Evaluating Economic Implications of Agricultural Innovations. A Theory-Based Impact Assessment of Biochar as a Soil Amendment and Improved Wastewater Irrigation in West African Cities

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Abstract

This paper proposes a methodology for systematically assessing the economic implications of agricultural innovations on different stakeholder groups, exemplified by biochar as a soil amendment and improved wastewater irrigation in the West African cities of Tamale (Ghana) and Ouagadougou (Burkina Faso). Intensive cultivation of vegetables on small urban open-space plots has resulted in declining soil fertility and yields. Insufficient irrigation and nutrients have promoted the use of wastewater irrigation amongst urban vegetable farmers, exposing urban producers and consumers to health-related risks. Productivity-enhancing innovations may simultaneously improve the livelihoods of urban farm households as well as, through reduced market prices, increase the food security of consumers. Additionally, improved irrigation technology to reduce pathogen loads on vegetables may enhance food safety but increases farmers' production costs. In order to assess economic impacts of such technology enhancements ex-ante, a household production function for urban vegetable farmers that integrates soil fertility indicators is developed, alongside an aggregate supply and demand model for urban vegetable markets. This will allow the dynamic estimation of income effects on urban farmers due to production changes with resulting price changes at the market level. To scrutinize further assumptions pertaining to consumers‘ and producers‘ perceptions on the costs of illness, studies on the opportunity cost of wastewater-related illness and willingness to pay for safe, certified food are being conducted. The combination and integration of a farm-level assessment of productivity changes, analysis of market-level changes and contingent valuation studies on consumers' preferences allows for a holistic, systematic assessment of the sustainability of agricultural innovations from the perspective of various stakeholder groups.

Keywords: Agricultural innovations, stakeholders, biochar, contingent valuation, cost-benefit analysis, impact assessment, market method, production function, soil fertility, wastewater irrigation.

1. Introduction

To meet the global challenge of food and nutrition security for a steadily growing and increasingly urban population, sustainable agricultural intensification will be inevitable (Tscharntke et al., 2012; Tilman, Balzer, Hill, & Befort, 2011). This particularly applies to Sub-Saharan Africa and other developing regions with persistent shortfalls in agricultural productivity and resulting poverty (FAO, 2014; Dzanku, Jirström, & Marstorp, 2014; The Montpellier Panel, 2013). Agricultural innovations play a key role for intensification but must be rigorously assessed for all relevant dimensions of sustainability in a particular local context. Apart from the technical feasibility, the ecological impacts and the socio-cultural appropriateness, the economic desirability of an innovation must be examined before a widespread roll-out can be recommended.

With growing urban populations and demand for food, a multitude of livelihood opportunities related to agricultural cultivation and trade have emerged. Due to inadequate storage and transportation infrastructures in much of the Sub-Saharan region, perishable crops such as vegetables are produced in close proximity to urban markets (Cofie, van Veenhuizen, & Drechsel, 2003). Despite its importance for livelihoods and food security, agriculture in West African cities such as Tamale and Ouagadougou increasingly gets under pressure from urban sprawl and competing land use options. The intensive cultivation of vegetables on small urban open-space plots has resulted in declining soil fertility and yields. This has promoted the use of nutrient-rich but unsafe water sources such as wastewater for irrigation of locally produced vegetables, exposing urban producers and consumers to health-related risks (Drechsel & Keraita, 2014; Wichelns & Drechsel, 2011).

To enhance soil fertility and reduce the health-related risks of wastewater irrigation, “Urban Food Plus” (UFP), an on-going multi-disciplinary African-German research project aimed at increasing resource use efficiency in West African urban agriculture (www.urbanfoodplus.org), has proposed biochar as a soil amendment and improved wastewater filtration technologies. Scientific interest in biochar, i.e. charcoal from various types of biomass such as unused crop residues, stems from research on so-called “terra pretas” in the Amazon rainforest (Lehmann, 2007). While not having fertilising properties per se, biochar may possibly improve soil characteristics. In addition, biochar holds the promise to be an effective carbon sink, thus curbing greenhouse gas emissions (Steiner, 2007; Glaser, 2001; Marris, 2006). The project also examines the properties of biochar as a medium for wastewater filtration. Apart from investigating the effects of biochar addition and improved wastewater irrigation on soil fertility and yields, the adoption potential and wider socio-economic implications of these innovations have to be established. Since mid-2013, UFP has been conducting multifactorial field trials in the cities of Tamale (Ghana) and Ouagadougou (Burkina Faso), along with crop and livestock production surveys, anthropological studies, food flow surveys and on-farm field trials. In the second phase (2016-2018), research activities will be replicated in Bamenda (Cameroon) and Bamako (Mali).

While research activities are still going on, this contribution proposes and integrated, theory-based methodology developed in the context of the UFP project to comprehensively and systematically evaluate the *economic* impact of agricultural innovations on different stakeholder groups and on urban food security and poverty alleviation through an ex-ante evaluation (i.e. before implementation).

2. Assessing agricultural innovations from the perspective of local stakeholders

Our research aims at exploring the effects of biochar application and wastewater filtration on the livelihoods of urban farmers, and, via effects on food quality, supply and prices, on urban food security and food safety. The UFP project is proposing a comprehensive, holistic approach towards assessing the sustainability of innovations that integrates the perspectives of urban farmers and consumers. Drawing on a variety of data on farm-level production and cultivation patterns, soil quality, household structure, income sources, farm households' costs of illness and urban consumers' willingness to pay (WTP) for safer, certified produce, the assessment combines insights from the natural sciences (soil science and agronomy), engineering sciences (wastewater engineering) and economics. Other social science disciplines such as geography (GIS-based spatial sampling and analysis) and anthropology (long-term ethnography of urban food markets and technology adoption) make further important contributions to the empirical investigation.

While the integration of various analytical perspectives and multiple data sources is innovative, the theoretical concepts on which our empirical assessment rests are not new, drawing on well-known and well-tested approaches developed in welfare economics that are typically applied for environmental valuation. These include revealed preference and stated preference approaches to cost-benefit analysis (King & Mazzotta, 2000; Carson & Bergstrom, 2003; Bockstael & McConnell, 2007; Bergen, Löwenstein, & Olschewski, 2013).

2.1 Farm-level assessment

As potential adopters, urban vegetable producers are the primary stakeholder group affected by the agricultural innovations proposed by UFP. Applying a production function for these urban farmers, we estimate the role of various input factors in determining agricultural output in the specific context of Tamale and Ouagadougou. Based on our theoretical assumption that biochar may not just alter the role of traditional production factors (e.g. intermediate inputs and labour) but also the quality of land via changes in soil fertility, the production function also accounts for landholding size moderated by soil quality parameters.

Standardized household data from 168 randomly sampled open-space farmers in Tamale and 237 in Ouagadougou were collected in 2014/2015. Along with the socio-economic data, soil samples were taken from each surveyed farm to determine the influence of various soil parameters on agricultural output. Integrating knowledge from UFP's field experiments and secondary literature on the interactions between biochar, other inputs, soil parameters and yields, as well as taking into account the costs of technology adoption, the potential net welfare effect of using biochar as a soil amendment on agricultural output can thus be simulated ex-ante. Focus group discussions with urban farmers complement the quantitative investigation and further explain the empirical observations.

2.2 Market-level assessment

For the farm-level analysis, we assume constancy of market prices, as long as only few farmers adopt and food markets remain unchanged. However, with increasing adoption, production quantities of vegetables are expected to increase on the urban market. This will have an effect on market prices and, hence, an impact on the welfare of urban consumers and producers. The assessment of welfare changes caused by widespread adoption of the proposed innovations focuses on simulating changes in production quantities on urban food markets and resulting price effects. Consequences for the food security of urban consumers (through more affordable vegetables) and corresponding income effects on urban producers (through reduced market prices) are expected. For the empirical analysis, aggregate supply and demand models for urban vegetable markets are developed, using time series data of the past 30 years on a regional and national level.

2.3 Assessing costs of illness and consumers' willingness to pay for food safety and food certification

To get an even more comprehensive and realistic picture of the adoption potential of the UFP-proposed innovations, further empirical studies explore farmers' costs of illness and urban consumers' willingness to pay for enhanced food safety, as achieved through wastewater filtration and food certification. Both analytical perspectives focus on the adoption potentials of improved wastewater irrigation technologies. A prototype for a small-scale, low-cost wastewater filtration and drip irrigation plant has been developed by the UFP engineers and is currently being tested under field conditions in Tamale. The economic viability of such a technology not just depends on the initial investment cost but more importantly on farmers' perception of longer-term benefits and disadvantages of adoption, i.e. the net balance between increased returns and increased production costs.

As wastewater-using farmers are exposed to particular health risks such as worm infections and other gastrointestinal disorders (Drechsel & Keraita 2014), a study among 300 urban farmers in Tamale was conducted to establish illness-related costs and to explore causalities between wastewater use and illness incidence. Apart from potentially reduced illness costs, farmers could also be motivated to adopt improved wastewater irrigation technologies if they can achieve higher prices for their products. We are therefore also establishing urban farmers' willingness to pay (WTP) for safely irrigated and certified vegetables. To establish this WTP, a first contingent valuation study was conducted in Tamale among 300 urban consumers. Corresponding cost of illness and WTP studies are planned for Ouagadougou.

3. Conclusions

As argued initially, assessing the sustainability of agricultural innovations has to go beyond the technological, social or ecological assessment level, i.e. the question whether an innovation "works" and is socially and ecologically acceptable or not. Our assessment approach will reveal whether the adoption of the UFP-proposed innovations "makes sense" from the perspective of urban farmers and consumers. Farmers will only have reason to adopt agricultural innovations if such innovations lead to the desired net productivity enhancements and increase their income, be it via a reduction in production costs, reduced opportunity costs (e.g. costs of illness) or better prices for their agricultural commodities.

The results to date clearly confirm the suitability of our theoretical and methodological approach. For instance, first regression results demonstrate a strong link between soil quality parameters and farmers' agricultural income. This confirms that an integration of socioeconomic and biophysical data is not just possible but highly desirable to assess the sustainability of agricultural innovations. However, quite a few analytical steps towards integrating data and research findings are still outstanding, as the research tasks of UFP are not yet completed. This particularly applies to modelling the interactions between urban vegetable production, markets and food security.

The ex-ante, forward-looking perspective of our investigations, i.e. the simulation of impacts of the proposed innovations before widespread adoption, is stressed as particularly useful, as it avoids a waste of scarce resources and experimentation with potentially unsustainable solutions on the back of poor urban farmers in Subsaharan Africa.

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