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Estimating the potential for expanding smallholder irrigation in Sub-Saharan Africa

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ABSTRACT

Smallholder irrigation may considerably contribute to agricultural productivity growth in Sub-Saharan Africa. However, the full potential of expanding smallholder irrigation under alternative irrigation technologies is not known. This paper presents a study to assess the irrigation expansion potential for four smallholder irrigation technologies: motor pumps, treadle pumps, communal river diversion, and small reservoirs. An integrated modeling system that combines GIS data analysis, biophysical and economic predictive modeling, and crop mix optimization techniques was developed for the assessment.

The study revealed a large potential for profitable smallholder irrigation expansion in Sub-Sahara Africa. Area expansion potential is 30 million ha for motor pumps, 24 million ha for treadle pumps, 22 million ha for small reservoirs and 20 million ha for communal river diversions. The technologies can benefit between 113 and 369 million rural people in the region generating net revenues of US $ 14–22 billion/yr, depending on technology. Final expansion potential depends on irrigation technology cost and commodity price developments.

1. Introduction

Sub-Saharan Africa (SSA) is lagging the rest of the developing world in economic growth and is faced with great challenges in development. Of the 54 countries in SSA, 33 are considered among the least developed countries determined by the United Nations (UN-OHRLLS, 2003). In addition, all countries with extremely alarming global hunger index scores (assessing the proportion of people who are undernourished, the proportion of children under five who are underweight, and the child mortality rate) are in SSA (von Grebmer et al., 2011). SSA has the highest poverty rate in the world; almost 50% of the population (or 380 million people) live on less than $ 1.25 a day (Chen and Ravallion, 2010) and, as a consequence of food shortages, the number of undernourished people in SSA is 239 million (FAO, 2010). The combined problems of hunger and poverty form a vicious downward spiral, limiting people's ability to earn income and purchase food and severely affecting the most vulnerable – pre-school children. Given that agriculture is the single most important source of rural livelihoods in Africa, an agricultural growth strategy will go a long way to reducing hunger and poverty. Improvements in agriculture will not only help secure food supply but also will contribute to the growth of household incomes in rural areas (Rosegrant et al., 2006).

Among the numerous challenges confronting the endeavors to enhance agricultural production in SSA is the large spatial and temporal variability and availability of water resources. Currently, agriculture in SSA is predominantly rainfed. The limited access to water in arid areas or during dry seasons or droughts often constitutes a restricting factor for farming and for improving agricultural productivity. Therefore, irrigation has often been regarded as a promising solution to boost levels of agricultural productivity in SSA. Donors, research analysts, and scientists within the international agricultural development community have promoted irrigation investments in SSA in recent decades, and agricultural production has increased in many areas where irrigation projects have been implemented (see FAO, 2000; Poussin et al., 2005, Adekalu et al., 2009, Lemoalle and de Condappa, 2010; Eshetu et al., 2010 and many others). At the same time, many irrigation projects in SSA have been considered failures, and actual areas irrigated are often below design levels (Rosegrant and Perez, 1997). With donor financing available to expand irrigation in the region, two questions seem pertinent: (1) To what extent can agriculture in SSA benefit from more extensive application of selected irrigation technologies; and (2) Should donors invest in large-scale irrigation schemes that often include large dams and reservoirs, or should they focus instead on supporting investments in small-scale irrigation systems. Enhanced information regarding the potential role of smallholder irrigation can help identify efficient investment options for irrigation development across the region.

In this paper, we assess smallholder irrigation potential in SSA at the continental scale. Large-scale assessment and planning for

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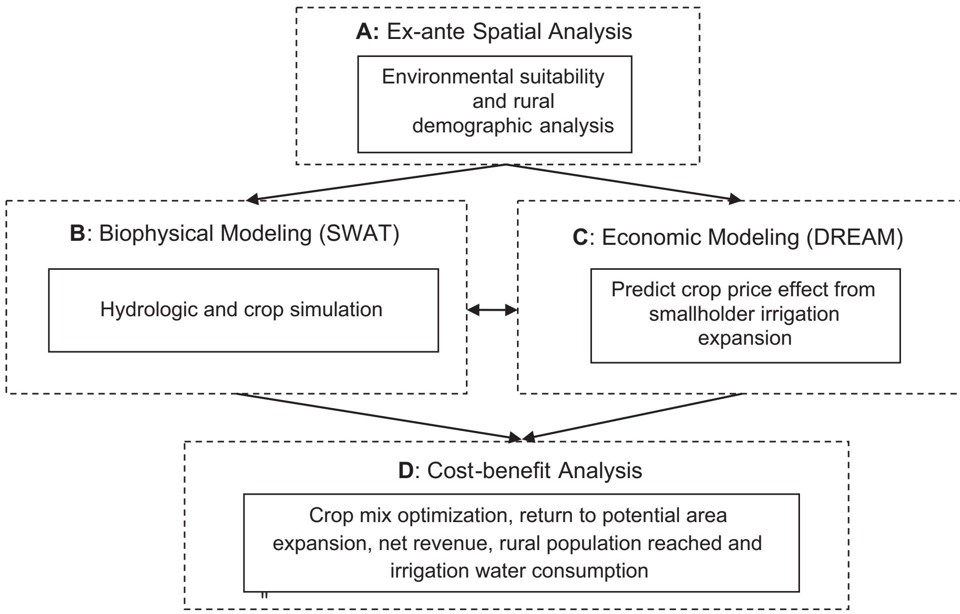

Fig. 1. Assessment framework for irrigation potential in SSA.

irrigation is a challenging task and requires that we consider an array of biophysical and socioeconomic factors. Prior to this study, there have been a few attempts to explore the prospect of improving agricultural production in SSA through investments in irrigation and rainwater harvesting at the continental or global level (FAO, 1997; UNEP, 2007; You et al., 2011). The outcomes of these studies are dependent upon the approaches and data used. In our work, we focus on four methods of capturing or diverting water for smallholder farmers: (1) motor pumps, (2) treadle pumps, (3) communal river diversion, and (4) small reservoirs. To assess the potential of these four methods, we develop a modeling system that combines GIS data analysis with predictive modeling tools. The integrated use of these techniques allows for in-depth analysis of the costs and benefits of smallholder irrigation for farmers and the environment.

2. Materials and methods

2.1. Assessment framework

Our assessment framework (Fig. 1) consists of several components, each of which is explained below.

2.1.1. GIS ex-ante analysis

We begin with GIS (Geographic Information System)-based environmental suitability analysis and rural demographic analysis. The environmental suitability analysis is performed on a class of gridded spatial data sets, pixel by pixel. We define a series of suitability criteria for smallholder irrigation to score the environmental suitability (from 0 to 100) of smallholder irrigation methods for each 500 m GIS grid cell to provide initial estimates of areas with application potential. The area estimated using environmental suitability analysis was further constrained by estimates from a rural demographic analysis, which we conduct to ensure there is sufficient labor on suitable land for irrigation technology adoption.

2.1.2. SWAT and DREAM predictive modeling

The GIS-based environmental suitability analysis and rural demographic analysis are viewed as ex-ante analyses in our assessment. Areas with irrigation potential estimated from the GIS analysis are refined through the predictive modeling exercise. Predictive modeling tools contain quantitative information describing biophysical and socioeconomic processes, and have the capacity to assess the consequences of irrigation on hydrology, agriculture and the economy. The two predictive modeling tools selected for use in this study are the soil and water assessment tool (SWAT) (Arnold et al., 1998) and the dynamic research evaluation for management (DREAM) model (Wood et al., 2005). SWAT is a comprehensive process-based river basin model, which provides functions for both hydrologic and crop simulation, and has a proven track record of successful applications worldwide. We use the SWAT model to obtain spatially disaggregated estimates of water availability, water consumption, and crop yields under smallholder irrigation technologies in SSA river basins. The SWAT-SSA model developed for this study integrates elevation, soil, land use and climate data from recently developed regional and global databases (Table 1). We divide SSA into 1231 river basins for SWAT modeling (supplementary online Fig. S1). These basins serve as spatial units for water accounting and agricultural production.

Table 1
Key data sets used to develop the SWAT-SSA model.

Category	Source
Elevation	HydroSHEDS (Lehner et al., 2008)
Soil	Harmonized world soil database (HWSD) (FAO/IIASA/ISRIC/ISSCAS/JRC, 2009)
Land cover	Global land cover (GLC) 2000 (European Commission Joint Research Centre, 2003)
Crop cover	You et al., 2009
Lakes & reservoirs	Global lake and wetland database (GLWD) (Lehner and Doll, 2004)
Climate[a]	Precipitation: — Global Precipitation Climate Project (GPCP) Temperature and relative humidity: — Goddard Earth Observing System model version 4 and version 5 (GEOS-4 & GEOS-5) Solar radiation: — Release 3 of the NASA/GEWEX Surface Radiation Budget (GEWEX SRB 3.0) project and NASA's Fast Longwave And SHortwave Radiative Fluxes (FLASHFlux) project

[a] Climate forcing data for SWAT include 1 degree daily (1DD) precipitation, temperature, solar radiation and relative humidity data were obtained from the NASA Langley Research Center POWER Project.