Ex Ante Welfare Analysis of Technological Change: The Case of Nitrogen Efficient Maize for African Soils

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This study evaluates the potential impacts of the Improved Maize for African Soils (IMAS) project in two countries of Africa: Kenya and South Africa. The IMAS varieties offer significant yield advantages for regions where low or no fertilizer is used. The analysis uses spatial production data and household data to account for the level of fertilizer use in different agroecological zones of the country as well as different types of maize producing households. Results suggest that IMAS will deliver a total of US$586 million in gross benefits with US$136 million and US$100 million of benefits to producers in Kenya and South Africa, respectively, and an additional US$112 million to consumers in Kenya and US$238 million to consumers in South Africa. These benefits could help more than 1 million people escape poverty in the two countries by 2025. Household level results suggest that small households in areas with relatively low levels of fertilizer use stand to gain significant benefits.

Dans la présente étude, nous analysons les répercussions potentielles du projet Improved Maize for African Soils (IMAS – maïs amélioré pour les sols africains) dans deux pays africains : le Kenya et l'Afrique du Sud. Les variétés de maïs utilisées dans le cadre du projet IMAS offrent la possibilité d'accroitre considérablement les rendements dans les régions qui utilisent peu ou pas d'engrais. Dans le cadre de notre étude, nous avons utilisé des données spatiales sur la production et sur les ménages pour déterminer le taux d'utilisation d'engrais dans les zones agroécologiques de chaque pays ainsi que les divers types de ménages qui cultivent le maïs. Les résultats de notre étude autorisent à penser que le projet IMAS permettra de dégager des avantages bruts évalués à 586 M$ US, dont 136 M$ US et 100 M$ US pour les producteurs du Kenya et de l'Afrique du Sud respectivement, ainsi que 112 M$ US et 238 M$ US supplémentaires pour les consommateurs du Kenya et de l'Afrique du Sud respectivement. Ces avantages pourraient permettre à plus d'un million de personnes d'échapper à la pauvreté dans ces deux pays d'ici 2025. Les résultats à l'échelle des ménages semblent indiquer que les ménages de petite taille installés dans les zones où l'utilisation des engrais est assez faible sont plus susceptibles de tirer des avantages importants.

INTRODUCTION

Fertilizer is a crucial agricultural input in much of the developed world and part of the developing world. This is a stark contrast with the limited use of fertilizer in Africa. There

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have been substantial discussions on what types of policies and programs are needed to realize the potential benefits of fertilizer in African agriculture (Heisey and Mwangi 1996; Jayne et al 2003; Morris et al 2007; Duflo et al 2009). The average fertilizer use rate in Africa in 2007 was 19 kg/ha. In contrast, farmers in Asia and Western Europe used 205 kg/ha and 199 kg/ha, respectively (International Fertilizer Development Center [IFDC] 2010). Moreover, fertilizer use in sub-Saharan Africa decreased by 11% from 1997/98 to 2007/08 (IFDC 2010). Fertilizer use is very important especially in maize, Africa's most important cereal crop (International Institute for Tropical Agriculture [IITA] 2009) helping hundreds of millions of vulnerable households (Smale et al 2011).

Given that the levels of fertilizer use in Africa have fallen recently, there have been research efforts to select plants with greater fertilizer efficiency as well as employ transgenic methods to further improve them. Biotechnology provides opportunities through tools ranging from Maker Assisted Selection (MAS) methods to transgenic methods which have the potential to generate important benefits on this front. The Improved Maize for African Soils (IMAS) project uses biotechnology tools to deliver maize varieties with better nitrogen-use efficiency, especially for low levels of fertilizer use, with expected yield increases of 50% by the end of the project (International Maize and Wheat Improvement Center [CIMMYT] 2012). Given that maize is the most important crop for African agriculture (IITA 2009), the successful generation and dissemination of fertilizer efficient maize is expected to generate significant benefits.

Usually, the use of biotechnology comes with the price of seed markups and intellectual property rights protection. The IMAS project is a collaboration between CIMMYT and DuPont, Pioneer Hi-Bred, the Kenya Agricultural Research Institute, and the South African Agricultural Research Council. However, their products will be royalty-free to companies that sell to smallholder farmers so that seeds are available to farmers at the same cost as other improved varieties (CIMMYT 2012). This collaboration is expected to generate fertilizer efficient maize and release the first varieties in 2016.

The objective of this paper is to evaluate the *ex ante* impact of the IMAS maize varieties in two target countries, Kenya and South Africa, over a 25-year time horizon. The method used takes under consideration two key agricultural and socioeconomic factors that make this study unique. First, we use Geographical Informations System data for Kenya and South Africa from the International Food Policy Research Institute (IFPRI) to develop maize production maps that match the fertilizer use zones created by other spatial studies on fertilizer use, especially in Kenya. This approach increases the accuracy of the study with respect to yield gains by fertilizer use and zone within each country and takes advantage of available data from other studies. Second, we use household data for each agroecological zone (AEZ) in Kenya to estimate monetary gains for different household types and also to estimate the number of smallholder farmers that could potentially escape poverty as a result of IMAS maize adoption.

The rest of the paper is organized as follows. Section "Background" provides a literature review of the studies on fertilizer use in Kenya and South Africa along with the fertilizer use zones used in this study and a description of the timeline of the IMAS project. The methodology is discussed in section "Methods." Section "Data" illustrates the data and results are presented in section "Results." Section "Conclusions" concludes.

Table 1. Kenya–Fertilizer use rate (kg/acre) on maize (only) during main growing season

Agroecological zone	1997	2000	2004	2007
Coastal Lowlands (CL)	11	5	3	7
Eastern Lowlands (EL)	10	18	15	16
Western Lowlands (WL)	24	14	10	12
Western Transitional (WT)	54	48	62	71
High Potential maize zone (HP)	65	67	74	75
Western Highlands (WH)	31	36	46	47
Central Highlands (CH)	68	64	64	58
Marginal Rain Shadow (MR)	12	15	43	43
Overall sample	56	55	60	59

Source: Kibaara et al (2008).

BACKGROUND

Fertilizer Use in Kenya and South Africa

There have been many studies on fertilizer use in Africa focusing at the country level (e.g., Heisey and Mwangi 1996; Yanggen et al 1998; Camara and Heienemann 2006; Morris et al 2007; IFDC 2010) and within country regions in Kenya and South Africa (e.g., Zyl et al 1995; Makokha et al 2001; Ariga et al 2008; Kibaara et al 2008; Duflo et al 2008; Olwande et al 2009).[1] Generally, studies suggest that fertilizer use has been relatively steady in Kenya and South Africa from 2002 to 2007 with an average use of 32 kg/ha and 46 kg/ha, respectively.

However, the average fertilizer use at the national level masks great variability at the regional and local levels. Kibaara et al (2008), Olwande et al (2009), Minde et al (2008), and Ariga et al (2008) used national household panel survey data for Kenya from 1996/97 to 2006/07 to examine fertilizer use by smallholder maize growers across different regions of Kenya. Table 1 describes fertilizer use for each AEZ in Kenya from 1997 to 2007. Clearly, the level of fertilizer use varies markedly across AEZ with a rate of 7 kg/acre in the Coastal Lowlands in 2007 and up to 58 kg/acre in the Central Highlands.

Fertilizer use is also reported for smallholder farms in Table 2 as estimated from household data by Jayne and Ariga (2009). The proportion of households using fertilizer on maize increased from an average of 56% in 1997 to 70% in 2007 at the national level, however, as illustrated in Table 2, there is a lot of variation across the different AEZ.

METHODS

To evaluate the benefits of IMAS varieties in Kenya and South Africa, we draw on the approach of Alston et al (1995) and Mills (1997) to account for zone-specific yield increases, and also that of La Rovere et al (2010) for the Drought Tolerant Maize for

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[1] Fertilizer throughout this study means both basal and top dress. Planting (or basal) fertilizer types consist of DAP, MAP, TSP, SP, NPK20:20:0, NPK23:23:0, while top-dressing types consist of CAN, ASN, UREA, SA.

Table 2. Percentage of smallholder farms using fertilizer on maize in Kenya

Agroregional zone	1996	1997	2000	2004	2007
Coastal Lowlands (CL)	0	0	3	4	14
Eastern Lowlands (EL)	21	27	25	47	43
Western Lowlands (WL)	2	1	5	5	13
Western Transitional (WT)	39	41	70	71	81
High Potential maize zone (HP)	85	84	90	87	91
Western Highlands (WH)	81	75	91	91	95
Central Highlands (CH)	88	90	90	91	93
Marginal Rain Shadow (MR)	6	6	12	11	16
Total sample	56	58	64	66	70

Source: Jayne and Ariga (2009).

Africa (DTMA) project.[2] To provide in-depth estimates for each country we rely on the AEZ for Kenya and maize production systems and South Africa.[3] Following Alston et al (1995) and Mills (1997) we model the yield increases associated with the technology as a unit cost reduction in production which generates a downward parallel shift in the maize supply curve in each AEZ.[4] The AEZ-specific unit cost reduction from: (i) varieties derived from scaled-up conventional breeding (CB) (Bänziger 2000); (ii) varieties derived from marker-assisted selection (Xu and Crouch 2008) for native traits; and (iii) transgenic maize varieties (Worku et al 2012) is calculated as:

$$K_{it} = k_{it} A_{it} P_{it-1} / \varepsilon_i \tag{1}$$

where K_{it} is the zone-specific per unit cost reduction in zone i and year t, k_{it} is the expected increase per hectare in maize yield in zone i and year t, A_{it} is the expected adoption rate in zone i in year t, P_{it-1} is the price realized in zone i in the previous year, and ε_i is the elasticity of supply. The zone-specific per unit cost reduction K_{it} is introduced as a parallel

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[2] The paper uses the same method as Mills (1997), however, we do not have information on price wedges among zones as zone specification here is based on fertilizer use.

[3] Maize production data by AEZ are not available for South Africa. Instead we use production data categorized by four production systems; high input, low input, irrigated, and subsistence. The rainfed, high input/commercial crop system is rainfed-based agriculture, but uses high-yield varieties and some animal traction and mechanization. It at least applies some fertilizer, chemical pest, disease, or weed controls. The rainfed, low-input/subsistence crop system refers to rainfed crop production which uses traditional varieties and mainly manual labor without (or with little) application of nutrients or chemicals for pest and disease control. Irrigated crop system refers to the crop area equipped with either full or partial control irrigation. Normally the crop production on the irrigated fields uses high level of inputs such as modern varieties and fertilizer as well as advanced management such as soil/water conservation measures (MapSpam 2012).

[4] Generally economic surplus models use a parallel shift of the supply curve in case of a technology that provides a unit cost reduction. However, a pivotal shift can also be used. See Alston et al (1995) for a more detailed discussion.

shift in the initial zone-specific supply curve which we assume to be linear and specified as:

$$Qs_{i0} = \theta_{i0} + \gamma_i P_{i0} \tag{2}$$

where Qs_{i0} is the quantity of maize supplied in zone *i* in year *0*, θ_{i0} is the initial supply intercept in zone *i*, γ_i is the fixed supply slope parameter, and P_{i0} is the price of maize in zone *i* in year 0. γ_i and θ_{i0} can be calculated from the initial price, quantity, and the elasticity of supply.

The shifted supply, arising from changed technology, for zone *i* in year *t* is:

$$Qs_{it} = \theta^r_{it} + \gamma_i P_{it} \tag{3}$$

where $\theta^r_{it} = \theta_{i0} + K_{it}\gamma_i$.

Similarly, assuming a linear zone-specific demand curve:

$$Qd_{it} = \alpha_{it} - \beta_i P_{it} \tag{4}$$

where Qd_{it} is the quantity demanded in zone *i* in year *t*, α_{it} is the initial demand intercept in zone *i* in year *t*, β_i is the demand slope at zone *i* and P_{it} is the initial price (that would have occurred in the absence of a change in technology) for zone *i* at time *t*. Again, the intercept and slope parameters can be derived from the initial price, quantity, and elasticity of demand. This specification allows for exogenous shifts in demand such as population growth (Mills 1997). The first conventional IMAS varieties are expected to be released in about five years (i.e., in 2016) and the transgenic varieties in about 12 years. This analysis evaluates potential gains for up to 15 years (until 2025). Considering the length of the time period covered in this analysis, population growth would likely cause an exogenous demand shift. Following Mills (1997), population growth is assumed to induce an outward parallel shit in the maize demand curve which is modeled as an increase in the intercept term (α_{it}) of the demand in period $t + 1$ and is calculated as:

$$\alpha_{it+1} = \alpha_{it} + \pi_i Qd_{it} \tag{5}$$

where π_i is population growth in zone *i*. For each period, equilibrium prices and quantities in each zone can be easily derived for the "with" research and "without" research scenario as $\sum Qd_{it} = \sum Qs_{it}$ and $\sum Q^r d_{it} = \sum Q^r s_{it}$.

Given the "with" and "without" research scenario, producers' and consumers' surpluses with the technology induced shifts for each period can be calculated as:

$$\Delta PS_{it} = (K_{it} + P^r_{it} - P_{it})\left[Q_{it} + 0.5\left(Q^r_{it} - Q_{it}\right)\right] \tag{6}$$

and

$$\Delta CS_{it} = (P_{it} - P^r_{it})\left[Q_{it} + 0.5\left(Q^r_{it} - Q_{it}\right)\right] \tag{7}$$

where ΔPS_{it} and ΔCS_{it} are the changes in producer and consumer surplus from research in zone *i* and year *t*, respectively. K_{it} is the unit cost reduction from the IMAS varieties, and P^r_{it} and Q^r_{it} are the equilibrium price and quantity, respectively, "with" research. P_{it} and Q_{it} are the equilibrium price and quantity "without" research.[5] The present value of the accumulated gains at the end of the investigation period is calculated using a 5% discount rate.

In this case, following Alston et al (1995), assuming linear supply and demand curves, consumers' and producers' surplus changes for South Africa can be obtained as:

$$\Delta PS_{it} = \left[K_{it}Q_{it} - \left(\frac{P^r_{it} - P_{it}}{P_{it}}\right)P_{it}Q_{it}\right]\left[(1 + 0.5\left(\frac{P^r_{it} - P_{it}}{P_{it}}\right)\varepsilon_L\right] \tag{8}$$

and

$$\Delta CS_{it} = \left[P_{it}C_{Lit}\left(\frac{P^r_{it} - P_{it}}{P_{it}}\right)\right]\left[(1 + 0.5\left(\frac{P^r_{it} - P_{it}}{P_{it}}\right)\eta_L\right] \tag{9}$$

where ε_L is the supply elasticity for maize in South Africa, η_L is the demand elasticity of maize, C_{Lit} is the maize consumption in South Africa in year t and the rest of the variables are as previously defined. Kenya is a net importer of maize and South Africa is a net exporter of maize, but the share of imports and exports are generally less than 10% of the total domestic production. Thus, we model both countries as a closed economy.[6]

Benefits for Different Types of Producing Households

Another important aspect of this study is the evaluation of the benefits of these new technologies at the household level. Given the prices for each zone and the unit cost reduction from IMAS varieties, producing household benefits for small (<1 ha), medium (<5 ha), and large (>20 ha) producers can be calculated as:

$$\mathrm{Pr}_{ijt}Y = K_{it}q_{ijt} - \left(P_{it} - P^r_{it}\right)q_{ijt} \tag{10}$$

where $\mathrm{Pr}_{ijt}Y$ is the producer benefit from maize for producing household type j, for AEZ i in year t. K_{it} is as previously defined, q_{ijt} is the equilibrium quantity produced by household j in zone i and year t, P_{it} is the equilibrium price of maize "with" research for zone i and year t, and P^r_{it} is the equilibrium price of maize for zone i "without" research in year t. Thus Equation (10) takes into account price changes which are different for each zone (due to different technological changes from different rates of fertilizer use).

Poverty Impacts

We also calculate the likely poverty impacts in terms of number of poor lifted out of poverty and poverty reduction expressed as percentage of poor for each country using

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[5] See Mills (1997) for additional details on the model. Equivalent and compensating variation can also be used instead of consumer surplus (for a discussion on the differences between the different measures, see Heien 1988).

[6] In the case of a small open economy, producers would capture most of the benefits and consumers would gain less compared to a closed economy as the selling price in the domestic market would not change due to the supply shift. However, the aggregate benefits between the "open" and the "closed" economy scenarios for small economies are similar (see Moyo et al 2007).

two different methods. First, for Kenya we use the value of the IMAS income gains for small, medium, and large farms, along with the 2007 poverty line (1,562 Kenya shilling per month; Suri et al 2008) and the severity of poverty provided for each AEZ by Suri et al (2008) to provide a count of the households that would cross the poverty line by 2025 as a result of IMAS benefits. Second, given that we do not have any household data for South Africa, to estimate the number of poor out of poverty there we use the method developed by Alene et al (2009):

$$\Delta N = \left(\frac{ES}{\text{AgGDP}} \times 100\% \right) \times \frac{\partial \ln(N)}{\partial \ln(\text{AgGDP})} \times N \tag{11}$$

where ΔN is the number of poor lifted out of poverty at the end of the period for which we estimate the benefits. Thus it is the cumulative benefit of estimates in year 2025. *ES* is the total benefits, thus the sum of producers' and consumers' surpluses as estimated above, AgGDP is the agricultural gross domestic product (total value of agricultural production), the next term is the elasticity of poverty reduction with respect to AgGDP growth, and *N* is the total number of poor. Although this is a rough measure of the number of people getting out of poverty, it has been used in previous studies (e.g., Alene et al 2009; La Rovere et al 2010) and when household data is not available, given the elasticity of poverty reduction with respect to poverty is within a reasonable range, it can provide an estimate of potential poverty implications associated with the policy.

DATA

Fertilizer Use Zones

Spatial information on fertilizer use and maize production is crucial for a more precise estimation of the potential benefits of IMAS. For the purpose of our study, the Spatial Production Allocation Model (SPAM) developed by IFPRI was used to provide production and planted area data for AEZ. We then use the fertilizer use rates for each AEZ in Kenya provided by Kibaara et al (2008).[7] Figure 1 shows maize yields in Kenya from the SPAM model. Production for each AEZ along with the fertilizer use for each zone can be used to estimate unit cost reductions for Kenya.

For South Africa we use SPAM spatial production data by type of maize production system (as defined by IIASA/FAO 2012) in South Africa (since production by AEZ is not available) which reports high input (8.5 million metric tons [Mt] of maize), low input (3.4 million Mt of maize), irrigated (1.8 million Mt of maize), and subsistence maize (0.5 million Mt of maize). We use the four production systems in our analysis and estimate *ex ante* benefits from the introduction of IMAS varieties for each production system. A map of maize yields in South Africa is shown in Figure 2.

Studies on fertilizer use for South Africa for each maize production system are not available. The Food and Agriculture Organization of the United Nations (FAO) (2005) reports that 95% of commercial farmers use fertilizer at an average rate of 55 kg/ha/year. Beukes (2010) reports some fertilizer use rates for some districts during the 2000–07 period

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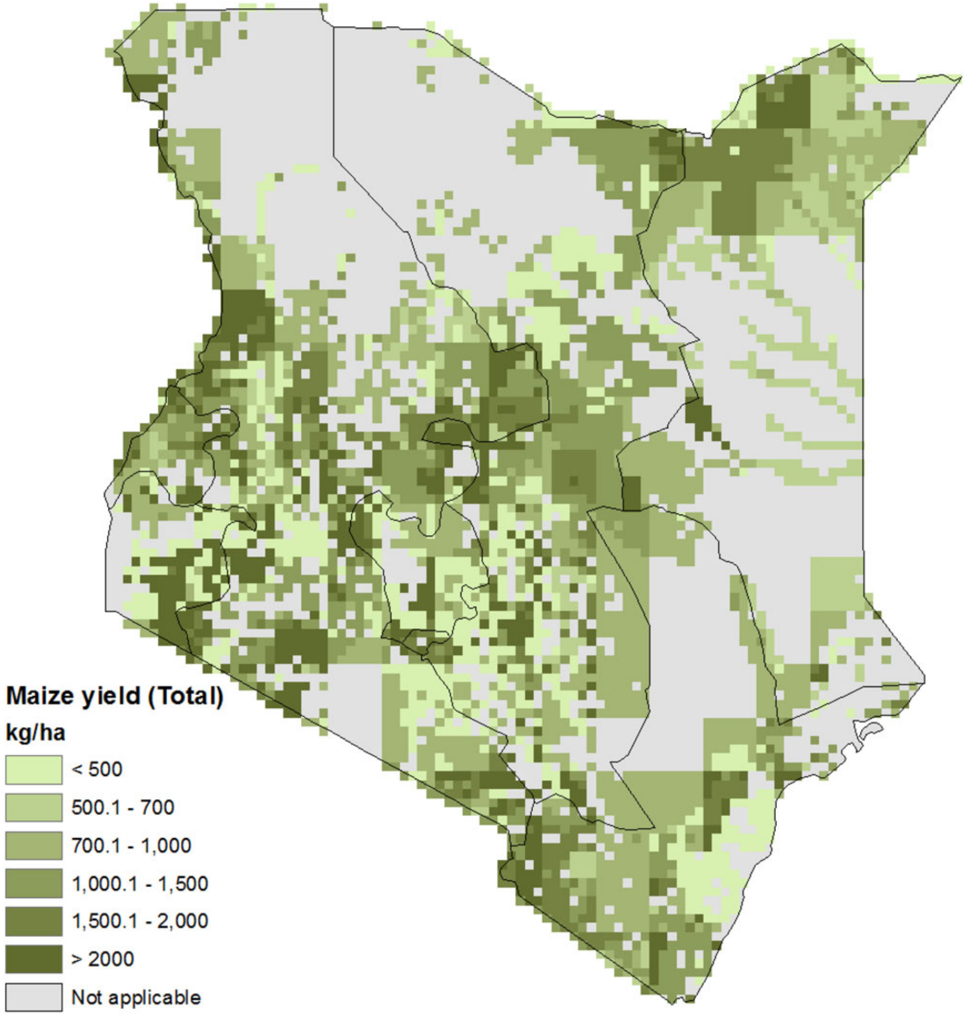
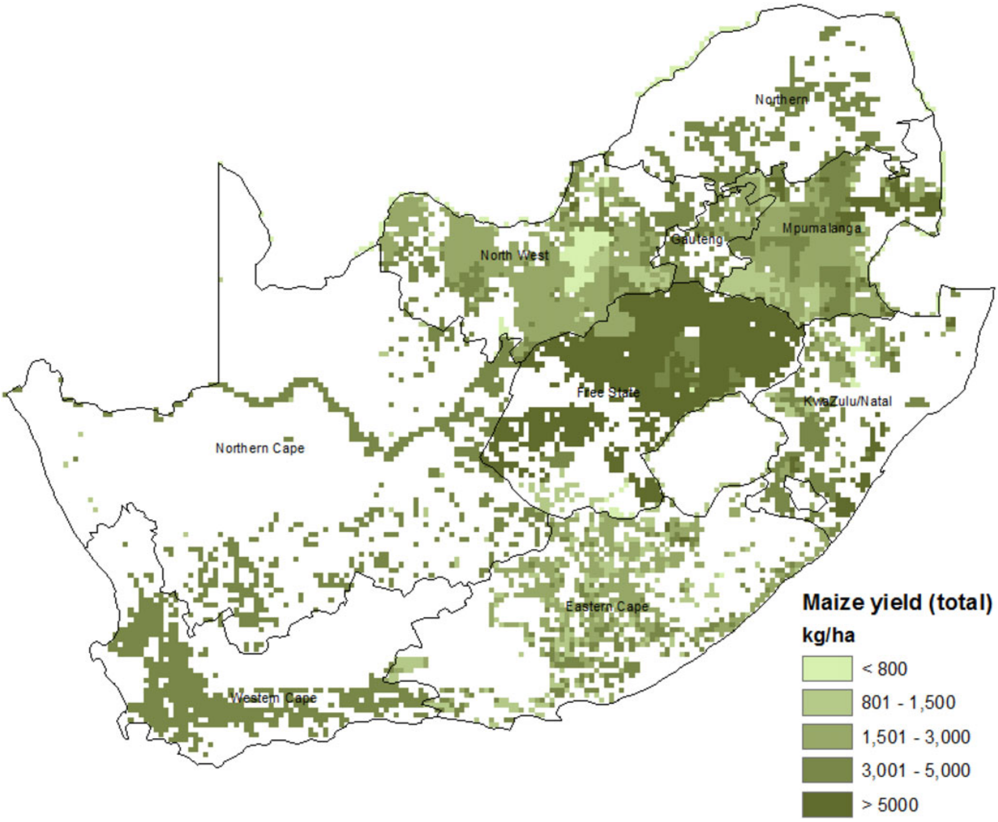
[7] The Western Transitional AEZ was not included in the analysis because its area in Kenya is very small and SPAM did not have enough information to allocate production data there.



Source: You et al (2000).

Figure 1. Kenya maize yields (kg/ha)

varying from 23 kg/ha/year up to 140 kg/ha/year in certain districts. Based on FAO fertilizer use and the district level reports, we use average fertilizer use rates of 55 kg/ha, 35 kg/ha, 65 kg/ha, and 20 kg/ha and fertilizer adoption in the high input, low input, irrigated, and subsistence production system, respectively. Based on FAO estimates, we assume that 95% of commercial farmers use fertilizer for simulations in high input and irrigated areas. We also assume that 70% and 60% of farmers use fertilizer in low input and subsistence areas, respectively, as South Africa has few small farmers and the highest use of fertilizer in Africa.

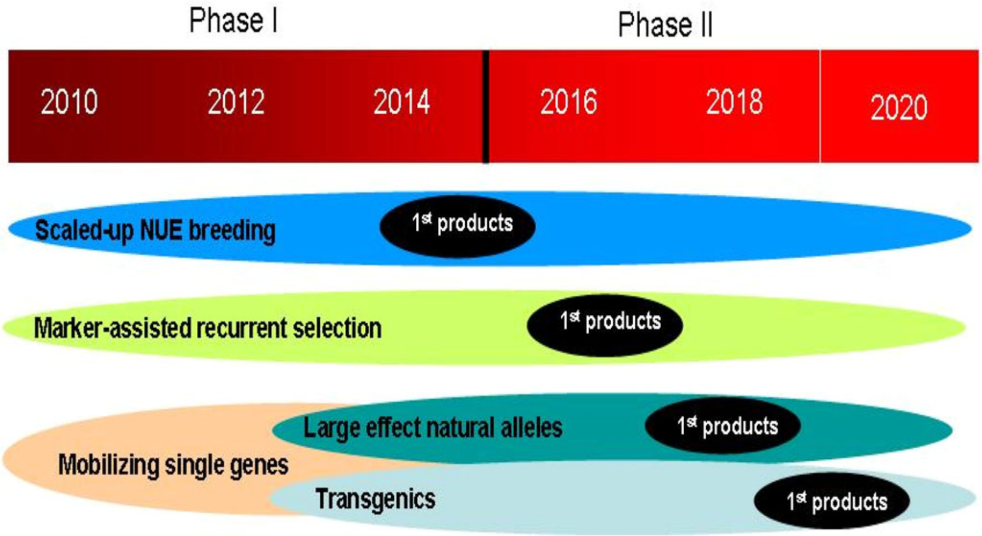


Source: You et al (2000).

Figure 2. Maize yields in South Africa (kg/ha)

Timeline of the IMAS Varieties

The IMAS project officially started in January 2010 and aims to deliver three types of fertilizer efficient maize varieties using a combination of techniques. First, IMAS varieties from CB selected for low nitrogen levels are expected to be in farmers' fields six years from the start of the project (Figure 3) generating yield gains of 16% on areas that use fertilizer at a rate of 0–29 kg/ha/year and 8% in areas where fertilizer use rate is 30–59 kg/ha/year (Table 3). In fact, the first generation of the IMAS varieties from CB is being tested on experiment stations and farmers' fields with yield gains of up to 30% compared to other varieties available to farmers (Tarekegne and Bisawanath 2013; CIMMYT 2014). Second, IMAS varieties from marker assisted selection applied to improved varieties from later stages of CB, which are anticipated to be available eight years from the start of the project, are expected to deliver 32% yield gains under low fertilizer use levels (0.29 kg/ha/year) and 16% yield advantage under higher fertilizer use levels (30–59 kg/ha/year). Finally, 13 years after the start of the project (i.e., in 2022) the first varieties from the use of transgenic



Source: Improved Maize for African Soils (IMAS) (2013).

Figure 3. Delivery timeline for development and delivery of nitrogen-use efficiency (NUE) maize varieties

Table 3. Yield advantage of IMAS varieties at different fertilizer use levels

	Percent yield gain for each fertilizer use level				
	Fertilizer use level (kg/ha)				
Year	0–29	30–59	60–89	>90	IMAS variety created with the outputs of the following crop improvement method
2016	16%	8%	3%	1.0%	Conventional breeding (CB)
2017	19%	10%	4%	1.1%	Conventional breeding (CB)
2018	24%	12%	5%	1.4%	MAS on early varieties from CB
2019	27%	14%	5%	1.6%	MAS on early varieties from CB
2020	32%	16%	6%	1.9%	CB and MAS
2021	33%	17%	7%	2.0%	CB and MAS
2022	34%	17%	7%	2.0%	CB and MAS
2023	35%	18%	7%	2.1%	CB and MAS
2024	40%	20%	8%	2.4%	Transgenic aided by CB and MAS
2025	53%	27%	11%	3.2%	Transgenic aided by CB and MAS

Source: Improved Maize for African Soils (IMAS) (2013).

methods are expected to be available at the farm level in Kenya and South Africa. The expected delay of the transgenics is due to meeting regulatory hurdles. Transgenics are expected to achieve even higher yield gains (40% in areas with fertilizer rates of 0–29 kg/ha/year and 20% in those with fertilizer application rates of 30–59 kg/ha/year).[8] As mentioned above, these rates are based on close consultation with the breeders that are working on the IMAS project and on expectations and projected outcomes of the project.

The IMAS project, during its initial stages (first six years) uses three complementary crop improvement methods to develop IMAS varieties, CB (the most basic method of breeding), and marker-assisted breeding (which is a biotechnology method that can make CB more effective and can shorten the results by more than half).[9] Finally, it will also use transgenic methods (genetic engineering methods which have proven to be very successful in the United States and other developed and developing countries) to develop IMAS varieties. The transgenic method will use successful genes from Pioneer's nitrogen-use efficiency pipeline which evaluates approximately 1,000 transgenic events yearly (CIMMYT 2012). Thus IMAS varieties are planned to be released at different times (as described in Table 3 and Figure 3) with latter varieties being more yield effective as the three crop improvement methods used to produce IMAS varieties are combined and improve results at an increasing rate. Our model assumes that farmers will adopt the new varieties and keep adopting other improved varieties as research becomes more effective and new, more productive varieties substitute others.

Advantage of IMAS Varieties versus Currently Grown Maize Varieties

The anticipated yield advantage of IMAS varieties from 2010 to 2025 at different levels of fertilizer use are the inputs for calculating the unit cost reduction in Equation (1). Table 3 compares the expected yield advantage of IMAS varieties to yields obtained with the varieties currently grown on farmers' fields in Kenya and South Africa. In our modeling, we assume that without IMAS, improved breeding will increase yields of current varieties at a rate of 1% per year.[10]

As mentioned, the IMAS varieties released will be improved from 2010 to 2025 through the use of CB at first, then MAS with CB and finally transgenic methods for the last two years.[11] The idea is that CB will generate varieties that can improve yields under low fertilizer levels, which will then be aided by MAS and then, toward the end of the project, transgenic methods will also be used to make them more effective and higher yielding. The last column of Table 3 indicates whether the variety is a product of CB, CB

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[8] Given that the regulatory process for transgenic crops is already in place in each country, transgenic varieties may finally become a reality in Africa. South Africa has already approved genetically modified crops and Kenya is taking important steps toward setting up the regulatory framework (for more details, see Gilbert 2011).

[9] For a good description of conventional and marker-assisted breeding, see Collard and Makill (2008).

[10] We contacted several CIMMYT breeders and the final estimates were provided by Dr. Gary Atlin (the associate director of the CIMMYT breeding program at the time) and other breeders. Generally, given the rate of improvement from other breeding programs, the assumption is that they will improve at a rate of 1% per year.

[11] Note that the lags for transgenics are almost completely due to the slow development of regulatory regimes. Transformations can be done quickly, and if not for the regulatory issues, transgenic varieties would be released much faster than the conventional varieties.

aided by MAS or transgenic methods, or a combination of the three methods to enhance and better select the most productive genetic material.

Adoption Rates

IMAS varieties are expected to follow similar adoption patterns as those of the DTMA varieties (see La Rovere et al 2010) during the next 15 years.[12] The adoption of IMAS varieties from CB in Kenya and South Africa is expected to start at 7% in 2017 and reach 10% by 2020 with the release of IMAS varieties from MAS from early CB varieties. From 2020, adoption rates are expected to grow by 2% per year and reach adoption rates of 20% by 2025. We need to mention that these are crucial assumptions for the *ex ante* estimates and they are provided by experts that are working in the IMAS project. Therefore, we also provide sensitivity analysis for the most critical assumptions used in our analysis; yield gains and adoption rates.[13]

Elasticities and Agricultural GDP

Supply and demand elasticities used in this study are taken from previously published studies. Kiori and Gitu (1992) estimated a demand elasticity of −0.4 and a supply elasticity of 0.68 for maize in Kenya. Omamo et al (2006) use a supply elasticity of 0.2 and a demand elasticity of −0.5. We use a value of demand elasticity of −0.5 based on Omamo et al (2006) and a supply elasticity of 0.4 (average of supply elasticities from the two studies) for Kenya. For South Africa we could not find recent elasticity estimates and use a demand elasticity of −0.42 for maize flour as estimated by Mabiso and Weatherspoon (2008), and a supply elasticity of 1 (Schimmelpfennig et al 1996).

AgGDP in South Africa is estimated at US$287 billion (CIA World Factbook 2009). Agriculture generates 3% in South Africa (CIA World Factbook 2009). We follow Fan et al (2008) and assume that the elasticity of AgGDP with respect to poverty reduction is 1.02 for South Africa (Eckert et al 1997).[14] In addition we use a population growth rate of 2.6% per year (UN 2010) for Kenya, and a poverty rate of 22% (World Bank 2010) and a population growth rate of 1.34% (Liebenberg and Pardey 2010) for South Africa.

Maize Prices

Maize prices for each district and AEZ in Kenya are shown in Table 4. The maize price used for South Africa is the average for the 2007–10 period and it is US$175 per Mt from the FAO Statistical Service (FAOSTAT 2009); this is the price used for all four maize production systems in South Africa.

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[12] The adoption rates of DTMA are based on expert opinion and surveys as described in detail in La Rovere et al (2010). These adoption rates were generated from experts with experience and knowledge of the seed industry in the two countries.

[13] We assume that adoption rates of small, medium, and large households are the same. This assumption is based on Doss et al (2003) who examined several microlevel adoptions studies in several Eastern African countries, including Kenya, and concluded that the adoption of improved varieties is not correlated with farm size.

[14] An elasticity of poverty with respect to AgGDP of one means that a 1% change in AgGDP reduces the number of poor by 1%.

Table 4. Maize price (KSH/90 kg bag) 2009 and 2010 in Kenya

Town	District	Zone	2009	Jan–July 2010
Nairobi	Nairobi	Central Highlands	2,600	1,890
Mombasa	Mombasa	Coastal lowlands	2,030	1,665
Kisumu	Kisumu	Western Lowlands	2,533	1,824
Eldoret	Uasin Gishu	High Potential maize zone	2,762	1,627
Nakuru	Nakuru	High Potential maize zone	2,640	1,696
Kisii	Kisii	Western Highlands	2,400	1,786
Nyahururu	Nyandarua	Central Highlands	2,700	1,505
Taveta	Taita/Taveta	Eastern Lowlands	2,600	1,789
Kitui	Kitui	Eastern Lowlands	2,700	1,440
Machakos	Machakos	Eastern Lowlands	2,700	1,731
Malindi	Malindi	Coastal lowlands	2,700	n.a.
Namanga	Loitok tok	Eastern Lowlands	2,800	1,083
Meru	Meru	Central Highlands	n.a.	1,238
Thika	Thika	Central Highlands	n.a.	1,500
Embu	Embu	Central Highlands	n.a.	1,575
Busia	Busia	Western Lowlands	n.a.	1,700
Kakamega	Kakamega	Western Lowlands	n.a.	2,000

Source: Ministry of Agriculture in Kenya.
Notes: Exchange rate in 2009 was 77 Ksh for $1US dollar. N.A. = no figures were available.

Household Data

We use household data to create different representative maize-producing households based on household surveys conducted by the Insect Resistant Maize for Africa project as shown in Table 5 for Kenya. We create three household types; small, medium, and large households, based on farm acreage for each district. In addition, the AEZ is known so that we can have representative households for each AEZ in Kenya.

Household data are not available for South Africa so the analysis is limited to the aggregate production system level and to the national level as described above.

A summary of the main data used in the model is provided in Table A1 of the Appendix.

RESULTS

Changes in producers' and consumers' surpluses from the introduction of IMAS varieties for each AEZ in Kenya are presented in Table 6.

Changes in producers' surplus vary noticeably across different AEZ in Kenya based on the level of fertilizer use in each zone. Production areas in the Coastal Lowlands, Eastern Lowlands, and Western Lowlands benefit the most from the IMAS varieties as they have the lowest level of fertilizer use (0–30 kg/ha), followed by maize production areas in the Marginal Rain Shadow. Maize producers in the other AEZ, by contrast, receive moderate benefits from the IMAS varieties as they already use relatively higher levels of fertilizer. Based on the parameters employed in this study, with no population

Table 5. Kenya–Maize area and production per representative small, medium, large households

			Maize production (kg)			Maize area (acres)		
		Observations	Small	Medium	Large	Small	Medium	Large
HP	Bomet	48	1,381	–	3,810	0.89	–	15.73
CL	Kilifi	90	897	1,360	1,815	1.59	6.5	13
CL	Kwale	105	597	1,043	4,605	1.55	7.86	10.5
EL	Machakos	114	1,568	8,472	5,517	2.31	7.05	308.67
EL	Makueni	77	1,391	1,120	1,005	1.72	8.22	15
CL	Malindi	75	629	543	1,118	2.04	7.63	14.06
HP	Mt. Elgon	12	1,334	3,510	–	1.45	8.5	15
EL	Mwingi	40	1,065	833	1,398	1.88	6	700
HP	Nakuru	160	1,324	9,660	–	1.06	7	270.2
HP	Trans Nzoia	96	1,594	8,730	32,150	1.02	–	1,268.5
WL	Bondo	10	1,849	–	–	1.85	–	–
HP	Bungoma	38	1,099	–	–	1.37	–	–
HP	Bureti	48	2,208	24,300	1,080	1.19	9	1,080.5
WL	Homa Bay	16	995	1,105		1.61	6	–
WH	Kakamega	28	1,116	–	6,255	1.33	–	12
HP	Keiyo	32	2,412	5,310	–	1.15	5.7	–
HP	Kericho	32	1,714	–	–	1.46	–	–
CH	Kirinyaga	20	864	14,670	–	1.22	8	–
WH	Kisii	35	2,694	–	–	0.92	–	–
WL	Kisumu	18	3,093	4,809	–	1.73	6.93	
EL	Kitui	48	1,075	1,665	788	1.94	9.03	67.5
MR	Koibatek	48	1,629	–	540	1.35	–	–
WL	Kuria	24	2,121	8,730	–	1.58	7	
HP	Lugari	25	813	–	–	1.31	–	–
CH	Maragua	20	864	450	–	0.76	6	
HP	Marakwet	16	2,774	–	–	1.22	–	–
EL	Mbeere	8	386	450	–	2.68	7	–
CH	Meru Central	30	3,899	–	–	1.03	–	–
CH	Meru North	10	663	–	–	1.25	–	–
CH	Meru South	10	279	–	–	0.4	–	–
WL	Migori	36	884	2,160	–	1.29	–	–
CL	Mombasa	30	708	1,815	1,800	1.47	6	–
CH	Muranga	20	559		4,050	1.1	–	–
HP	Nandi north	48	3,438	10,800	3,960	2.24	5.4	–
HP	Nandi south	32	2,086	–	–	1.07	7.85	102.5
WH	Nyamira	23	547	–	–	1.06	–	–
WL	Nyando	12	328	–	–	2.44	–	–
CH	Nyeri	30	488	–	–	0.57	–	–
WL	Rachuonyo	23	777	970	–	1.36	–	–
WL	Siaya	30	783	2,970	–	1.38	5.25	–
WL	Teso	34	1,722	–	–	1.54	5.25	–
CH	Tharaka	8	1,966	–	1,140	1.71	–	–
CH	Thika	5	1,143	–	18,000	1.06	–	303

(*Continued*)

Table 5. Continued

			Maize production (kg)			Maize area (acres)		
		Observations	Small	Medium	Large	Small	Medium	Large
HP	Uasin Gishu	80	3,219	–	–	1.03	6	18
WH	Vihiga	7	527	–	–	0.59	–	–
MR	West Pokot	10	1,665	–	–	1.12	–	–

Note: "—" Means information missing or not applicable.

growth, the IMAS project expects to generate a total US$248 million by 2025 in Kenya. Producers benefit slightly more than consumers across all AEZ. Producers in maize producing areas with low levels of fertilizer use benefit the most from the technology. While most producer benefits will accrue to those with lower levels of fertilizer use, technology benefits are expected to be more equally distributed among consumers across the country.[15]

With population growth, the IMAS benefits would generate a total of US$279 million, or 13% more than when not factoring for population growth in Kenya. US$248 million can therefore be attributed specifically to the development of IMAS varieties.

Adopting household benefits for representative small, medium, and large scale households from different districts across Kenya are presented in Table 7. Two factors are the main determinants of the size of benefits to the households. The first is level of fertilizer use, with more gains associated with lower levels of fertilizer use. The second is the size of the maize planted area, with larger areas resulting in higher benefits. For example, small, medium, and large households situated in the Machakos (Eastern Lowlands), Bondo (Western Lowlands), and Kisumu (Western Lowlands) districts would benefit the most as they currently use low levels of fertilizer compared to their counterparts in other areas. Some households, such as those in High Potential maize zone and Western Highlands will benefit very little, as they are applying relatively higher fertilizer rates. The magnitude of these benefits in the low fertilizer use AEZ is considerable especially when taking into account that the average annual income for the 1997–2007 period of a household in Kenya was US$1,490 (Suri et al 2008) but varies markedly across agroecologies with US$744 in the Western Lowlands to US$2,070 in the High Potential maize zone.

Finally, we also estimate the number of people that might be expected to escape poverty as a result of IMAS project benefits. The results, shown in Table 7 suggest that about 71,000 poor households or 497,000 poor (assuming households have seven family members) would escape poverty by 2025 from the adoption of IMAS varieties. These households are among the poorest and reside in areas with low fertilizer use and small farm size.

We also estimate the net present value of the benefits from a potential adoption of IMAS varieties in South Africa under each maize production regime (Table 8).

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[15] Data on consumption by AEZ are not available to calculate the market clearing conditions for each AEZ. So the model assumes no trade between AEZ.

Table 6. Producer and consumer benefits and number of poor households lifted out of poverty from IMAS in Kenya by 2025–no population growth

Agroecological zone	Producer surplus (present value thousands $)	Consumer surplus (present value thousands $)	Number of households lifted out of poverty by 2025
No population growth			
Coastal Lowlands	23,941	19,153	8,450
Eastern Lowlands	47,193	37,754	18,027
Western Lowlands	41,719	33,375	5,876
High Potential Maize Zone	1,569	1,255	–
Western Highlands	1,246	997	3,860
Central Highlands	818	654	–
Marginal Rain Shadow	19,188	18,488	34,525
Total	135,675	111,677	70,738
With population growth			
Coastal Lowlands	28,308	21,212	8,450
Eastern Lowlands	55,800	41,813	18,027
Western Lowlands	49,328	36,964	5,876
High Potential maize zone	1,858	1,393	17,326
Western Highlands	1,476	1,106	3,860
Central Highlands	968	726	–
Marginal Rain Shadow	19,188	18,488	34,525
Total	156,926	121,703	88,064

Note: A 5% discount rate is used.

Results (with no population growth) suggest that a total of US$338 million will be generated for producers and consumers in South Africa, with consumers receiving 82% of the benefits. Most benefits will be generated in high potential production areas followed by the low input areas. This distribution is different from the benefits in Kenya, where producers gain most of the benefits due to a more elastic supply (1 vs. 0.4 in Kenya) in South Africa. When factoring for population growth the benefits total US$380 million. In terms of poverty reduction, 521,000 people are expected to escape poverty by 2025 due to IMAS in South Africa.

Considering that the IMAS project investment is US$17 million, the rate of return of the project is several times the initial investment.[16] Thus, based on the parameters employed in this study the IMAS project seems an attractive investment in agricultural research in sub-Saharan Africa.

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[16] The direct cost of the IMAS project is US$17 million but there are other costs related to the selection and breeding for these varieties (that started well before the IMAS project). Thus, these results should be interpreted with caution as they represent upper bound estimates on returns.

Table 7. Household benefits in Kenya by 2025 (present value, US$)

AEZ	District	Benefits by farm type Small scale	Medium scale	Large scale
HP	Bomet	17	–	48
CL	Kilifi	143	216	288
CL	Kwale	95	166	732
EL	Machakos	327	1,768	1,151
EL	Makueni	290	234	210
CL	Malindi	100	86	178
HP	Mt. Elgon	100	86	178
EL	Mwingi	222	174	292
HP	Nakuru	17	122	–
HP	Trans Nzoia	20	110	406
WL	Bondo	367	–	–
HP	Bungoma	14	–	–
HP	Bureti	28	307	14
WL	Homa Bay	197	219	–
WH	Kakamega	13	–	70
HP	Keiyo	30	67	–
HP	Kericho	22	–	–
CH	Kirinyaga	11	178	–
WH	Kisii	30	–	–
WL	Kisumu	613	953	–
EL	Kitui	224	347	164
MR	Koibatek	148	–	49
WL	Kuria	420	1,731	–
HP	Lugari	10	–	–
CH	Maragua	11	5	–
HP	Marakwet	35	–	–
EL	Mbeere	81	94	–
CH	Meru Central	47	–	–
CH	Meru North	8	–	–
CH	Meru South	3	–	–
WL	Migori	175	428	–
CL	Mombasa	112	288	286
CH	Muranga	7	–	49
HP	Nandi north	17	122	–
HP	Nandi south	43	136	50
WH	Nyamira	–	–	–
WL	Nyando	6	–	–
CH	Nyeri	65	–	–
WL	Rachuonyo	6	–	–
WL	Siaya	154	192	–
WL	Teso	155	589	–
CH	Tharaka	341	–	–
CH	Thika	24	–	14

(*Continued*)

Table 7. Continued

AEZ	District	Benefits by farm type Small scale	Medium scale	Large scale
HP	Uasin Gishu	14	–	219
WH	Vihiga	41	–	–
MR	West Pokot	6	–	–

Notes: "–" Means information missing or not applicable. We use a 5% discount rate.

Table 8. Producer and consumer benefits from IMAS in South Africa by 2025 growth (present value, thousand US$)

Production area	Producer surplus (present value thousands $)	Consumer surplus (present value thousands $)
No population growth		
High Potential	50,653	120,604
Low Potential	39,272	93,505
Irrigated	4,166	9,918
Subsistence	5,998	14,280
Total	100,089	238,307
With population growth		
High Potential	58,134	133,892
Low Potential	45,057	103,781
Irrigated	4,782	11,018
Subsistence	6,881	15,849
Total	114,855	264,541

Note: A 5% discount rate is used.

CONCLUSIONS

This study estimates the potential benefits from introducing IMAS varieties in Kenya and South Africa during the next 15 years for each AEZ. Our estimates suggest that a total of US$248 million in Kenya and US$338 million in South Africa—for both consumers and producers—will be generated and are directly attributable to IMAS, particularly for those producers located in areas with low levels of fertilizer use. In South Africa, consumers will be receiving most (82%) benefits, with most benefits generated in the high potential production areas. When adjusted for expected population growth, the benefits would total US$279 in Kenya and US$379 million in South Africa. In terms of poverty, more than 1 million poor are expected to escape poverty in Kenya and South Africa. Using district level household data, we also find considerable benefits at the household level especially in AEZ where fertilizer use is very low, which are generally very poor areas.

Given the initial costs of the IMAS project, we find that the returns are several times higher than the initial investment making IMAS varieties an attractive area for continued research. The rate of return is similar to investments in drought resistant maize (La Rovere et al 2010) and drought resistant wheat (Kostandini et al 2009) in sub-Saharan Africa. IMAS varieties may also reduce hunger across the poorest households whose consumption relies heavily on their maize production. This could be an area for future research.

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APPENDIX

Table A1. Main parameters employed in the model

Parameter	Kenya	South Africa
Adoption rate 2017–25	0–20%	0–20%
Demand elasticity	−0.4	−0.42
Supply elasticity	0.5	1
Maize price	US$175/Mt	See Table 4
Agricultural GDP	–	US$287 billion
Elasticity of Ag. GDP with respect to poverty reduction	–	1.02
Population growth rate	2.6%	1.34%
Poverty rate	US$1490 annual poverty line	22%
Fertilizer yield gains	Table 3	Table 3

Note: All sources for these parameters are listed in the methods section.