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Advancing climate-smart-agriculture in developing drylands: Joint analysis of the adoption of multiple on-farm soil and water conservation technologies in West African Sahel

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ABSTRACT

Water stress and soil infertility are the greatest constraining factors for higher agricultural productivity in drylands, prompting the current interest in soil and water conservation (SWC) practices in water-constrained regions. To provide a more comprehensive understanding of challenges surrounding the adoption of SWC practices in these regions, we used a joint analysis framework combining both multivariate and ordered probit models to analyze adoption-decisions for eleven on-farm SWC practices. Our case study, involving 500 farmers from a representative West African Sahelian zone, revealed that although the adoption of SWC practices is widespread in the West African drylands, there is still an important potential to improve and upscale their specific adoption rates. Almost all farmers (99%) used at least one of the eleven practices considered in this study, whereas specific adoption rates ranged from 5% for contour vegetation barriers to 87% for manure application. More than 70% of the farmers used up to three practices only, and less than 30% used between four to nine practices. Many practices are interdependent, with some practices being complementary and others substitutable. The analysis of the determinants of the adoption and the intensity of adoption revealed that SWC practices are labor-, knowledge- and capital-intensive. We found that the major drivers of farmers' decisions to adopt, as well as to intensify the use of, most SWC practices are the presence of children (aged 6 to 14) in the household, land holding, land tenure, awareness and training on SWC and access to alternative – but non-agricultural labor constraining – cash sources such as remittance and cash farming. A higher number of migrating household members increases the probability of intensifying the use of SWC practices, but only when this is in line with the household's land endowment and labor needs for farm activities. This comprehensive study will be of significance for a finer understanding of SWC practices in West African Sahel. More generally, it will likely help policy makers to upscale the adoption of sustainable SWC practices for the advance of climate-smart agriculture in developing drylands.

1. Introduction

Past agricultural development strategies have place emphasis on irrigated agriculture and "high-potential" rainfed lands in an attempt to increase food production and stimulate economic growth (Fan and Hazell, 2000; Ruben and Pender, 2004; Mortimore et al., 2009). These strategies were driven by the conventional wisdom that productivity returns on investment are highest in irrigated and high-potential rainfed lands, and that economic growth in these areas should also deliver substantial "trickle-down" benefits for the poor, including those living in less-favoured areas. This approach has been very successful in enhancing agricultural productivity and reducing food insecurity and poverty in the developing world, and was a strong positive factor in the success of the green revolution in many countries. At the same time, however, large areas of less-favoured lands including drylands have been neglected; they represent today, the rural areas with the lowest

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economic growth, poorer households and hunger-prone populations under the constant threat of natural resources degradation (Kuyvenhoven, 2004; Ruben and Pender, 2004; Gerber et al., 2014; Barbier and Hochard 2016). Indeed, dryland farmers face multiple constraints, due to poor soils, short growing seasons, low and uncertain rainfall, desertification and recurrent droughts along with poorer infrastructure and market access, that affect their abilities to overcome chronic poverty and food insecurity. Drylands represent more than a third of the world's population (Mortimore et al., 2009), 90% of whom are located in developing countries and mainly rely on degrading agricultural lands for their livelihoods (Barbier and Hochard 2016; Gerber et al., 2014). Estimates indicate that more than half of the world's poor live in drylands (Mortimore et al., 2009). However, as showed by Kok et al. (2016), there are also pronounced differences within drylands, particularly in terms of water availability, poverty, stage of development and sustainable intensification options.

Given the failure of the past attempts for successfully addressing the challenges of poverty and food insecurity, particularly in developing drylands, a growing interest is now being placed on creating an enabling environment, which can help to enhance agricultural productivity and people's livelihood while preventing increased land degradation in less-favoured areas. Recent perception, supported by empirical evidences, suggests that agricultural investments in drylands may lead to higher agricultural productivity and social and economic returns than if they were made in high-potential areas. Studies have indeed showed that there are no agro-hydrological limitations to double or triple staple crop yields in drought-prone areas (Rockström et al., 2002). However, achieving this potential requires that more attention be given to the most limiting factors for agricultural productivity increase in these regions such as low soil fertility and water stress (Zougmoré et al., 2010) through win–win agricultural investments addressing simultaneously food security, poverty alleviation and sustainable natural resources management (Ruben and Pender, 2004; Barbier, 2000). This recent perception comes into line with the major pillars of Climate-Smart Agriculture (CSA) which is being promoted to sustainably address the issues of food security and poverty eradication in front of climate change. Actually, there are a wide range of agricultural practices that can potentially increase food production, enhance the resilience and adaptive capacity of the farming system, as well as reduce emissions through carbon storage in agricultural soils. However, adoption of these technologies and capturing the synergies between them entail significant barriers (Teklewold et al., 2013), and this has led to a very low adoption rate for many of these practices in less-favoured areas in Sub-Saharan Africa (Cordingley et al., 2015).

Since its adoption as a new approach to channel agricultural investments in a changing climate context, CSA has inspired several empirical studies. Correspondingly, many recent studies have been conducted in Africa using joint frameworks to understand the drivers of adoption decisions of sustainable agriculture technologies, with a special focus on soil and water conservation (SWC) practices (Kassie et al., 2015; Teklewold et al., 2013; Arslan et al., 2015; Ndiritu et al., 2014). However, the scope of these studies in terms of geographical area and practices analyzed is very limited. Most were carried out in eastern and southern Africa focusing on countries with relatively good climate conditions such as Zambia, Malawi, Tanzania, Ethiopia and Kenya. Studies using joint frameworks to extensively analyze adoption decisions for multiple SWC practices in drylands, particularly West African Sahel, are scarce. Moreover, taken as a whole, the aforementioned studies did not consider several SWC practices including those, such as zaï, stone bunds, half-moons, or agro-forestry, which are of greatest importance in sustaining agricultural production and people livelihoods in West African Sahel. In some cases also (Kassie et al., 2015; Ndiritu et al., 2014), SWC practices were considered as a single technology and encompassed in a single variable, while they may entail several simultaneous or sequential practices deserving a separate analysis as distinct variables.

Some few studies analyzed adoption decisions of SWC practices in the West African Sahel. However, their focus was only on one or two isolated technologies using single adoption models (Sidibé, 2005) or descriptive and inferential statistic tools (Slingerland and Stork, 2000; Bodnar and De Graaff, 2003). But SWC practices adoption decisions are interdependent (Gebregziabher et al., 2015; Kassie et al., 2015), and farmers, typically in drylands, adopt multiple technologies to deal with various constraints. Therefore, studies failing to take this fact into account may mask some realities that farmers face in taking decisions (Dorfman, 1996). Furthermore, given the emerging paradigm of CSA aiming at simultaneously achieving triple-win goals – mitigation, adaptation and food security – the scope of policy implications following single-adoption models is considerably limited as those policies may fail to address the required trade-offs and resource efficiency expected from today's farming.

We wish here to contribute to the understanding of the drivers of the adoption of SWC practices with the aim to comfort policies to advance CSA in drylands. Within the literature on CSA, this is as far as we know the first study to analyze adoption decisions for such a wide ranging set of climate-smart practices in drylands, particularly in West African Sahel. Following some above-mentioned studies, we used a joint analysis framework for the adoption of multiple technologies, but we considered here a larger number of SWC practices ranging from soil fertility management, erosion control, water harvesting, to agro-forestry measures, including those which had been given little focus so far. In the literature on agricultural technology adoption in general, we are not aware of any previous study providing such a comprehensive joint analysis of the adoption of multiple SWC practices in the West African Sahel. Moreover, following Teklewold et al. (2013) we extended the focus of our analysis from the probability of adoption to the intensity of adoption measured as the number of technologies adopted using the ordered probit analysis framework. However, by contrast to these authors, who focused on five practices, we considered eleven technologies, corresponding to the major SWC practices in significant use in the West African Sahel.

2. Econometric modeling approach

After earlier works by Feder (1982), literature on the adoption of multiple agricultural technologies has focused on *single* versus *joint* analysis frameworks (Dorfman, 1996; Kassie et al., 2015). Single adoption models often analyze the decision to adopt a single technology by using univariate econometric modeling frameworks, with scant attention to the other interrelated technologies. Farmers in dryland areas face multiple production constraints and risks, such as droughts, pests, diseases, nutrient deficiency, dry spells as well as limited resources access, and consequently adopt a combination of technologies to deal with these risks. Depending on the constraints and benefits associated with the different technologies, their adoption may be interdependent, either as complements (positive correlation) or as substitutes (negative correlation). Using a single modeling framework to analyse adoption decisions in such cases can result in biased conclusions as single econometric adoption models ignore potential correlations between the different adoption equations (Dorfman, 1996).

Against this background, our econometric approach included two parts. First, we used the multivariate probit (MVP) modeling approach which simultaneously allows estimating interdependent multiple adoption decisions while allowing the unobserved and