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Transitioning to groundwater irrigated intensified agriculture in Sub-Saharan Africa: An indicator based assessment

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ABSTRACT

Growing populations, changing market conditions, and the food security risks posed by rainfed cropping and climate change collectively indicate that Sub-Saharan African nations could benefit from transforming agricultural production to more intensive yet resilient and sustainable systems. Although highly underutilized, emerging evidence indicates that groundwater may be more widely available than previously thought, highlighting its potential role in facilitating such a transformation. Nevertheless, the possibility for such a transition is conditioned by number of complex factors. We therefore construct a transition index that integrates data considering groundwater and energy availability and cost, market access, infrastructural needs, farm conditions and natural resource stocks, labor availability, climate, population density, as well as economic and political framework variables, using a principal component analysis based methodology. Using the consequent multi-dimensional transition index and constituent intermediate indices, we provide an assessment of groundwater irrigation potential discussed in consideration of Burkina Faso, Ghana, Malawi, Ethiopia, Nigeria, Zambia, Namibia, Cameroon, and Zimbabwe. Our results, though preliminary, provide a methodology for conducting such an integrated assessment, while deriving a holistic set of policy options considering the transition towards appropriate use of groundwater for agricultural development.

1. Introduction

Sub-Saharan Africa's (SSA's) predominant agricultural systems are generally characterized by rainfed and extensive crop and pastoral systems, many of which experience yield gaps and are well below their productive potential (Tittonell and Giller, 2012). The extremely low use of fertilizer (1% share in world fertilizer market) and irrigation provision (3% of the cultivated area) of this region reflect these underlying characteristics and the subsistence nature of farming (FAO, 2008). It has been suggested that a transition to more intensive agricultural production systems designed with sustainability and resilience principles in mind could help to address the challenges of meeting the food security and livelihood demands of SSA's increasing populations (Hazell and Wood, 2008; IFPRI, 2012), while maintaining ecosystem services and protecting rangelands and forests from conversion to cropped agriculture (Fisher, 2010; Palm et al., 2010; Vanlauwe et al., 2014). Though there is a constellation of factors responsible for the current state of SSA's predominant agricultural systems, dependence on rainfed production is a major factor influencing farmers' high level of risk aversion that limits investments in more intensified farming systems (Haile, 2005; Rockström et al., 2010). It has been argued that the environmentally sound provision of irrigation could be a key factor enabling a transition from low to more sustainably intensified systems that could benefit smallholders (Burney and Naylor, 2012), while buffering against the anticipated negative repercussions of climate change (Lobell et al., 2008). Given recent studies showing that groundwater is more prevalent in SSA (MacDonald et al., 2012) than previously thought, the current study analyzes the factors that could enable or hinder the transition to groundwater based irrigated agriculture in a sub-set of SSA countries.

In countries where groundwater is physically available, the potential for economic gain (profit differential) that could be real-

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ized from the transition from predominantly rainfed production to irrigated agriculture, which we term it as transition pressure, could be a driving force in the intensification process (Amjath-Babu and Kaechele, 2015). It should be noted that numerous social, agronomic, economic and environmental factors must be aligned to encourage the transition process (Godfray and Garnett, 2014). The current work looks at the interactive nature of these determinants. The pressure to transition to more intensively irrigated production is currently low in SSA and one must consider the underlying institutional, economic, energetic, hydrogeologic, climatic, societal, and policy related causes that impede the transition to sustainable intensification. Such an understanding could reveal potential pathways and areas of investment to facilitate the sustainable use of groundwater for irrigation, which could have important ramifications for food security and income generation in many of the SSA countries studied.

1.1. Why the transition is important

Rapidly increasing populations, economic growth, and climate change make the transition from low productivity farming to a more intensive yet environmentally and socially sustainable agriculture an important task in the context of SSA. In SSA, population growth has outpaced the growth in food production (Johnson et al., 2003), with a number of countries becoming net food importers or food aid receivers. In 2008, Sub-Saharan African nations imported 21.9 million tons of grain equivalents while an additional 4.2 million tons were received as food aid (USDA, 2010). Another development that underscores the importance of such a transition is the recent escalation in food prices (Mitchell, 2008), which exposed the vulnerabilities of the current world food supply and pricing system, with special relevance to cereal crops and SSA. Nevertheless, avoiding a long term persistent food crisis is likely to be of greater concern than dealing with short term price escalations (Battisti and Naylor, 2009). In addition, provision of irrigation for smallholders can also be a key tool in poverty alleviation and meeting developmental goals (Burney and Naylor, 2012).

Barrios et al. (2008) showed that undesirable changes in precipitation and temperature from the 1960s onward can account for a major share of the production deficit in SSA (in comparison to other developing country regions). The sensitivity of farm income to precipitation is evident from a number of studies using Ricardian approaches. The elasticity of rainfall to farm income ranges from 2.5 in Ethiopia (Molua, 2009) to 3.18 in Kenya (Kabubo-Mariara and Karanja, 2007). It has also been reported that increased temperature scenarios projected for SSA can improve average farm income under irrigated conditions (the elasticity of temperatureto income being 0.5), while it can substantially harm rainfed farming (where the elasticity is −1.9) (Kurukulasuriya et al., 2006). Hence, in order to move African agriculture towards climate resilience, i.e. less sensitive to rainfall and temperature changes, while meeting the increasing demands of a growing population and economy, a transition to (supplementary or fully) irrigated cropping is likely to be essential. Unlike the previous green revolution that bypassed SSA, the sustainability of planned intensification efforts is an important consideration in the African context in which socially equitable and environmentally sound development is needed (Horlings and Marsden, 2011).

1.2. Concept of transition and factors affecting the transition

Induced innovation theory seeks to explain the transition from traditional agricultural systems that are heavily reliant on land expansion and labor inputs to maintain or increase production, to intensified farming systems. The theoretical premise is that population pressure and scarcity of land induce adoption of intensive farming practices which in turn encourage associated institutional change in an ultimately reflexive and mutually supportive cycle (Hayami and Ruttan, 1985). While we recognize that smallholders are as interested in risk reduction as they may be in profits (Tittonell and Giller, 2012), for the purposes of this study we assume that the profit differential between these systems that can be realized under local physical, economic, social and infrastructural conditions can adequately reflect the transition pressure that could induce the adoption of innovations in farming practices. The concept is presented in Fig. 1. As the focus of this paper is to analyze the potential of groundwater based irrigated intensified agriculture in Sub-Saharan Africa, we construct a preliminary index that could reflect such a transition. The domains considered for this index include groundwater, energy, markets, infrastructure, farm conditions, labor availability, climate, population and economic pressures, and political stability. The sub-indicators selected for the construction of the transition index are average depth to groundwater table and average yield of groundwater wells for the domain 'groundwater', rural electricity access and diesel price for the domain 'energy', average travel time required to reach a populated area with markets, and the farm gate price of representative marketed crop (maize predominantly) for the domain "market". The average cost of drilling boreholes (per meter depth) and the percentage of paved roads were both used for the domain 'infrastructure', and average nutrient depletion rate for nitrogen, potassium, and phosphorus, and the value cost ratio of fertilizers, were used for the domain 'farm conditions'. The percentage of land surface that contains 90% of the population was used as an index of population density in rural areas for the domain "labor availability', while arable land per capita and GDP per capita were used for 'population and economic pressure'. Mean precipitation represented the domain "climate" and fragility index for political framework conditions. The transition index was calculated for ten Sub-Saharan African countries, including Burkina Faso, Zimbabwe, Cameroon, Namibia, Zambia, Nigeria, Ethiopia, Malawi, Kenya and Ghana for which complete data were available.

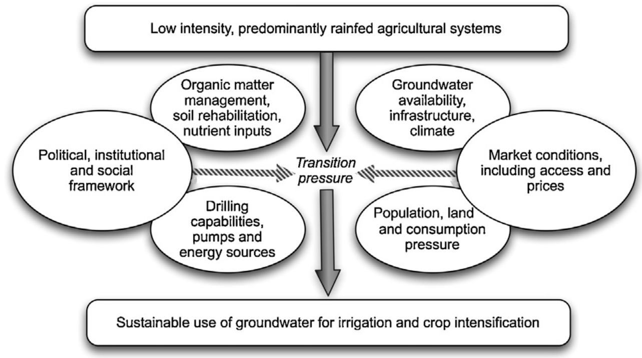

Fig. 1. A generalized concept of transition from subsistence to intensive farming as applied in this study.
Note: Circles represent the domains interacting with the transition between the states of farming (subsistence to intensive), represented by the rounded rectangles. Transition pressure is the profit differential between the systems, given the domain conditions.

Let us now present several points justifying the inclusion of these indicators in the transition index. Physical and economic access to groundwater are preconditions for groundwater based development and hence the depth to groundwater level, yield of wells, and cost of drilling and pumping are the defining variables in any assessment of groundwater's agricultural potential. It is already well established that the excessive cost of well construction is identified as one of the major obstacles in groundwater development in Africa (Tuinhof et al., 2011). In addition, the availability and cost of energy sources, such as grid-based electricity and diesel fuel,