2013) over a total of 115 presentations dealing mainly with plant genetics, food processing, and markets (IITA, 2013). Altogether, this demonstrates the need to work on soil fertility and nutrient management in yam.

3 Can the Integrated Soil Fertility Management framework be useful for yam systems?

The Integrated Soil Fertility Management (ISFM) framework is based on the combined use of organic and mineral nutrient sources in conjunction with appropriate crop varieties and adaptations to the local context (Chivenge *et al.,* 2011; Kearney *et al.,* 2012; Vanlauwe *et al.,* 2010 and 2015) to improve soil fertility and crop production. Recent results suggest that the combined addition of mineral and organic fertilizers increases yam yields compared to non-fertilized controls (Ennin *et al.,* 2013; Lawal *et al.,* 2013; Tournebize *et al.,* 2013; Susan John *et al.,* 2016).

Mineral fertilizers might however have unexpected effects. Hgaza *et al.* (2012) observed in *D. alata* a strong increase in tuber yield following the addition of mineral NPK fertilizers to a low fertility savanna soil, but they also showed that this input had triggered an increased uptake of N derived from the soil by the crop. Since this input had not caused any change in root morphology and growth (Hgaza *et al.,* 2011), the authors concluded that the NPK addition had increased the rate of soil organic matter mineralization. This phenomenon needs further investigation as it can have negative consequences on these soils, which have very low organic matter contents. Whether such an effect would also occur following organic fertilizer inputs should also be assessed. In the same study, Hgaza *et al.* (2012) showed that the maximum recovery of fertilizer N in the tuber was below 30%.

This limited recovery can be explained by the low planting density, which is typical for West Africa and by the coarse and superficial root system of *D. alata* (Hgaza *et al.,* 2011). This low recovery rate suggests high rates of N losses to the environment. Mineral fertilizer inputs have also been reported to increase tuber rotting during storage and to negatively affect the organoleptic properties of tubers (Vernier *et al.,* 2000). Such effects are known in potatoes (McGarry *et al.,* 1996) and the underlying mechanisms are probably similar in yams. Since fertilizers (organic and/or mineral) use will become unavoidable to increase yam productivity, the effects of fertilizer on tuber quality will need to be studied.

Intercropping or rotating yams with legumes are alternative ways to supply the crop with N. Intercropping yam with herbaceous legumes increases tuber yields and nutrient recycling rates (Maliki *et al.,* 2012a). Intercropping yam with the woody legume *Gliricidia sepium* is promising as it can be used as a stake for yam vines while providing N derived from the atmosphere (Budelmann, 1989 and 1990; O'Sullivan *et al.,* 2008). However, the additional labor required for pruning *G. sepium* can offset its positive impact on crops.

In Benin, farmers have developed strategies to cope with soil fertility depletion. These include the selection and cultivation of less demanding yam cultivars, the introduction of yam in rotations to benefit from the residual effect of fertilizers added to previous crops and decrease pests and diseases pressure, and the cultivation of yams in sites where water, organic matter and nutrients tend to accumulate such as lowlands and old cattle corrals (Floquet *et al.,* 2012). Another example of such adaptation is found in the province of Passoré (Burkina Faso) where yam is grown under semi-arid conditions (700 mm year^{-1}) on hydromorphic soils, in rotation with other staple crops and with the use of organic and mineral fertilizers (Dumont *et al.,* 2005; Tiama *et al.,* 2016). The impact on yam yield formation, nutrient dynamics and use efficiency of these adaptations have not yet been studied.

Altogether, there is a potential for ISFM in yam systems but this needs to be linked to farmers' options and preferences and to the demand expressed by the different actors along the value chain. The implementation of ISFM will however be challenging. For instance, for producers having still access to older woody fallow, even though such fallows are becoming scant and remote from villages, is ISFM be more efficient in terms of returns to labor? Moreover, in situations where land is scarce and continuously cropped, is it be still possible to mobilize organic resources for ISFM at reasonable opportunity costs?

4 The challenge for adoption of innovations in yam systems

There is little information on the economic and social acceptance of soil management practices for yam (Maliki *et al.,* 2012b) and more generally on the adoption of new technologies in yam systems (Dao *et al.,* 2003; Soro *et al.,* 2010). In communities where yam is grown as a cash crop, farmers might be interested to take up innovations contributing to increase income. But in communities where yam is grown for self-consumption, there might be less interest in adopting such innovations. To our knowledge, these hypotheses have not been tested yet. Overall, the adoption of new technologies in yam seems limited. For instance, the minisett technology that uses small and healthy tuber parts, which was developed decades ago (Aighewi *et al.,* 2014), has not been widely adopted (Okoro and Ajieh, 2015). Similarly, high yielding yam varieties tolerant to disease and growing without staking have not been widely adopted (Alene *et al.,* 2015). Notable exceptions have been the large adoption in Ivory Coast of the *D. alata* varieties Florido and C18, which are easy to grow while showing good resistance to diseases (Doumbia *et al.,* 2004 and 2014). Moreover, C18 is well appreciated for cooking "foutou", a yam-based dish (Doumbia *et al.,* 2014), which is a driver for technology adoption in West Africa, as food quality is very important to producers and consumers (Adesina and Baidu-Forson, 1995).

The adoption of ISFM practices is influenced by the socio-economic status of farmers. Maryena and Barrett (2007) studying Kenyan smallholders suggest that farmers with the least financial resources are less adopting ISFM techniques. Indeed, those farmers are generally quartered on "non-responsive" soils (Vanlauwe *et al.,* 2015) where the addition of fertilizer does not pay off (Maryena and Barrett, 2009), thus limiting their adoption.

Most of the internal (labour, organic matter from planted fallow or mixed agroforestry component) and external (mineral fertilizers, herbicides, improved planting materials) resources needed to implement ISFM may require high investments from the individual farmer or the community which could limit the return on investment and thus the adoption of ISFM practices. Indeed, technology adoption is hypothesized to be influenced by expectations to gain additional income, mainly through increased productivity or improved access to remunerative markets. In contrast, land use insecurity is an important disincentive to invest in any land improving measures (Saidou *et al.,* 2007), as producers may not reap the benefits of their investments. Overall, finding out the right mix of ISFM measures requires a high level of collaboration between actors to define a joint intervention strategy and activities to generate scalable outputs built on farmers' experiences and perceptions and suited to the diversity of local contexts.

5 Innovation platforms as a tool to foster collaborative design of innovations

Low adoption rates of soil improving options are often linked to the fact that researchers neither pay sufficient attention to the multitude of problems farmers really face (Ramisch, 2014; Nederlof and Dangbégnon, 2007), nor build on the diversity of problem-solving practices developed by farmers in their diverse biophysical and socio-economic contexts (Fujisaka, 1994). Furthermore, many constraints are out of the range of the relationship between farmers and researchers and concern input supply, land tenure, market access, ability to negotiate fairer prices or better adjust to new consumers' or processing units' demand (Cheesman *et al.,* 2017). Since the eighties, farming system research made the point that producers are operating in diverse and risk-prone environments under numerous constraints, so that a one-fit-for-all technology cannot be relevant. New approaches have to be implemented within farmers' contexts so that they can make the best possible use of existing human and natural resources, cope with specific constraints, and take into account a range of tradeoffs (Giller *et al.,* 2011).

Innovation platforms (IPs) are organizational set up which foster innovation. «Innovation platforms are a way of organizing multi-stakeholder interactions, marshalling ideas, people and resources to address challenges and opportunities embedded in complex settings» (Davies et al., 2017). Innovation platforms are often organized around a farm product and include relevant stakeholders connecting households and community operational settings with state policies and institutions. Experiences with such a sociotechnical design in Africa reveal that local IPs both affect market connections and technological knowledge within the product value chain (Adekunle *et al.,* 2012). Jiggins *et al.* (2016) summarizing the results from a range of well documented IPs in West Africa pinpoint the importance of building trust for shared action and of shared learning in experimental processes of change. Hounkonnou *et al.* (2016) conclude from their experiences with nine IPs that the design can help leverage institutional constraints and create favorable niches of change. Whether such niches can trigger changes in the technological and institutional regimes still needs to be proven. There are few published reports on how the work of IPs can be used to foster sustainable soil fertility management. For instance, Tittonell *et al.* (2012) showed how IPs could be used to discuss and understand the implementation of conservation agriculture principles by African smallholders. But, no publication was found on how IPs could foster sustainable soil fertility management in tropical root and tuber crops.

6 Conclusions and future directions

This review demonstrated the necessity to develop feasible and acceptable soil management practices in yam. The following recommendations for future research can be derived from this review. Research must be conducted in a transdisciplinary manner involving the relevant actors from the practice, from the problem definition, to the co-design of soil management innovations, the evaluation of research results and their communication (Baveye *et al.,* 2014). In order to reach this goal, the research should foster IPs including beside producers also actors involved in the yam value chain (agricultural inputs traders, transporters, yam traders and processors) as well as authorities, the media, microcredit organisations and agricultural extension agencies as all these systems and actors will influence the decision of farmers to implement innovative soil management (Figure 1). The research should be conducted by interdisciplinary teams including experts in natural sciences (soil and plant sciences) and in social sciences (anthropology, sociology, and agricultural economics). The co-designed soil management innovations should be tested following the mother/baby trials scheme (Snapp *et al.,* 2002). The scientist-managed mother trials would allow testing soil options and obtaining robust data on their impacts on soil properties and plant production, which is essential for an orphan crop like yam. Farmers would then be able to select options they are interested in and test them in baby trials showing how they would adapt these options to fit their constraints and opportunities. This work should be done in sites showing a large diversity in terms of their biophysical and socio-economic characteristics to derive generic rules on soil/plant relationships in yam as affected by soil management and on how to develop and adjust the innovation supply to specific contexts. Working on such a large scale will require the use of techniques allowing high throughput soil and plant analyses as infrared spectroscopy (Shepherd and Walsh, 2007), and non-destructive image analyses techniques to analyse yam foliar surface or the leaf nitrogen content in the field (Walter *et al.,* 2015). Modelling approaches will be needed to predict yam growth and development under different conditions (Marcos *et al.,* 2009) and to predict farm income (Bernet *et al.,* 2001) as affected by the implementation of innovations. Finally, research will have to trigger collaboration with so-called organizations of change such as national institutions of agricultural extension to out and upscale the approach and options developed by research and anchor the acquired knowledge in the agricultural knowledge system.

7 Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationship that could be construed as a potential conflict of interest.

8 Author Contributions

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9 Funding

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10 Acknowledgments

The authors warmly thank Dénis Ouédraogo and François Lompo from INERA (Burkina Faso) for their inputs in the discussion.

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Figure 1. Systems to be captured and actors to be addressed to develop feasible and acceptable integrated soil fertility management options for yam systems that can be communicated to stakeholders. (A) Represents the biophysical, economic and institutional drivers (macro level), (B) the yam value chain (meso socio-economic level), (C) the household level (micro socio-economic level), and (D) the yam system (micro level in the field).

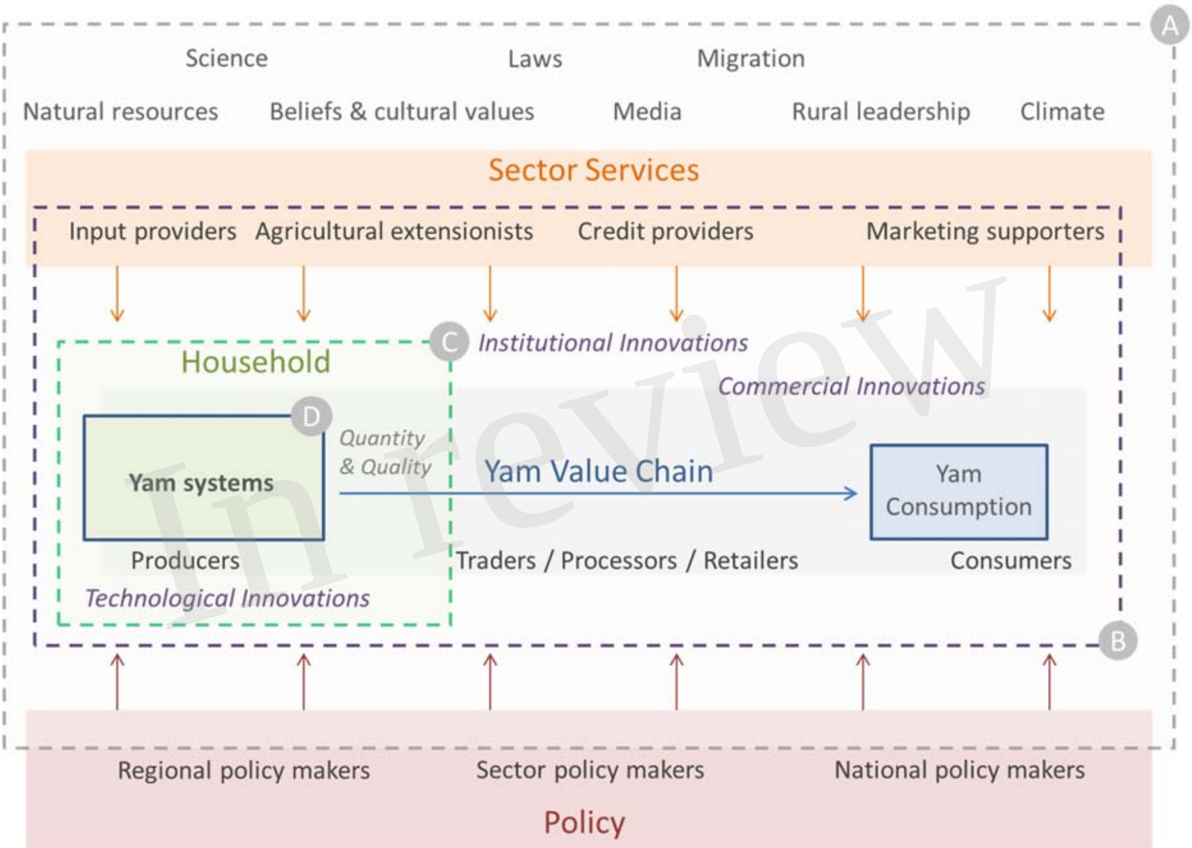

Figure 1.JPEG