



The role of agrobiodiversity in strengthening the resilience of small-scale farmers: biophysical and economic trends towards 2050

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1. Abstract

In this study we analyze the capacity of agrobiodiversity to increase resilience of banana-based smallholders in Uganda as affected by disease incidence or climate change and associated price changes until 2050. We explore trade-offs and synergies by means of various indicators of economic, environmental and nutritional impact determined by selected cropping patterns. As a result of increased agrobiodiversity, in all scenarios considerable improvements could be achieved for almost all indicators, which results in higher farm resilience. Our results also indicate that climate change can increase vulnerability of smallholder farmers in Uganda with respect to their income, whereas banana disease can put pressure on nutrition and sustainability of production. Increasing revenues from cropping associated with a stronger focus on a small number of profitable crops would come with a trade-off due to increased vulnerability to yield and price fluctuations. When it comes to crop diversification, it has a significant positive impact on soil health, especially soil erosion, and nutrition. Our analysis of correlations between areas of different crops and the performance indicators reveals a further layer of trade-offs at crop level. In particular, under baseline scenario yam leads as an income-generating crop, with high vitamin A yield but with negative consequences to environment and high revenue instability.

2. Context and challenge, including key interactions (range and nature) the case study addresses

A key topic for sustainable development research is to understand the role agrobiodiversity plays in reducing vulnerability and increasing resilience of Socio-Ecological Systems (SESS) at local, regional, or global level

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(Groot et al. 2016).⁴ Agricultural biodiversity in fact influences how SESs respond to disturbances, and vulnerability and resilience studies contribute to disentangling the human and biophysical characteristics of SESs and their mutual interactions (Gallopín 2006). Agricultural biodiversity is a key element of healthy and stable ecosystems and a major driver of ecosystem services (Duncan, Thompson, and Pettorelli 2015; Hooper et al. 2012). Its role in agriculture, as agrobiodiversity, is critical for food security around the world. It provides numerous benefits that include a diversity of foods and income opportunities (Love and Spaner 2007). It is particularly important for diversified and nutritious diets as well as for the genetic resources that allow farmers and plant breeders to adapt a crop to heterogeneous and changing environments (Fowler and Hodgkin 2004), an issue particularly important under the pressures of climate change. Another important benefit is the provision of certain ecosystem services such as disease and pest resistance, soil health and water conservation (Hajjar, Jarvis, and Gemmill-Herren 2008). This diversity is a key asset of the rural poor in developing countries that depend on agriculture for their livelihoods and well-being (Jarvis, Sthapit, and Sears 2000).

However, it is important to also recognize that the costs of maintaining biodiversity are sometimes large. Furthermore, there is a temporal mismatch between these costs and benefits generated. Farmers play a fundamental role in agricultural biodiversity conservation by cultivating diverse plants on their farms. Costs associated with this effort can be significant, and often the socioeconomic and environmental benefits generated can be limited. These costs diminish over time, while benefits at landscape, national and global scale can be substantial.

Costs and benefits of conserving agrobiodiversity on-farm manifest themselves in a variety of outcomes (e.g., income, food and nutrition security, soil health and natural environment) that shape the vulnerability and resilience of the SESs. Therefore, to better design interventions leading to higher agrobiodiversity, it is crucial to understand and quantify the trade-offs between these different outcomes. This information is needed in order to identify those incentives farmers could get should they maintain diversity on-farm and that are needed to generate greater ecosystem services at larger scales. Furthermore, it is necessary to analyze them in light of the global challenges of the future.

The purpose of this study is to link global future risks to livelihood strategies of a smallholder farmer in sub-Saharan Africa (SSA), and assess the potential of agrobiodiversity as adaptation measure to occurred disturbances. We quantify possible trade-offs between different outcomes on farm level that are primarily faced by a farmer. We focus our analysis on the case of a small banana-growing farm in Uganda facing challenges of a banana disease outbreak and climate change consequences for the agricultural sector until 2050.

In Uganda banana and plantain are two of the most important staple food crops, contributing to rural populations' household food security and revenue. Additionally, bananas play an important role in environmental conservation, whereby they provide a good soil cover that reduces soil erosion on steep slopes and are a principal source of mulching material for maintaining and improving soil fertility (Kalyebara et al. 2006). Smallholder banana systems dominate the banana-farming systems in Uganda (Kikulwe et al. 2018). A smallholder farm system is "...a decision making unit comprising the farm household, cropping and livestock

⁴ Generally speaking, the scientific community usually understands vulnerability as the susceptibility to harm and the "propensity to be adversely affected" (IPCC 2014; Adger 2006). Resilience, on the contrary, is the ability of a system to absorb perturbations and, eventually, reorganize in order to accommodate change (Adger 2000; Gitz and Meybeck 2012).

systems, that transform land, capital (external inputs) and labor (including genetic resources and knowledge) into useful products that can be consumed or sold” (Fresco and Westphal 1988). Smallholder banana systems are perennial, low-input and rural-based systems. The first purpose of these systems is food security, but commercial interests have recently become increasingly important.

3. How did research efforts deal with the synergies and trade-offs?

The explorations trade-offs and synergies were determined by the cropping patterns, which consisted of nine crops in the original farm set-up (banana, plantain, maize, cassava, sweet potato, beans, coffee, yam and grassland) and could be extended with seven candidate intervention crops (avocado, mango, pawpaw, groundnut, jackfruit, Irish potato and tomato). On the basis of scientific evidence, we linked every farm configuration in every macro-environment (scenario) to a number of outcomes.

In this study, we consider three macro-scenarios representing possible global futures, built around climate change, socioeconomic trends and banana disease outbreak.

To explore trade-offs and synergies among various indicators of economics, environmental impact and nutrition, six objectives were included in the explorations:

- i. Maximize revenues from crops (USD per farm)
- ii. Minimize variance of crop revenues (USD)
Excessive food price volatility has broad negative consequences, adversely affecting primarily poor producers and consumers by elevating risks of future prices (von Braun and Tadesse 2012; Kalkuhl et al. 2013). As a result of high risk, net food producers, especially in developing countries where financial markets do not function well, may lower their input use and production (Binswanger and Rosenzweig 1986; Donato and Carraro 2015; Haile, Kalkuhl, and von Braun 2014).
- iii. Minimize erosion potential (-)
Soil erosion negatively impacts productivity due to direct effects on crops. It has negative environmental consequences due to pollution of natural waters or adverse effects on air quality due to dust and emissions of radiatively active gases (Lal 1998).
- iv. Maximize yield vitamin A (persons fed per annum)
Vitamin A deficiency (VAD) is considered one of the most prevalent micronutrient deficiencies worldwide, mainly affecting children in developing countries (Wirth et al. 2017). In East and Central Africa the prevalence of VAD significantly exceeds the World Health Organization’s threshold point of 15% (WHO 2017). Dietary diversification is considered an intervention strategy that is sustainable without external support and has an ability to simultaneously combat multiple micronutrient deficiencies (Tontisirin, Nantel, and Bhattacharjee 2002).
- v. Maximize farm nitrogen balance (kg N/ha)
Soil nutrient depletion is considered one of the major causes of declining food production per capita in SSA. Literature suggests that adequate soil management will be required to sustain food security in light of increasing population densities (Drechsel et al. 2001).

- vi. Maximize crop diversity (evenness; Shannon diversity index)
One of most frequently used measures of diversity is the Shannon (H) index (Morris et al. 2014). It quantifies the ecological diversity and “evenness” of distribution of species on a farm (measured as a farm’s frequency distribution). $H = 0$ if there is only one species on the farm and maximum when each species occupies the same area on the farm. Thus, a monoculture or situations where a few crops occupy large areas in relation to the total size of a farm result in a low value for the Shannon index (Oyarzun et al. 2013).

4. What kinds of partnerships were critical?

This research was made possible thanks to collaboration of Bioversity International, Wageningen University and Research, CGIAR Research Program (CRP) on Roots Tubers and Bananas’s Flagship 5 on Improved livelihoods at scale, cluster 1 on Foresight and impact assessment, and cluster 2 on Sustainable intensification/diversification. Another important contribution came from the CRP on Policies, Institutions and Markets Flagship 1 on Technological innovation and sustainable intensification Cluster 1 on Foresight modeling.

5. Lessons learnt, including knowledge gaps and good practices in employing these approaches at scale

We prove that agricultural biodiversity can significantly improve resilience to climate change and banana disease of a small farm in Uganda until 2050. For all indicators (except revenue variance) and in all scenarios, considerable improvements could be achieved after introduction of the new crops.

Analysis of distributions of indicator values within the solution sets of the three scenarios (including 16 crops) indicates that the main contrasts between scenarios could be observed for the economic indicators of revenues and their variance. Climate change will create more income opportunities—potential and average crop revenues are the highest under this scenario; however, this comes with higher uncertainty of income; the highest average and potential revenue variance are under this scenario. Banana disease significantly decreases the potential for achieving vitamin A yield and slightly increases soil erosion potential. These results suggest that climate change can increase vulnerability of smallholder farmers in Uganda with respect to their income, and banana disease can put pressure on nutrition and sustainability of production.

Analysis of trade-offs and synergies between the selected outcomes reveals intuitive patterns. For instance, increasing revenues from cropping would come with a trade-off of slightly more erosion potential (Table 1). Moreover, the variance of revenues strongly increased with increasing total revenues, indicating more vulnerability to yield and price fluctuations for farmers. These trade-offs can be associated with a stronger focus on a small number of profitable crops. When it comes to crop diversification, it has a significant positive impact on soil health, especially soil erosion and nutrition (vitamin A yield). Even though, on average, crop diversity has some negative impact on revenue variance, relatively low variance of revenues was found at the highest levels of crop diversity (i.e., Shannon diversity index).

Table 1. Trade-offs and synergies among indicators for the “business as usual” scenario; positive numbers indicate a synergy, negative numbers a trade-off

	Shannon index	Erosion potential	Crop revenues	Revenue variance	Vitamin A yield	Nitrogen balance
Shannon index		0.627	0.177	-0.361	0.399	0.240
Erosion potential			-0.082	-0.154	0.278	0.307
Crop revenues				-0.958	0.791	-0.052
Revenue variance					-0.911	-0.148
Vitamin A yield						0.498
Nitrogen balance						

Finally, correlations between areas of different crops and the performance indicators can be used to inform farmers about the consequences of their planting choices. The production of yam was strongly correlated with crop revenues, but would also lead to higher erosion potential and variance of revenues and, hence, more economic and environmental risks for farmers. Tomato cultivation could contribute strongly to vitamin A yield and the nitrogen balance of the farm, while still generating significant but volatile revenues. The least performing crops from an economic, environmental and nutritional perspective were groundnut, beans, and coffee.

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