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Evaluation of new farming technologies in Ethiopia using the Integrated Decision Support System (IDSS)

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ABSTRACT

This study investigates multi-dimensional impacts of adopting new technology in agriculture at the farm/village and watershed scale in sub-Saharan Africa using the Integrated Decision Support System (IDSS). Application of IDSS as an integrated modeling tool helps solve complex issues in agricultural systems by simultaneously assessing production, environmental, economic, and nutritional consequences of adopting agricultural technologies for sustainable increases in food production and use of scarce natural resources. The IDSS approach was applied to the Amhara region of Ethiopia, where the scarcity of resources and agro-environmental consequences are critical to agricultural productivity of small farm, to analyze the impacts of alternative agricultural technology interventions. Results show significant improvements in family income and nutrition, achieved through the adoption of irrigation technologies, proper use of fertilizer, and improved seed varieties while preserving environmental indicators in terms of soil erosion and sediment loadings. These pilot studies demonstrate the usefulness of the IDSS approach as a tool that can be used to predict and evaluate the economic and environmental consequences of adopting new agricultural technologies that aim to improve the livelihoods of subsistence farmers.

1. Introduction

The number of people who live below the poverty line in the world is estimated to have declined; however, there are still about 800 million people who are suffering from chronic hunger (FAO, 2013). Sub-Saharan Africa remains the region with the highest prevalence of undernourishment (FAO, 2013). The poor in sub-Saharan Africa usually live in rural areas (DFID, 2004; IFAD, 2011) and more than 90% earn less than $2/day (IFAD, 2011).

Agriculture is the leading economic sector in many developing countries despite production based on subsistence farming that suffers from low yields and high vulnerability due to climate change (Awokuse and Xie, 2015; Tibesigwa and Visser, 2015). In sub-Saharan Africa, 40–70% of rural households earn more than three-quarters of their income from on-farm sources (IFAD, 2011). For example, agriculture in Ethiopia accounts for 47% of GDP, 90% of exports and 85% of employment (IFAD, 2009). This suggests that investment in agriculture can contribute to food security and poverty reduction for the majority of the rural poor (DFID, 2004; WorldBank, 2008). Research across the world has proven that investment in agriculture can result in a sharp increase in economic development and poverty reduction (Gallup et al., 1998; Pretty et al., 2011; Thirtle et al., 2001; WorldBank, 2008). Green Revolution in Asia during the 1970s is one well-known example, where the adoption of science-based technology pulled Asia from the age of famine to regional food surplus within 25 years (Djurfeldt et al., 2005; Hazell, 2009).

Agriculture in sub-Saharan Africa is largely rainfed. Rainfed agriculture is the dominant source of staple food production (Cooper et al., 2008; FAO, 2011; Rosegrant et al., 2002) and covers 93% of the region's agricultural area (CA, 2007; FAO, 2002). There is a large yield gap (i.e. the difference between what is actually harvested from farmers' fields and what could potentially be achieved) in sub-Saharan agriculture. In tropical regions with reliable rainfall and

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sufficient nutrient application, average rainfed commercial agricultural yield exceeds 5–6 t/ha (CA, 2007; Rockström and Falkenmark, 2000) while the average rainfed yield in sub-Saharan Africa is less than 1.5 t/ha (Rosegrant et al., 2002).

Research has shown that the yield gaps in sub-Saharan Africa cannot be explained only by biophysical conditions (e.g. lower amounts of rainfall), but also due to sub-optimal management conditions (Licker et al., 2010; Rockström et al., 2002). Amede (2012) indicated that low yield in the rainfed agro-ecological landscapes of Ethiopia is typically not due to the lack of water alone rather a result of the inefficient management of water, soils, and crops. Supplementary irrigation combined with fertilizer application in a field experiment in the northern Burkina Faso increased the yield level three fold compared to the normal farmers' practices (Fox and Rockstrom, 2003). In semi-arid Kenya, Barron and Okwach, (2005) showed that supplementary irrigation with improved nutrient application can increase average yield by 70%. In-situ water harvesting practices contribute to dry spell mitigation and yield improvements. Tied-ridges, also known as furrow damming, are found to improve barley yields by 44% compared to traditional tillage methods in the semi-arid region of northern Ethiopia (Araya and Stroosnijder, 2010). Moreover, soil and water management interventions improve land productivity by restoring degraded land (Lal, 2001; Reij et al., 2009; Vohland and Barry, 2009), maintain biodiversity (Norfolk et al., 2012; Pandey, 2001; Vohland and Barry, 2009), and limit nutrient loss from fields by controlling soil erosion (Gebreegziabher et al., 2009; McHugh et al., 2007).

There is growing interests in developing policies by governments and international development agencies on the implementation of small-scale soil and water management interventions in most of the sub-Saharan African countries (Gebregziabher et al., 2013). However, the scale of adoption of these technologies is very limited although there is proven evidence that small-scale interventions can improve agricultural production. The adoption of small-scale soil and water management interventions is affected by various socio-economic factors. Gebregziabher et al. (2013) reported that there exist specific main determinants that affect the adoption of rainwater management technologies in the Upper Blue Nile basin in Ethiopia such as household demographic characteristics (such as age and gender), participation in off-farm activities, migration, ownership of livestock, ownership of land, and other factors. Boyd et al. (2000) show how improved access to markets and increased producer prices stimulate investment in in-situ water harvesting systems at the household level in Tanzania. Munamati and Nyagumbo (2010) showed that resource status and gender determined the success of in-situ water harvesting in the Gwanda district of Zimbabwe.

IDSS is comprised of a suite of previously validated, spatially explicit models (Soil and Water Assessment Tool (SWAT), Agricultural Policy/Environmental eXtender Model (APEX), and Farming Simulator (FARMSIM)), and databases that have been extensively applied in both U.S. and international settings. It provides an integrated approach linking production (APEX), economic (FARMSIM), and environmental (SWAT) consequences of the introduction of new technology, policy, and training for decision makers in agriculture at multiple temporal and spatial scales (Fig. 1). IDSS involves cropping systems analysis at the field scale, environmental risk assessment at the watershed scale, and nutritional and economic analyses of proposed interventions at the farm scale. The multi-scale and multi-aspects assessment is facilitated through passing information between SWAT, APEX, and FARMSIM such that proposed interventions are evaluated from different perspectives within a connected modeling framework. On the biophysical modeling side, SWAT and APEX share field/watershed information such as soil properties, historical weather data, or crop data. In addition, distributed parameters such as those related to water balance that are calibrated at the watershed scale are transferred to APEX for field scale analyses where observation data is unavailable. On the other hand, refined crop parameters at the field scale are transferred to SWAT to improve the calculation of evapotranspiration. Crop yield outputs on various intervention scenarios predicted by APEX are used in FARMSIM for feasibility assessment on the nutritional and economic point of view. Therefore, IDSS informs decision makers with unbiased assessment results.

SWAT was developed to predict the impact of land-management practices on water, sediment, and agricultural chemical yields in watersheds with varying soil, land use, and management conditions (Neitsch et al., 2012). SWAT can simulate hydrological cycles, vegetation growth, and nutrient cycling with a daily time-step by disaggregating a river basin into sub-basins and hydrologic response units (HRUs). HRUs are lumped land areas within the sub-basin comprised of unique land cover, soil and management combinations. SWAT has been applied in Ethiopian watersheds and demonstrated satisfactory performance (Dile et al., 2013; Dile and Srinivasan, 2014; Betrie et al., 2011; Setegn et al., 2010a,b; White et al., 2011). APEX is a biophysical simulation model that shares many of the attributes of SWAT. It is used to evaluate detailed crop management technologies and decisions that can affect agricultural production and environmental sustainability (soil, water, greenhouse gases, etc.) at the scales of individual fields, whole farms, or small watersheds (Ford et al., 2015; Gassman et al., 2010; Tuppad et al., 2009; Wang et al., 2012). FARMSIM is a farm level agro-economic model that simulates the nutritional uptake of farm family in a stochastic environment so the impacts of technology on the nutritional status of the farm family can be evaluated. FARMSIM is an extension of the Farm Level and Income Policy Simulation (FLIPSIM) model available in Microsoft Excel format which has been used extensively to simulate the impacts of alternative policies and farming systems on representative farms (e.g. Nyangito et al., 1995, 1996a,b; Richardson and Clair, 1981; Richardson et al., 1983, 2000). FARMSIM is explicitly programmed to simulate small holder farms in developing countries. In addition, it simulates the family unit as the "first" consumer of farm production.

Currently there are many biophysical and socio-economic models that show the impacts of small-scale interventions (e.g. Abildtrup et al., 2006; Chilonda and Van Huylenbroeck, 2001; Garg et al., 2012; van de Giesen et al., 2005). Moreover, there has been a number of models published for integrated hydrologic-agronomic-economic analysis (e.g. Cai et al., 2003; Lefkoff and Gorelick, 1990; Volk et al., 2008) but few model is capable of simulating hydrologic and agronomic components using comprehensive physically-based algorithms due to the complexity of the modeling system. The Spatial Decision Support System (Volk et al., 2008) is similar to IDSS in terms of implementing detail biophysical processes by integrating existing models and may be more advanced in assimilating data between process models. However, it is designed for ecologic-economic evaluation of land management or landuse changes. Little research has been done to show the impacts of these agricultural interventions using process-based simulation tools within an integrated decision framework on agricultural productivity and nutritional and economic impacts at the field scale and environmental consequences at the watershed scale. In this paper, the IDSS tool is applied to assess the effects of fertilizer, irrigation, genetically improved crop and crop rotation on production, environment, nutrition and economic wellbeing of small holder farmers in Fogera woreda of the Upper Blue Nile Basin, Ethiopia. This study demonstrates the use of IDSS for comprehensive assessment of complex agricultural technologies designed to increase food production, improve nutrition, enhance economic well-being, and minimize negative environmental consequences for small-holder farms.