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Determinants of integrated soil fertility management technologies adoption by smallholder farmers in the Chinyanja Triangle of Southern Africa

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A B S T R A C T

Integrated Soil Fertility Management (ISFM) technologies have proven to be viable options for improving land productivity and increasing yield. However, adoption of the set of complementary technologies that are required in ISFM is quite variable and studies tend to focus on single technologies. In this study we used cluster analysis to group technologies and ordered probit to determine the probability of multiple technology adoption. The result show that usage of ISFM in the Chinyanja Triangle (Southern Africa) is grouped into 3 technological sets based on complementarities. The set of nutrient dense technologies of inorganic fertiliser, compost and animal manure (ISFMset3) indicates that they are used by farmers who face similar opportunities of having land that require minimal input, sell produce at farm gate as opposed to market, have more transport and communication facilities, and recover from livestock loss. Loss of crops, however, deter adoption of this set. The technological set comprising of fallow, rotation and grain legumes (ISFMset2) which enhances biomass accumulation and nitrogen fixation with complementary effects in cereal dominated farming system, is more likely adopted by households with land that require more inputs, are more educated, own more bicycles and have higher financial capital. Other four technologies (ISFMset1 including mulch, lime, compost and agroforestry) are used by a few individuals to address specific constraints in nutrient and water retention, and acidity. The result also indicated variations in usage of ISFMset3 between sites. These results are instrumental in identifying factors that influence adoption of a set of ISFM technologies in the Chinyanja Triangle and could be of use in targeting research and development initiatives.

1. Introduction

Soil health is of great importance to the African economies as farming is the main livelihood strategy for the majority of the population. So far, increases in food production to feed the growing population in sub-Saharan Africa (SSA) have been attained through agricultural extensification with little improvement to the existing farmland (FAO, 2014). However, this cannot be a sustainable venture because population pressure will not allow expanding agricultural land and in case where it is done it will cause further degradation. As a result, vulnerable farmers who constitute the majority of the agrarian community in the region cultivate margins of arable land and as demand grows, cultivation is further extended into fragile and conserved areas (Lambin and Geist, 2008). Furthermore, often fields are cultivated without nutrient amendments, further reducing soil fertility and widening yield gaps (Chilimba et al., 2005). Due to these and other challenges such as climate change, farming families in SSA continue to face challenges of food insecurity and malnutrition with 23% of the population classed as food insecure and 40% of children under age of five stunted (The Montpellier Panel, 2013; UNICEF, 2013). In SSA alone, malnutrition is estimated to affect about 38.6 million people under the age of five and was projected to grow to 41.6 million in the year 2015 with potential for further increase if unchecked (UNICEF, 2013).

In the Chinyanja Triangle of southern Africa (an area covering part of Malawi, Mozambique and Zambia), land holdings are sub-

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divided among siblings, presently owning 0.5–2.0 ha. Such portions of land are often too small and increasingly difficult for farmers to meet household food requirements with the existing low-input, low-output production practices (Amede et al., 2014). Inequity in access to land with wealthier farmers and estates owning larger parcels of prime arable soils also puts smallholders at a disadvantage (Sekeris, 2010).

Research efforts to increase production per unit area through intensification are hampered by heterogeneity in local socio-economic and biophysical conditions across landscapes (The Montpellier Panel, 2013). Some global research outputs that worked elsewhere, such as use of higher yielding varieties and fertilisers, are failing to replicate their reported successes on poor farmers' plots in SSA (Mueller et al., 2012). The Integrated Soil Fertility Management (ISFM) framework proposed by Vanlauwe et al. (2011) suggests that progressive adoption of combinations of practices (technologies and methods) can maximise agronomic use efficiency of the applied nutrients and improve crop productivity, owing to complementary effects of technologies including improved crop varieties, use of inorganic and organic fertilisers coupled with good husbandry practices.

However, adaptation of the various ISFM components to technological, household, farm, environmental and societal conditions seems to be a challenge, and adoption has been low. It is generally considered that the cause of low agricultural technology adoption is because farming households in SSA are resource constrained (Chilimba et al., 2005; Mugwe et al., 2009). Farmers' choice to use a particular set of technologies on a farm is not only dictated by biophysical attributes, but also by socioeconomic situations which vary greatly resulting in heterogeneous farming patterns across a landscape (Yengoh, 2012). Further land fragmentation among offspring has also shown to have negative effects on adoption of some soil fertility improving technologies such as agroforestry (Chinangwa, 2006).

Most studies treat adoption as a binary choice of individual technology or combination of technologies while the extent of adoption is analysed using truncated Tobit models or Cragg's double-hurdle model (Akinola and Alene 2010; Wiredu et al., 2014; Kassie et al., 2015). The dichotomous models show the probability of adopting at least one technology (Mugwe et al., 2009; Asfaw et al., 2011) without distinguishing between the farmers who adopt one technology and those who adopt multiple technologies. Moreover, defining the cut-off point between adopters and non-adopters is the main challenge in examining the factors that influence the level of adoption of ISFM as a package. Using the equation by Golob and Regan (2002), the choice set for combinations of ISFM technologies tend to be large and difficult to interpret the effects of explanatory variables on each of the technologies and their combinations. However, farmers often exploit multiple ISFM technologies and adopt a set of best fits as a package that provide a higher potential advantage of complementarities in dealing with a multitude of production constraints (Marenya and Barrett, 2007; Wiredu et al., 2014).

ISFM technology adoption is therefore inherently multivariate and dealing with it using binary and truncated methods exclude useful information about interdependent and simultaneous adoption decisions (Dorfman, 1996). Moreover, there could be a problem of independence of irrelevant alternatives (IIA) (Freese and Long, 2000). Studies using dummy variables assume that inclusion or removal of some technology *C* in a farming system would not affect the odds of choosing individual technology *A* over *B*. However, human behaviour rarely adheres to IIA (Ray, 1973) and farmers choice of technology in smallholder farming systems is largely influenced by the societal preference than own satisfaction (Le et al., 2012).

In this study, we take a broader perspective and included practices (technologies and methods) that are being promoted/used in the Chinyanja Triangle region for the ultimate aim of improving soil fertility. Apparently, popularization of some techniques over others raises the question as to why farmer's technology acceptance differs within similar settings. We use a classification system based on Rogers' concept of technology clusters (Rogers, 1995), which posits that likelihood of adoption is based around similar perceived characteristics of a technology or medium. For multiple technologies, one potential practical question that we face is to determine the usage boundary among technologies. We used statistical clustering procedure to first group technologies based on their usage by households. We then considered the number of ISFM technologies adopted to analyze multiple adoption decisions using a pooled and random effects ordered probit model (OPM). Using this approach, the study's main aim was to identif factors that enhance adoption of ISFM technologies in maize mixed cropping system of the Chinyanja Triangle. To realise this overarching goal the study aims to address the following questions: (i) what are the common combinations of ISFM technologies employed by smallholder farmers in the study areas; and (ii) which are the key farm and household attributes that drive farmers' decision to adopt a set of ISFM technologies. An understanding of socio-ecological determinants of a number of technologies is deemed crucial in designing optimal sets of technologies and out-scaling best fits for addressing multiple soil fertility constraints and enhancing productivity.

2. Methodology

2.1. Study area

The study was conducted in the Central region of Malawi, Tete Province of north-western Mozambique and Eastern Province of Zambia (Fig. 1). The sites are within the Chinyanja Triangle (CT) which is dominated by Nyanja people who share language dialects, similar beliefs, and history, suggesting similarities in approaches to resource utilisation and more importantly on land management (Amede et al., 2014). While land tenure regulations differ in the three study countries, usufruct rights at local scale are similar. Locally, chiefs are the custodians of land within the jurisdiction of their chiefdoms and it is shared/transferred mainly through a matrilineal lineage system (CGIAR, 2014).

The Chinyanja Triangle has three distinct eco-zones with plateaus on the northern end, sub-humid escarpments around the centre and semi-arid Shire, Luangwa and Zambezi river valleys towards the south. The study was conducted in the sub-humid escarpments that face higher demand for cropland (Denning et al., 2009). The site falls within the maize mixed farming system (Dixon et al., 2001) extending across plateau and highland areas at altitudes of 800–1500 m.

Maize is the main staple food while sources of cash for smallholders include migrant remittances, cattle, small ruminants, tobacco, and cotton, plus sale of maize and pulses (Myburgh and Brown, 2006). Nsipe in Ntcheu District and Linthipe in Dedza district both in Malawi have been under cultivation for several generations while the Furancungo site in Macanga district of Mozambique and Budula-siliya in Mambwe district of Zambia have recently been re-occupied and newly opened, respectively. Comparison based on population shows that densities (persons km^{-2}) are lower (9 and 13) in Macanga and Mambwe but relatively higher (138 and 172) in Ntcheu and Dedza districts, respectively (Republica de Mocambique, 2005; Republic of Malawi, 2008; Republic of Zambia, 2012). Land holdings also vary from 0.5 ha in the south of Malawi to 2.0 ha in Zambia and Mozambique (Amede et al., 2014).