Land Use Policy 78 (2018) 158–165

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Spatially-explicit effects of seed and fertilizer intensification for maize in Tanzania

Adam M. Komarek*, Jawoo Koo, Ulrike Wood-Sichra, Liangzhi You

International Food Policy Research Institute, Washington, DC, USA

ARTICLE INFO

Keywords:
DSSAT
Economic surplus model
Malabo Declaration
Policy
Value-cost ratio

ABSTRACT

Slower than desired growth in crop yields coupled with rising food demand present ongoing challenges for food security in Africa. Some countries, such as Tanzania, have signed the Malabo and Abuja Declarations, which aim to boost food security through increasing crop productivity. The more intensive use of seed and fertilizer presents one approach to raising crop productivity. Our simulation study examined the productivity and economic effects of planting different seed cultivars and increasing fertilizer application rates at multiple spatial scales for maize in Tanzania. We combined crop simulation modelling with household data on costs and prices to examine field-scale and market-scale profitability. To scale out our analysis from the field scale to the regional and national scale (market scale) we applied an economic surplus model. Simulation results suggest that modest changes in seed cultivars and fertilizer application rates can double productivity without having a negative effect on its stability. The profitability of applying extra fertilizer, calculated as its value-cost ratio, increased if improved seed cultivars replaced local seed cultivars. Rankings of district-scale profits differed from rankings of district scale yields, highlighting the importance of considering economic factors in assessments of input intensification. At the national scale, simulation results suggest the total benefit could be US$ 697 million over 5 years if there was a 39 percent adoption rate of planting improved seed and applying extra mineral fertilizer. Providing economic assessments of input intensification helps build evidence for progressing the Malabo and Abuja Declarations.

1. Introduction

In Eastern and Southern Africa approximately 22 percent of total caloric consumption came from maize in 2005–2007 (Shiferaw et al., 2011). Smallholder farmers cultivate much of this maize, and their livelihoods depend on maize productivity. Improving the productivity of these smallholders presents one pathway to better livelihoods (Larson et al., 2016). Repeated studies have shown the yield gains associated with improved seed and mineral fertilizer for maize in Africa (Droppelmann et al., 2017). A wide range of policies in Africa have focused on increasing crop productivity (Jayne and Rashid, 2013). These policies have ranged from country-specific policies that subsidize seed and fertilizer to continent-wide commitments on increasing productivity and input use such as the Malabo and Abuja Declarations. The Malabo Declaration aims to at least double crop productivity by 2025 in specific African countries (AU, 2014). However, yield trends suggest many African countries may struggle to double productivity before 2025 (Ray et al., 2013), despite countries often increasing their agricultural budgets (Benin and Yu, 2013). In addition, fertilizer use in many African countries lags behind the 2015 goal of applying 50 kg ha^{-1} of fertilizer stated in the 2006 Abuja Declaration (ADBG, 2006). Against this backdrop of policies and declarations, spatial heterogeneity exists in biophysical and economic conditions among regions within countries, among farmers within regions, and among fields within farms. Capturing the effect of this spatial heterogeneity on crop productivity and economic measures may help increase the relevance of input intensification studies for discussions on the Malabo and Abuja Declarations.

Our simulation study asked three questions for maize monoculture in the Mbeya administrative region of the Southern Highlands of Tanzania (Fig. A.1); (1) how do changes in seed cultivars and fertilizer application rates affect the yield and partial profit of maize in different districts of Mbeya?; (2) what are the value-cost ratios of fertilizer use for different seed cultivars in different districts of Mbeya?; and 3) how do maize grain prices, producer surpluses, and consumer surpluses change in Mbeya, the rest of the Southern Highlands, and for all of Tanzania if maize seed and fertilizer practices intensify in Mbeya (and then spillover to 80 percent of the rest of the Southern Highlands)? Maize is Tanzania's main staple crop and Mbeya is Tanzania's largest maize producing administrative region (MoA, 2014). Our study

* Corresponding author.

https://doi.org/10.1016/j.landusepol.2018.06.033
Received 30 October 2017; Received in revised form 2 March 2018; Accepted 20 June 2018
Available online 02 July 2018
0264-8377/

combines crop simulation modelling, with household price and cost data, and an economic surplus model. We focused on seed and mineral fertilizer because they are common inputs into maize production. However, using these inputs is often a complementary strategy to applying sustainable farming practices, such as integrated soil fertility management. Multiple approaches exist to achieving the Malabo and Abuja Declarations, such as increasing the use of improved seeds and fertilizers, greater use of sustainable farming practices, or a combination of the preceding two approaches. Our study considered more intensive seed and fertilizer use.

Studies on increasing the use of fertilizer have often focused on the value-cost ratio of fertilizer, defined as the value of extra grain yield associated with an additional unit of fertilizer applied. Studies on the value-cost ratio have taken both a field-scale perspective with agronomic experiments (Kihara et al., 2016) and a household-scale perspective with household survey data (Burke et al., 2017; Liverpool-Tasie et al., 2017; Sheahan et al., 2013; Xu et al., 2009; Ragasa and Chapoto, 2017). Previous studies highlighted the heterogeneity of fertilizer profitability within specific regions, including the importance of planting improved seed to raise fertilizer-use efficiency. Although microeconomic studies on value-cost ratios provide information on the profitability of inputs at the field-scale, policymakers are often interested in the market-scale effects of widespread changes in practices. At the market scale, studies have focused on the economy-wide implications of changes in crop productivity. Ricker-Gilbert et al. (2013) found that lifting maize production by subsidizing fertilizer costs in Malawi and Zambia had a slight negative effect on retail maize prices. Pauw and Thurlow (2011) simulated the effect of exogenously-imposed changes in total factor productivity on economy-wide indicators in Tanzania. You and Johnson (2010) explored crop investment options for countries in Africa with an economic surplus model. Kassie et al. (2017) also applied an economic surplus model to show that combining practices such as improved seed and fertilizer for maize increased producer and consumer surpluses in Ethiopia. Studies in Tanzania have developed targeting domains for scaling out sustainable intensification technologies by identifying sites with similar bio-socio-economic characteristics (Muthoni et al., 2017; Nijbroek and Andelman, 2016).

Our simulation study adds insights into the studies mentioned above by providing additional evidence on the economic effects of changes in seed and fertilizer use in Tanzania at the field scale, regional scale, and national scale. Our study supplements microeconomic adoption studies by considering the effect of different rates of adoption to input intensification on maize prices and changes in producer and consumer surpluses. Using a cropping systems model to simulate yield effects helps isolate the effects of seed and fertilizer use across heterogenous climates and soils. Our study supplements economy-wide analyses by providing a more granular examination of practices that may increase maize yields and how this yield increase may affect prices and economic surpluses. Our results both complement and supplement Pauw and Thurlow (2011) because we address how to achieve yield growth and then examine the market-scale effects of the yield growth. Studies on market-scale effects of agricultural inputs often estimate adoption, yields, and costs using econometric methods with household data (Kassie et al., 2017; Shiferaw et al., 2008; Moyo et al., 2007). We provide an alternative method by simulating the yield effects and then combining the simulations with survey data on prices and costs to assess the economic effects of input intensification. Finally, we provide a concrete example of maize, seed, and fertilizer focusing on yields, prices, and costs, which helps provide a case study to recently proposed targeting domains in Tanzania (Muthoni et al., 2017; Nijbroek and Andelman, 2016).

2. Methods

We first simulated maize grain yields for different practices related to seed and mineral fertilizer (hereafter fertilizer) application rates over multiple years with a cropping systems model to capture spatial and temporal heterogeneity in yields. We then calculated partial profits and value-cost ratios (*VCRs*) for different practices by combining the simulated yields with household survey data on prices and costs. Finally, we examined the price and economic surplus effects (market-scale effects) for the different practices at three spatial scales: Mbeya, the rest of Southern Highlands (i.e., the Southern Highlands excluding Mbeya), and the rest of Tanzania (i.e., all of Tanzania excluding the Southern Highlands).

Table 1
Simulated practices related to maize seed and fertilizer.

Practice	Seed cultivar	Fertilizer applied (kg N ha^{-1})
1 (baseline)	local	10
2	local	40
3	improved	10
4	improved	40

Note: The improved cultivar was SC0627 and the local seed cultivars were either CM1509, CM1510, or CM1511. Fertilizer applied was urea, a water-soluble mineral fertilizer that contains 46% nitrogen (N).

2.1. Field-scale methods

2.1.1. Productivity

We simulated maize grain yields for a baseline (practice 1) and 3 input intensification practices (p) over 30 years from 1980 to 2009 in the Decision Support System for Agro-technology Transfer (DSSAT) v4.5 (Jones et al., 2003; Hoogenboom et al., 2010). We used the CERES-Maize model within DSSAT. Our baseline included maize monoculture planted with local seed plus 10 kg N (nitrogen) ha^{-1} applied as fertilizer (Table 1). The baseline reflects the most common approach to growing maize based on data in MoA (2014) and the Tanzanian National Panel Survey (NBS, 2012) (Fig. A.2). The input intensification practices included different combinations of seed and fertilizer: practice 2 included local seed and 40 kg N ha^{-1} as fertilizer, practice 3 included improved seed and 10 kg N ha^{-1} as fertilizer, and practice 4 included improved seed and 40 kg N ha^{-1} as fertilizer. Each simulated practice applied no manure to the field and had 80 percent of crop residues removed from the field, which matched local practices. The planting density of seed varied by district and by seed cultivar. Seed cultivars planted differed among the different districts based on data in MoA (2014). Practices with 40 kg N ha^{-1} reflect an application rate in line with area-specific fertilizer recommendations for the Southern Highlands that have been historically provided by Tanzania's Ministry of Agriculture (Jama et al., 2017). Appendix A provides additional details on the practices.

We simulated the four practices from Table 1 in all districts of Mbeya. We applied a grid-based approach where DSSAT simulated maize growth for each practice in all 5 arc-minute grid cells in Mbeya that reported growing maize (IFPRI and IIASA, 2016). Climate and soils differed among the districts. We parameterized DSSAT using AgMERRA historical daily weather data (Ruane et al., 2015) at a 30 arc-minute resolution overlaid on gridded soil profile data (Han et al., 2015) at a 5 arc-minute resolution. Parameterization also included collating district-scale crop management data including seed cultivars and fertilizer application rates (MoA, 2014), regional-scale maize planting windows (range of planting dates) (FAO, 2010), and crop cultivar coefficients (Table A.1). We reset soil parameters at the start of each simulation year to the initial soil parameters. We reset soil parameters because we simulated a monoculture, as opposed to different cropping practices that may involve sizable differences in the accumulation of soil water or nutrients. We then calibrated and evaluated the parameterized model.

To calibrate our model we sourced yield data from different districts in Mbeya from MoA (2014) that applied a comparable mix of practices to our baseline. The calibration of process-based cropping systems