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Economic impact of DroughtTEGO® hybrid maize in Kenya

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This paper utilizes the Economic Surplus Model (ESM) to provide an *ex-post* evaluation of the economic impact of drought tolerant hybrid maize technology in Kenya. Results indicate that the adoption of DroughtTEGO® varieties will generate economic benefit to producers with a net present value of US$ 2.1 billion over a 20-year period. These benefits are sustainable when adoption levels remain above 32% and yield advantage at least 21% over the commercial hybrids. These results present a compelling reason for investing in development, deployment and upscaling of the technology to mitigate the effects of drought among maize producers in Africa.

Key words: Adoption, climate-smart, DroughtTEGO®, drought mitigation, economic impact, economic-surplus model.

INTRODUCTION

Farming in most parts of Sub-Saharan Africa (SSA) is often associated with low productivity and declining yields because of challenges such as drought, declining soil fertility and low adoption of improved technology amid serious pest infestation and disease prevalence. All these constrain crop production and productivity with serious consequences on millions of farmers whose livelihood dependency on agriculture is not disputable (Jayne et al., 2014). Particularly, drought is a phenomenon of immense economic importance due to its direct link with crop yield variability and grain price spikes with serious consequences on food security and poverty (Esper et al., 2017; Kim et al., 2019). Although droughts and other extreme weather events are not a new phenomenon in Africa, their frequencies have increased in the past three decades as a result of climate change (Verschuren et al., 2000; Willy and Kuhn, 2016). Kim et al. (2019) estimated that globally, droughts caused an average of 8, 7 and 3% yield losses in wheat, maize and soybean respectively per drought event between 1983 and 2009,

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corresponding to 0.29, 0.24 and 0.15 t ha^{-1}. These losses are likely to increase in the future as droughts become more prevalent as a result of climate change induced global warming (Hahn et al., 2009; Trenberth et al., 2014).

To mitigate the impact of drought, farmers have a score of options at their disposal including improved crop management practices as well as growing of crop varieties that are tolerant to drought and adapted to low-moderate rainfall conditions. Improved management practices include, but are not limited to, in-situ water conservation techniques, early planting, cover crop/mulching and minimum tillage all which help to conserve available water resources for the benefit of crops. Most of these practices have been packaged in what is popularly known as conservation agriculture (CA) which has been lauded for its potential to increase crop yields under drought conditions as well as generate immense environmental benefits (Hobbs et al., 2008). Although these management practices have a great potential to mitigate the risk associated with drought, their benefits may be limited if not accompanied by growing of crops with improved geneticpotential for drought tolerance.

Historical efforts in agricultural research have demonstrated that reduction in yield variability can be guaranteed without compromising yield levels (Birthal et al., 2012). Particularly, the development of climate-smart drought-tolerant varieties has the potential to enhance the capacity of crops to withstand water stressed conditions while at the same time improve crop productivity and efficiency in the utilization of limited soil moisture. Drought tolerance traits have been introduced in a score of crops such as groundnuts, maize, sorghum, millet, rice and cassava among others.

Maize is particularly an important cereal crop for many rural agrarian households in SSA where over 300 million people derive their livelihoods from the crop (Ekpa et al., 2018). Maize is also an important crop for food and nutrition security, because it accounts for approximately half of the calorie consumption in Eastern and Southern Africa, and twenty percent in West Africa (Macauley and Ramadjita, 2015). Despite the importance of maize in Africa, its yields are perpetually impacted by drought (Rezende et al., 2020) putting maize dependent livelihoods at risk.

In a bid to mitigate the negative impact of drought on maize yields, many drought tolerance technologies have been developed and disseminated in the region. One of the most promising drought tolerance technologies was developed through the Water Efficient Maize for Africa (WEMA) Project partnership. The WEMA project was implemented by the African Agricultural Technology Foundation (AATF) and its partners including the National Agricultural Research Systems (NARS) in six African countries in Eastern and Southern Africa (Ethiopia, Kenya, Mozambique, South Africa, Tanzania, Uganda) between 2008 and 2017. This collaborative effort led to the development and release of several conventional hybrids that are drought-tolerant and adapted to low-to-mid altitude agro-ecologies in the target countries. The conventionally bred drought-tolerant varieties developed under the WEMA initiative are currently marketed under the DroughtTEGO® brand and have the potential to enhance maize productivity in drought-prone areas for improved livelihoods, particularly among resource-limited smallholder farmers (Beyene et al., 2015, 2016; Edge et al., 2018; Oikeh et al., 2015; Rezende et al., 2020). Over 70 DroughtTEGO® maize hybrid varieties with average yield of 4.5 tons/ha were released in Kenya for commercialization. Since their release, the adoption and diffusion of the varieties have been steady with hybrid WE1101 being the most popular (Macharia et al., 2017; Muinga et al., 2019). The varieties have expressed an average yield advantage of 53% above commercial hybrids in Kenya (Obunyali et al., 2019). The physiology of the DroughtTEGO® varieties enables the plant to utilize less water to build biomass, an attribute that is lacking in many of the commercial hybrids, which do not have the capacity to withstand water stress conditions. Moreover, when considering the National average maize yield for Kenya, the DroughtTEGO® varieties have a 150% yield advantage (Obunyali et al., 2019). An evaluation by Marechera et al. (2019) indicates that the DroughtTEGO® varieties are associated with higher productivity, maize incomes and total household income leading to lower poverty levels. This is consistent with findings from similar studies such as Birthal et al. (2012), Martey et al. (2020) and Simtowe et al. (2019) who reported that drought tolerant crop varieties increase yields, reduce probability of crop failure and also reduce inter-seasonal yield variation hence a great potential for poverty eradication.

Against this backdrop, the current study utilized parameters generated from primary and secondary data to estimate the economic benefits associated with the adoption of DroughtTEGO® hybrid maize varieties for a 20-year period (2017-2036). Sensitivity analysis was also conducted to determine the conditions under which these benefits can be sustained. Given the importance of the maize crop to national and regional food security, the importance of studies that assess the impact of technologies such as DroughtTEGO® cannot be over emphasized.

The aggregate economic impact assessment on drought tolerance technologies is critical for several reasons. First, the assessments are important for accountability for the use of scarce public funds in the research and development of such technologies; Second, the assessments are intended to inform policy makers about the likely magnitude and distribution of pay-offs of the technologies under evaluation; Third, the results can allow scientists and policy makers to better judge the importance of upscaling the technology to other countries. Despite the importance of such studies, there are few attempts found in literature to estimate the aggregate impacts of drought tolerant technologies especially among African farmers. A study by Kostandini et al. (2009) provides an ex-ante assessment of the benefits of transgenic drought tolerance technology at regional level while that of La Rovere et al. (2010) estimates the economic benefits of Drought Tolerant Maize for Africa (DTMA) for 13 countries in Eastern, Southern and Western Africa. Whereas these studies provide critical insights on the contribution of both transgenic drought tolerant varieties and those emanating from conventional breeding, the current study builds further to these contributions in two ways: First, the current study provides empirical evidence of the economic impact of conventionally developed DroughtTEGO® technology at both county and national levels using the DREAM model, a type of Economic Surplus Model, and data from farmer managed fields compared to field data as commonly used by other studies. Secondly, the current study considers intra-country variations in agro-ecological conditions, and therefore, provides an estimation of economic benefits accruing to farmers at different regions within Kenya. This broader assessment is seen as a catalyst that could strengthen the relevance of dissemination of these technologies to other parts of SSA with similar maize production constrains.

CONCEPTUAL FRAMEWORK

The current paper estimates the economic benefits associated with adoption of DroughtTEGO® maize varieties that have drought tolerance traits. Aggregate benefits at national level are the sum of benefits accruing to individual producers and consumers in the economy as a result of adoption of the technology. Producer benefits accrue as a result of supply shifts associated with technological change while consumers benefit from changes in market prices. However, in an open economy, consumers and farmers are price takers and therefore the foreseen benefits only accrue to producers as a result of reduction in yield variability leading to changes in overall output. Maize farmers are assumed to be rational, making production and consumption decisions simultaneously to optimize their objective functions: farm profits and household utility. Farmers allocate their scarce resources within an environment that is defined by technology, institutions, markets (domestic and international), public goods and policy (Sadoulet and de Janvry, 1995). They also face yield and market risks associated with drought and exogenous price dynamics in domestic and international markets. In this case, farmers can only control the risks associated with drought, through the adoption of strategies that can minimize drought related intra-plot yield variability. The adoption of varieties with drought tolerance attributes (such as the DroughtTEGO®) is expected to shift the supply curve outwards hence increase the producer surplus, consequently improving their welfare. Estimation of the changes in producer surplus and therefore the economic benefits associated with DroughtTEGO® varieties can therefore be used as an effective means of demonstrating the economic impact attributable to the technology.

The estimation of the impact of DroughtTEGO® varieties as described here needs to address two fundamental challenges that are often encountered in this type of analysis. First, it is usually difficult to establish causality between the intervention and the final impact as it is often difficult to link the intervention with the end results. Secondly, it is challenging to establish a realistic counterfactual that will give a reference point for the situation without intervention. This is crucial because impact is defined as the difference between the situation without intervention and the situation after intervention. To overcome these challenges in the current study, the percentage yield benefits associated with the DroughtTEGO® technology were estimated using Propensity Score Matching (PSM) procedure, which helps to find perfect matches for each adopter among the non-adopters hence taking care of the challenge of finding a reliable counterfactual. Further, the study utilized clearly and explained assumptions drawn from comprehensive and reliable data sources.

METHODOLOGY

Analytical framework

The current study focuses on estimating the welfare effects of adoption of drought tolerant hybrid maize varieties (DroughtTEGO®) at regional (County) and National level in a small open economy. The study utilizes the Economic Surplus Model (ESM) which was preferred due to its ability to estimate impacts at sector level and beyond; and because it is widely used to evaluate impact of similar technologies due to its less restrictive assumptions and minimum data requirements (Alston et al., 1995). The ESM is the most common approach for the evaluation of the effects of such technologies as it uses a partial equilibrium approach to estimate the net benefit attributable to technologies and the distribution of such gains between producers and consumers, expressed as changes in producer and consumer surplus (Alston et al., 1995). Several studies have used this ESM and, in some cases, variants of the model to predict the economic impact of agricultural technologies (Alene et al., 2009; Alston et al., 1995; De Groote et al., 2011; Krishna and Qaim, 2008; Kristjanson et al., 1999; Napasintuwong and Traxler, 2009). Kostandini et al. (2009) and La Rovere et al. (2010) have followed these approaches to estimate the economic benefits of drought-tolerant crop varieties.

Several spreadsheet templates for ESM are available for economic surplus computation including: 1) MODEXC, originally developed by International Centre for Tropical Agriculture – CIAT (Lynam and Jones, 1984); 2) RE4, developed by the Australian Centre for International Agricultural Research – ACIAR (Davis et al., 1987); and 3) Dynamic Research EveluAtion for Management (DREAM) developed at ISNAR/IFPRI (Alston et al., 1995). In the current study, DREAM model was used because of its robust nature and wide applications in similar studies (Chepchirchir et al., 2018; Lusty and Smale, 2003; Macharia et al., 2012; Macharia et al., 2005; Pachico, 1998). Again, DREAM is designed to assess the benefits of technical change in a broad range of policy, market, technology, and adoption conditions. The DREAM model assumes that technology adoption leads to an outward shift in the product's supply curve that triggers a process of market-clearing adjustments in one or multiple markets affecting the flow of the final benefits to producers and consumers (Alston et al., 1995). The changes in producer and consumer surpluses as a result of technology adoption are captured in Equation 1:

$$\Delta PS_{i,t} = (k_{i,t} + PP^R_{i,t} - PP_{i,t})\left[Q_{i,t} + 0.5(Q^R_{i,t} - Q_{i,t})\right]$$

where *ΔPS* is the producer benefits that are attributable to the technology, PP^R and *PP* are producer prices with and without technology, Q^R and *Q* are the aggregate annual production with and without technology. $k_{i,t}$ is the realized supply curve shift (reduction in the per unit cost of production) and measures the downward shift of the supply curve attributable to technical change in region i and time t. Thus, the producer experiences a change in income due to a lower production cost per unit. These series of benefits can be converted into present value totals by conventional discounting techniques. The present value of producer surplus is computed as follows:

$$VPS_i = \sum_{t=0}^{20} \Delta PS_{i,t} / (1+r)^t$$

$$= \Delta PS_{i,0} + \Delta PS_{i,1}/(1+r) + \Delta PS_{i,2}/(1+r)^2 + ... + \Delta PS_{i,20}/(1+r)^{20}$$

where, VPS_i refers to the present value for producer surplus, for region i; and r is the discount rate. After estimating the benefits associated with the DroughtTEGO® technology, it was imperative that we assess the viability of the investment. This was achieved using three commonly used methods: net present value (NPV), internal rate of return (IRR), and benefit-cost ratio (BCR). The NPV is defined as the sum of the present values of the cumulative cash flow induced by an investment generated over a defined time period. Costs and benefits of the technology that occur in future periods are discounted using the formula:

$$NPV = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+r)^t}$$

where, B_t is benefits of the technology, C_t represents the technology costs, r is the discount rate, and n is time periods for which the technology will be implemented. A technology project is profitable and acceptable if the NPV exceeds zero.

The IRR is the discount rate r^*, at which the project's NPV equals zero. Thus, the IRR is a measure of the actual investment efficiency regardless of the discount rate. A project is deemed acceptable when the IRR exceeds the prevailing interest rate.

$$NPV = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+r^*)^t} = 0$$

The third investment criterion used to measure the efficiency of investment is the benefit-cost-ratio (BCR). Its computation is like that of the NPV but is expressed as a ratio of the sum of a project's discounted benefits to the sum of the project's discounted costs. A project is deemed to be acceptable, if the BCR is greater than or equal to one.

$$BCR = \frac{\sum_{t=0}^{n} \frac{B_t}{(1+r)^t}}{\sum_{t=0}^{n} \frac{C_t}{(1+r)^t}}$$

Data on economic surplus parameters

The parameters required in the DREAM model include: (1) "equilibrium" quantities and prices, to define the size and structure of the market under consideration at a specified point in time; (2) evidence of how the technology will change either producers' cost structures or consumers' willingness to pay for different products where the technology will be adopted (the K factor); (3) adoption rate; (4) economic parameters on the market response to change (elasticities of both supply and demand), to predict how producers and consumers will react to new prices generated by market forces; and (5) research and extension costs incurred in obtaining the new technology. Wood et al. (2001) provide the operational guidelines for using DREAM model as well as the underlying concepts and analytical steps. This section now proceeds to provide a description of the data used and sources and the data/assumptions used in the Model are presented in Table 1.

Primary household data that was needed for generation of some of the model parameters were collected from 642 maize farmers in Kenya. The farmers were randomly and proportionally sampled from five regions in Kenya: Western, South Rift, Central Highlands, Upper Eastern and Lower Eastern (Figure 1), where DroughtTEGO® varieties were commercialized. These regions also represent different agro-ecological conditions (Obunyali et al., 2019). The number of farmers interviewed in each region was determined by the maize production statistics in the area and the population (Table 1). At the sub-county level, one administrative location was selected purposively, and villages selected with the help of field staff and county officials. Data collected included Maize production and marketing variables, gender, age and education level of farmer, household size, and membership of a farmers' organization. Additional information collected was access to extension services, and knowledge of varieties planted by each farmer. Farm-level variables collected included size of the farm, area allocated to maize production, crops grown, soil quality, distance of irrigation water source, type of maize seeds used by farmers, access to information on DroughtTEGO® maize seeds, methods of technology transfer; and advantages and drawbacks of using DroughtTEGO® maize seeds and household food consumption.

Secondary data used in the model estimation were collected from different sources. The total annual average maize production in Kenya for the year 2017 was obtained from the Ministry of Agriculture, Livestock, Fisheries and Cooperatives, who estimated the value at about 3,688,500 tonnes, and the area under maize production at 2,215,023 ha, resulting in maize productivity of 1.47 tons/ ha. Estimates from actual seed production and sales obtained from AATF indicated that as at 2019, the seed sales for the DroughtTEGO® varieties was approximately 4,000 tons, implying that the varieties had been planted on approximately 7% of the total maize area in Kenya. Kenya's per capita maize consumption is estimated at 103 kg/person/year (CIMMYT, 2015).

The analysis must also consider realities on the level of production and consumption. Maize production estimates at County

Table 1. Major data and assumptions for the DREAM model.

Parameter	Bomet	Vihiga	Migori	Kakamega	Nyeri	Machakos	Kenya	Source
Population (000)	876	590	1,116	1,868	759	1,422	47,564	KNBS, 2019
Number of households interviewed	102	75	135	60	170	100	642	Field survey
Quantity of production (1,000 tons)	74.7	64.5	103.9	259.0	29.7	92.0	3,688	MOALF, 2017, Field survey, FAO (2017)
Consumption quantity (1,000 tons)	73.4	47.46	92.8	168	32.67	103.04	5,016	MOALF, 2017, Field survey, FAO (2017)
Price of maize ($/tonne)	176	186	165	146	216	225	198	Field survey, FAO (2017),
Yield change (%)	17	27	57	37	52	54	42	PSM analysis, Obunyali et al. (2019)
Maximum adoption level (%)	65	65	65	65	65	65	65	Estimates from expert opinion and duration model analysis
Discount rate (%)	10	10	10	10	10	10	10	CIA, (2020)
Research costs (million US$)	6.4	5.7	7.7	12	6.7	9.8	99	AATF finance office

1US$= 102 Kenya shillings (https://www.centralbank.go.ke/forex/).

level indicate that most of the counties are not maize sufficient as the annual consumption requirement is higher than production. The major maize surplus counties in Kenya are Bungoma, Nandi, Elgeyo Marakwet, Kakamega, Migori, Kisii, Nakuru, Kericho, Uasin-Gishu and Trans Nzoia (Owuor, 2019). These areas account for about 95% of the total marketed maize in Kenya. Deficit counties who rely on maize imports include Nyeri, Machakos and Murang'a. The Counties included in this study were drawn from the two categories. Since Kenya is a maize deficit country - and almost all maize produced is consumed locally, with about 0.1% export and 31% import (FAO, 2019), a small open economy model is assumed to assess the overall benefits and their distribution. The analysis at county level also assumes a small exporting/importing economy model since they can sell to or buy from their neighbouring counties. The national and world maize prices were obtained from the FAO Statistical Database (FAO, 2017). Import parity price for maize from East Africa was utilized, while that for farm level was gathered through household surveys. County and National level prices were adjusted for internal transportation and marketing. All price data were specified in Kenya shillings and converted into US dollars (US$) using the average exchange rate during the survey (2017) of 1 US$=102 Kenya Shillings.

The potential yield benefits were obtained using the Propensity Score Matching (PSM) procedure using household data. It is important to note that impact evaluation is fundamentally concerned with causal inference, whereby we seek to measure profit or benefits for "treated", that is, individuals that have adopted DroughtTEGO® relative to what the outcomes would have been if they never adopted the DroughtTEGO® varieties. Since it is impossible to observe adopters (treated) as non-adopters (untreated) and vice versa, PSM was utilized. The basic concept of the PSM is to match observable characteristics of both adopters and non-adopters according to the estimated propensity score (Rosebaum and Rubin, 1983). The PSM procedure creates conditions of randomized experiment designs to evaluate a causal effect as in a controlled experiment. The idea is to compare individuals who, based on observables, have a very similar probability of receiving treatment (similar propensity score), but one of them received treatment and the other did not. The Nearest Neighbor Matching (NNM) method was implemented to estimate the average impact and the Caliper and Radius Matching (CRM) methods was basically included to check the robustness of the estimated results and as alternative specifications for assessing the sensitivity of results with respect to matching methods.

Table 2 gives descriptive statistics of covariates utilized in the analysis. Our dependent variable is a dummy variable that takes value one (1) if household adopted a *DroughtTEGO®* variety and the value zero (0), if none was planted. The outcome variables of interest in this study are maize income. Maize income per kilogram of maize seed planted is taken to be a proxy for agricultural productivity. This is because most of the farmers in the study regions plant several crops in one plot (intercropping) making it complex and hard to quantify area allocated for maize production. Farmers intercrop maize with other crops such as beans, pigeon pea, groundnuts, cowpeas, sweet potatoes, soybeans, among others. Maize income was calculated as total maize revenue minus variable costs divided by amount of seed planted (maize income in Ksh/ kg). The estimation procedure was expected to account for any unit cost reduction that could have arisen due to technology adoption. On average, 26% of the total households considered for this study adopted 1–6 *DroughtTEGO®* maize varieties (Muinga et al., 2019). The unconditional mean maize benefit was, 69 US$ per kg of seed planted as compared with 38 US$/ kg before matching. However, average net maize income increased by 42% after matching.

To ensure the robustness of the estimated average effect, the sensitivity of the estimates to hidden bias was conducted using the Rosenbaum bounds test. The test indicated that the significance level was not affected even after increasing gamma values three times (Table 3). Plausibility of the covariates was also assessed by re-estimating the propensity score on the matched sample, for adopters and matched non-adopters and pseudo-R^2 was then compared to that of before and after matching. The pseudo-pseudo-R^2 dropped significantly from 23% before matching to about 10-12% after matching, suggesting that the matching procedure was successful in terms of balancing the distribution of covariates between the adopters and non-adopters (Table 4). The insignificance after matching indicates that there were little or no variations between the independent variable values for the treated and control groups. Again, the distribution of the estimated propensity scores before and after the matching was plotted for visual assessment. In general, the graph shows that there was substantial overlap and similarity among the adopters and non-adopters. Thus, the common support condition imposed satisfies the balancing property (Figure 2). A summary of PSM results presented in Table 5 indicate that the average benefit accrued from adoption of DroughtTEGO® was 42%. These benefits also vary from County to County, reflecting the potential and rate of adoption in each county.

In ex ante studies, future adoption rates are normally based on

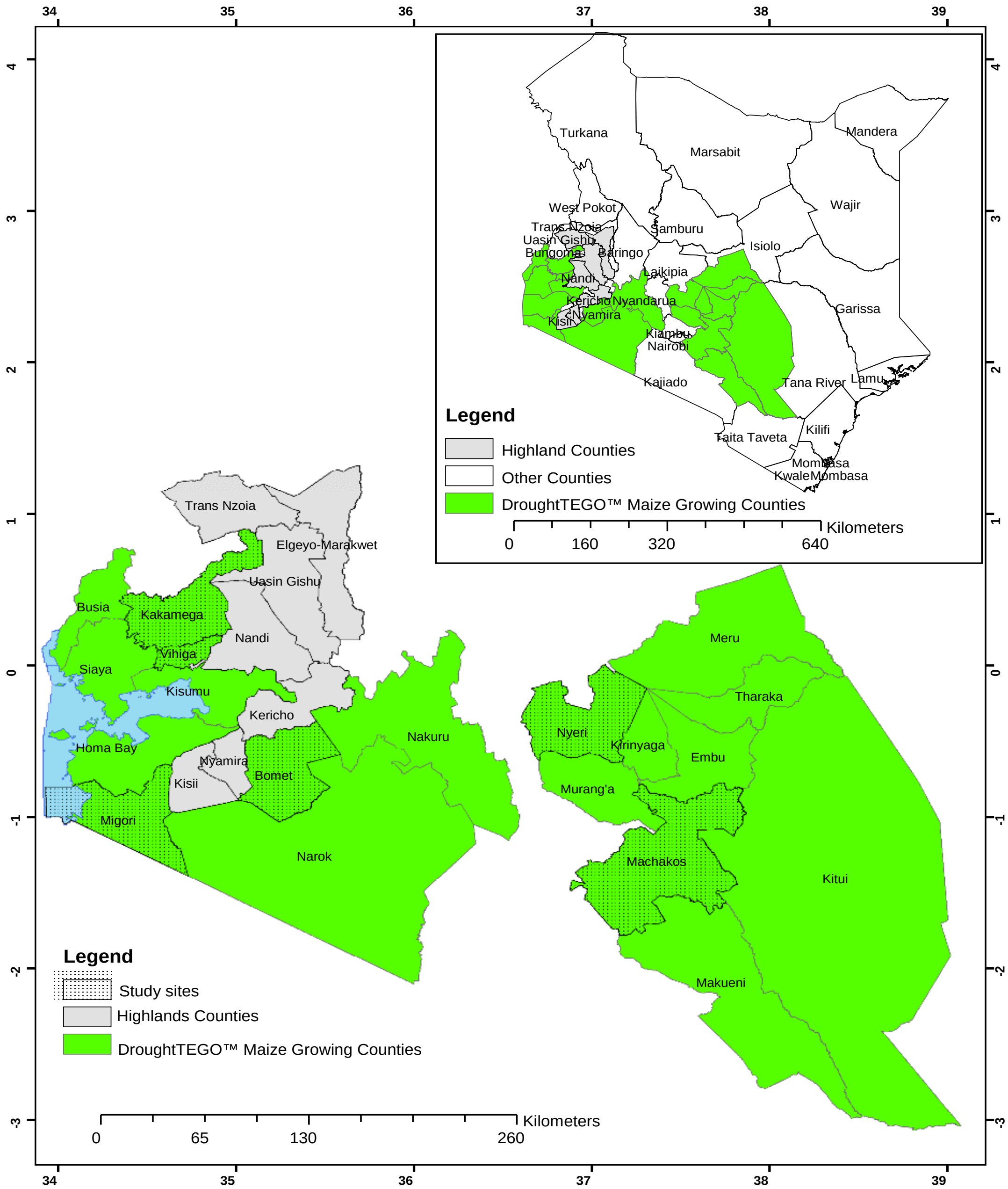

Figure 1. Map showing the *DroughtTEGO*® growing counties and the study area sites.
Source: Adapted from Obunyali et al. (2019).

expert estimates (Hareau et al., 2006). DroughtTEGO® varieties have shown an impressive adoption rate starting at 6% in 2016 at national level (Hailey, 2015) reaching over 26% in 2017 (Marechera et al. 2019; Muinga et al., 2019) within three years of initiating commercialization. Muinga et al. (2019) estimated the expected adoption was calculated at 89%. However, in the current paper, a conservative maximum adoption level till 2036 was assumed to be constant at 65% with a base value of 26%.

The analysis further assumes a planning horizon of 20 years. To define present values of project costs and benefits, a discount rate of 10% is assumed (CIA, 2020). International and local research, extension, and seed multiplication costs were obtained from AATF. International research includes the costs of breeding, research materials, training, and evaluation costs provided by AATF, while local research and extension costs are the cost borne by the National Agricultural Research Systems (NARS) partners in Kenya. The project cost was US$ 99 million (AATF Finance Office).

Approach used for sensitivity analysis

Sensitivity analysis was conducted to test the robustness of the results by changing each parameter of interest (yield benefit, adoption rate, research costs and interest rates) while holding the other parameters constant at the base values. This can also be used to set the thresholds of the parameters below which the benefits will disappear. This was done under three scenarios: (a) reducing the value of the baseline value by 50%; (b) Increasing the

Table 2. Characteristics of *DroughtTEGO*® varieties adopters and non-adopters, summary statistics before matching in Kenya.

Variable	Full sample n = 642		Non-adopters n = 476		Adopters n = 166		Difference
	Mean	S. E	Mean	S. E	Mean	S. E	
Outcome							
Total maize income per kg of seed used (US$/kg)	49.96	3.85	38.07	3.88	69.19	7.45	31.11***
Independent							
Age of household head (years)	49.40	0.55	48.89	0.66	50.88	0.98	-2.00*
Household head with no formal education (1= yes)	0.08	0.01	0.08	0.01	0.06	0.02	0.02
Household head with primary education (1= yes)	0.47	0.02	0.45	0.02	0.51	0.04	-0.05
Household head with secondary education (1= yes)	0.34	0.02	0.34	0.02	0.33	0.04	0.01
Household head with > secondary education (1= yes)	0.11	0.01	0.12	0.01	0.10	0.02	0.02
Gender of household head (1= male)	0.83	0.01	0.82	0.02	0.87	0.03	-0.06*
Family size living in the household in adult equivalent (count)	5.96	0.13	5.67	0.15	6.79	0.29	-1.12**
Number of adults working in the farm (count)	2.28	0.06	2.13	0.06	2.71	0.13	-0.58***
Dependency ratio (proportion over 64 and under 18years of age (%)	42.45	1.02	42.93	1.23	41.06	1.83	1.86
Main source of information is government extension (1= yes)	1.00	0.00	1.00	0.00	1.00	0.00	
Main source of information is another farmer (1= yes)	0.39	0.02	0.43	0.02	0.27	0.02	0.17***
Main source of information demonstration and field trials (1= yes)	0.11	0.01	0.09	0.01	0.18	0.01	-0.09***
Main source of information is radio (1= yes)	0.05	0.01	0.04	0.01	0.08	0.02	-0.04*
Farm size (acres)	2.28	0.09	2.26	0.11	2.35	0.19	-0.09
Household keeps farm records (1= yes)	0.11	0.01	0.09	0.01	0.17	0.03	-0.09***
Women control household resources (1= yes)	0.59	0.02	0.59	0.02	0.60	0.04	-0.01
Rating of food security in the last 2 years	1.75	0.04	1.58	0.04	2.22	0.07	-0.63***
Farmer perceives the drought tego seed to be expensive (1= yes)	0.06	0.01	0.05	0.01	0.08	0.02	0.04*
Bomet	0.16	0.01	0.18	0.02	0.10	0.02	0.08***
Vihiga	0.12	0.01	0.08	0.01	0.23	0.03	-0.15***
Migori	0.21	0.02	0.22	0.02	0.19	0.03	0.03
Kakamega	0.09	0.01	0.04	0.01	0.23	0.03	-0.19***
Nyeri	0.26	0.02	0.28	0.02	0.22	0.03	0.06*
Machakos	0.16	0.01	0.20	0.02	0.04	0.01	-0.16***

SE- robust standard errors, statistically significant at the 0.01 (***), 0.05 (**), 0.1 (*) level of probability (t-test are used for differences in means).

baseline value of the parameter by 25%;and (c) Assuming a worst-case scenario where all the parameters are changed simultaneously assuming the low adoption rates, high project costs and poor performance of the technology resulting to much lower yield advantage.

RESULTS AND DISCUSSION

Economic surpluses

Estimates of economic surpluses are shown in Table 6.

The total benefits from the adoption of the improved maize varieties for a 20-year period have a present value of about US$ 2.12 billion

Table 3. PSM Sensitivity analysis results.

Gamma	Sig+	Sig-	t-hat+	t-hat-	CI+	CI-
1.00	0.00	0.00	49.11	49.11	46.83	51.90
1.05	0.00	0.00	48.64	49.37	46.45	52.06
1.10	0.00	0.00	48.36	49.76	46.21	52.53
1.15	0.00	0.00	48.15	50.11	46.09	52.82
1.20	0.00	0.00	47.99	50.27	45.88	53.14
1.25	0.00	0.00	47.85	50.46	45.80	53.25
1.30	0.00	0.00	47.73	50.68	45.34	53.39
1.35	0.00	0.00	47.72	51.15	45.09	53.47
1.40	0.00	0.00	47.57	51.31	44.89	53.63
1.45	0.00	0.00	47.49	51.51	44.52	53.68
1.50	0.00	0.00	47.34	51.61	44.29	53.82
1.55	0.00	0.00	47.12	51.62	44.19	53.92
1.60	0.00	0.00	46.94	51.86	44.04	54.07
1.65	0.00	0.00	46.72	52.00	43.93	54.27
1.70	0.00	0.00	46.61	52.06	43.80	54.48
1.75	0.00	0.00	46.34	52.15	43.65	54.57
1.80	0.00	0.00	46.21	52.51	43.46	54.84
1.85	0.00	0.00	46.21	52.64	43.33	55.09
1.90	0.00	0.00	46.06	52.86	43.07	55.45
1.95	0.00	0.00	45.94	53.04	42.81	55.50
2.00	0.00	0.00	45.87	53.18	42.63	55.51
2.05	0.00	0.00	45.86	53.23	42.44	55.51
2.10	0.00	0.00	45.72	53.25	42.35	55.62
2.15	0.00	0.00	45.41	53.39	42.32	55.68
2.20	0.00	0.00	45.26	53.40	42.28	55.84
2.25	0.00	0.00	45.09	53.47	42.18	55.88
2.30	0.00	0.00	45.02	53.53	42.10	55.97
2.35	0.00	0.00	44.87	53.63	42.05	56.06
2.40	0.00	0.00	44.63	53.66	41.99	56.16
2.45	0.00	0.00	44.51	53.69	41.97	56.26
2.50	0.00	0.00	44.39	53.76	41.93	56.31
2.55	0.00	0.00	44.28	53.83	41.87	56.35
2.60	0.00	0.00	44.20	53.85	41.83	56.48
2.65	0.00	0.00	44.16	53.92	41.79	56.78
2.70	0.00	0.00	44.08	54.06	41.72	56.91
2.75	0.00	0.00	44.03	54.07	41.61	57.10
2.80	0.00	0.00	43.96	54.25	41.59	57.10
2.85	0.00	0.00	43.89	54.32	41.50	57.14
2.90	0.00	0.00	43.83	54.46	41.38	57.14
2.95	0.00	0.00	43.75	54.49	41.20	57.28
3.00	0.00	0.00	43.66	54.54	41.13	57.28

accruing to maize producers at National level. When regional level estimations are considered, benefits differ substantially across the Counties, with a larger proportion of the benefits accruing to three counties: Kakamega (US$ 90 million), Machakos (US$ 71 million) and Migori (US$ 70 million). Except Kakamega, these counties are prone to drought and therefore the high benefits are encouraging because the farmers who are vulnerable to drought related risks stand to benefit greatly from the technology. The low benefits in the remaining counties could be as a result of low adoption rates that were witnessed there.

The total benefit is about 16 times the amount that was spent on research and extension to develop the DroughtTEGO® technology. The IRR at the National level was 150% while that of the counties ranged between 19

Table 4. Matching quality indicators before and after matching for *DroughtTEGO*® varieties adoption studies in Kenya.

Matching algorithm	Pseudo R^2		LR X^2(p – value)	
	Before matching	**After matching**	**Before matching**	**After matching**
CRM	0.23	0.10	45.05 (p = 00)***	11.53 (p = 0.93)
NNM	0.22	0.12	41.80 (p = 00)***	15.98 (p = 0.72)

SE- robust standard errors, statistically significant at the 0.01 (***), 0.05 (**), 0.1 (*) level of probability (t-test are used for differences in means).

Table 5. DroughtTEGO® seed productivity US$/kg of seed planted.

Method	Adopters	Non-adopters	Difference=Average treatment effect on the treated (ATT)	% Increase
CRM	67.8	48.3	19.6	40.5
NNM	65.4	45.9	19.5	42.5
Average	66.6	47.1	19.5	42.0

CRM = Common Referent *matching;* NNM= Nearest Neighbourhood *matching;* 1US$= 102 Kenya shillings (https://www.centralbank.go.ke/forex/).

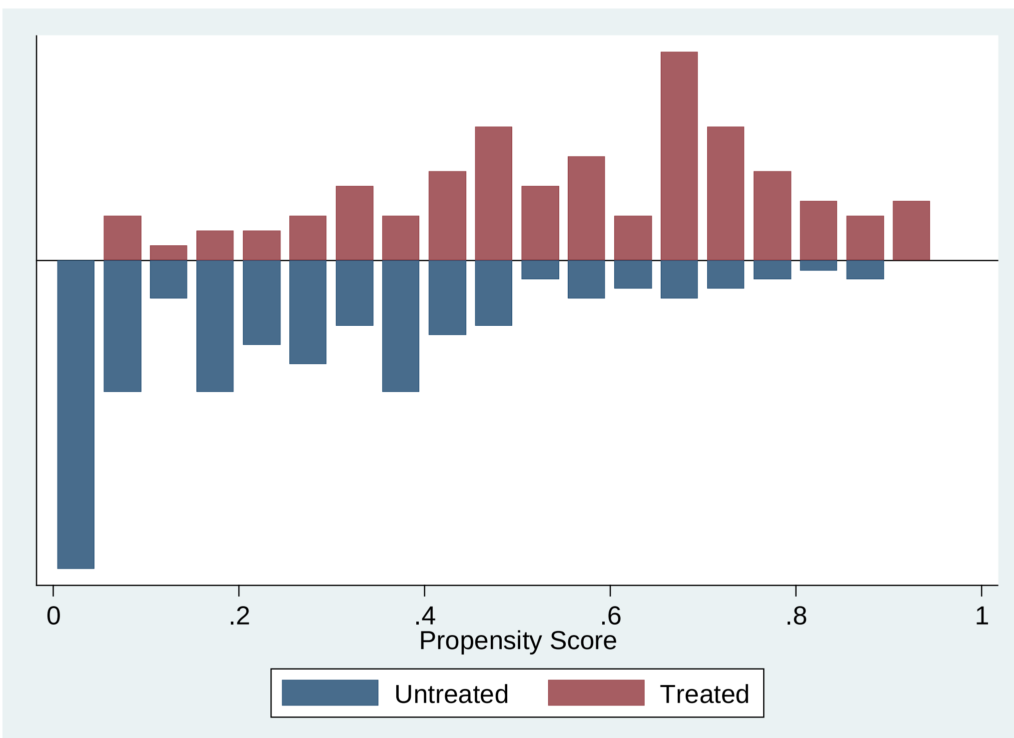

Figure 2. Common support graphical representation.

and 82%. These IRR values are very attractive because they are above the prevailing discount rate of 10%. The IRR values were comparable with the values reported in other studies estimating the returns on investment in agricultural research such as Alston et al. (1995) who found an average rate of return of 65% on agricultural research in a meta-analysis across over 1000 studies. The BCR values at National and County levels are all

Table 6. Expected Economic surplus for adoption of DroughtTEGO® varieties.

Region	NPV (Million US$)	Costs discounted (Million US$)	Benefit/cost ratio	Internal rate of return (%)
Bomet	9.89	5.64	1.76	18.53
Vihiga	12.26	5,16	2.38	23.43
Migori	70.43	7.91	8.91	76.80
Kakamega	90.02	10.45	8.61	81.76
Nyeri	23.78	6.09	3.90	35.26
Machakos	70.54	8.91	7.92	73.60
Kenya	2,120.11	90.01	23.56	150.00

1US$= 102 Kenya shillings (https://www.centralbank.go.ke/forex/). Source: Authors' computations.

Table 7. Sensitivity analysis of economic impact of DroughtTEGO® maize hybrid varieties in Kenya.

Scenario	Description	Projected value	NPV (Billion US$)	Costs discounted (Billion US$)	Benefit cost ratio
1	50% reduction in yield benefit	21	1.01	0.09	11.27
2	50% increase in project cost (million US$)	148	2.12	0.13	15.76
3	50% reduction in adoption rate	33	1.03	0.09	11.45
4	25% increase in yield benefit	53	2.74	0.09	30.40
5	25% increase in adoption rate	81	2.70	0.09	29.98
Worse case	*(*Benefit 21%; project cost US$ 148 million, Adoption rate 33%*)*		0.50	0.13	3.74

1US$ = 102 Kenya shillings (https://www.centralbank.go.ke/forex/). Source: Authors' computations.

above the threshold value of 1 implying that the investment in the development of DroughtTEGO® hybrid maize varieties was worthwhile.

Sensitivity analysis

Sensitivity analysis was conducted considering various scenarios and results are presented in Table 7. First, considering a scenario of reducing yield benefit by 50% (while holding the other parameters constant at the base values) the total net present value of economic benefits amounted to US$ 1.01 billion, with a benefit/cost ratio of 11:1. This implies that even when the yield benefits reduce by half as a result of biotic and abiotic conditions beyond the control of farmers, we would still expect the technology to yield substantial economic benefits.

If the projected costs were increased by 50% to US$ 0.13 billion the BCR decrease to 15.8:1. Further, reducing the adoption rate to 33% results in NPV of US$ 1.03 billion.

When the DroughtTEGO® varieties have 53% yield advantage over and above the varieties available in the market, the benefits increase to US$ 2.70 billion. Increasing the adoption rate to 81% increases the economic benefits by 27% to US$ 2.74 billion. Finally, under extremely unlikely scenario (the worst-case scenario) with yield benefit of 21%, adoption rate of 33% and project cost increases by 25%, the results show a substantial reduction in the total economic benefits to US$ 0.50 billion with a BCR of 4:1. From this assessment, it emerges that the results are generally robust and could be maintained as the parameters change. However, there are thresholds below which these benefits may disappear. For example, the adoption rates need to be maintained above 32% while the varieties' genetic purity must be maintained to sustain yield advantage of more than 21% above the commercial hybrids. Besides a strong technology stewardship programme, adoption needs to be sustained through continuous promotion, extension service provision and awareness creation to ensure that the farmers also adopt complimentary technologies and practices such as fertilizer application and weed management.

Conclusion

This study provides an *ex-post* evaluation of the economic impacts of adoption of DroughtTEGO® maize hybrid varieties in Kenya. The economic surplus model based on DREAM model was applied to estimate the economic impact. The model indicates a benefit of US$ 2.12 billion for 20 years. Given that the economy is open, prices are assumed to be exogenous, and therefore, all the benefits accrue to producers. The benefit cost ratio was estimated at 24:1 and an internal rate of return of 150%, indicating that the investment was highly profitable. Sensitivity analysis revealed that the benefits associated with the DroughtTEGO® technology are highly responsive to adoption rates, yield advantage and interest rates. The technology will remain profitable if adoption rates are sustained above 32%. Further, strategies must be put in place to maintain genetic purity of the technologies to ensure that at least they perform 21% above the commercial varieties.

Given that maize is a staple crop not just in the Kenyan low- to medium altitude agro-ecologies where the current analysis focused on, it is expected that the technology will spill over to geographic areas not intentionally targeted by the research investment both within Kenya and neighbouring countries to significantly increase the benefit. Other indirect positive impact expected from this technology includes employment opportunities for the poor and landless farmers. However, we note that the increased production of Maize a s result of adoption of DroughtTEGO® varieties may not completely substitute Maize imports. Although this technology provided substantial maize production gains, it is not a panacea to maize shortages in Kenya and should be considered as one tool in a larger toolbox that can enable Kenya and other SSA countries to become net Maize exporters. Further studies on the social-economic impact of DroughtTEGO® maize hybrid varieties are recommended.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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