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**To cite this article:** Girma Gezimu Gebre, Dil Bahadur Rahut, Jeetendra Prakash Aryal & Harriet Mawia (2023) Potential impact of scaling adaptation strategies for drought stress: a case of drought-tolerant maize varieties in Tanzania, *International Journal of Agricultural Sustainability*, 21:1, 2189396, DOI: [10.1080/14735903.2023.2189396](https://doi.org/10.1080/14735903.2023.2189396)

**To link to this article:** <https://doi.org/10.1080/14735903.2023.2189396>



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Published online: 17 Mar 2023.



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# Potential impact of scaling adaptation strategies for drought stress: a case of drought-tolerant maize varieties in Tanzania

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## ABSTRACT

Drought-tolerant maize varieties (DTMVs) offer hope as an adaptation strategy for farmers facing increasing frequency of droughts in sub-Saharan Africa. Adoption of these varieties also offers hope to enhance sustainability in the agricultural production system. However, these varieties are not yet widely cultivated, and the potential economic benefits not fully understood. This study examines the scalability of DTMVs in Tanzania under three scenarios: (i) scalability conditional on knowledge of DTMVs; (ii) scalability conditional on (physical) seed availability in addition to awareness; and (iii) scalability conditional on seed affordability in addition to awareness and (physical) seed availability. The study uses household production and consumption data from major regions in Tanzania. The results from the economic surplus model indicate that by 2032, the adoption of DTMVs could generate between US\$ 373 million and US\$ 499 million in cumulative benefits for both producers and consumers. Such benefits could potentially lift up to 1.6 million people out of poverty by 2032. It is estimated that consumers would get 40% of the benefits and producers 60%, with the largest benefits occurring in the major maize-producing regions of Mbeya, Rukwa, Ruvuma, Mwanza, Arusha, and Kagera. Consumers in Dar es Salaam would also benefit significantly from the price reductions resulting from increased production. The largest returns on investment would occur in Dodoma, Geita, Simiyu, Singida, and Kagera. These findings justify the investment of both public and private funds to support the scaling of DTMVs in Tanzania.

## ARTICLE HISTORY

Received 14 November 2022  
Accepted 6 March 2023

## KEYWORDS

Drought-tolerant maize varieties; scalability; economic impact; Tanzania

## 1. Introduction

Climate change extremes such as drought cause losses annually of between 10-20% (Pauw et al., 2010), or even more, of the Gross Domestic Product (GDP) among sub-Saharan African countries (De Pinto et al., 2019; IPCC, 2018; Mairura et al., 2021). This poses a threat to the sustainability of agricultural production among small-scale rural communities that are dependent on rain-fed agriculture (Atube et al., 2021; Fadina & Dominique, 2018;

Kabubo-Mariara & Mulwa, 2019; Nord et al., 2021; Simtowe et al., 2021). The threats are even higher in countries with a large agricultural GDP (AgGDP), like Tanzania (Ochieng et al., 2021), where the AgGDP contributes about 30% to the total GDP. Intergovernmental Panel on Climate Change (IPCC) predicts that, by 2050, crop productivity in sub-Saharan Africa will have declined by 5% for maize, 14% for rice, and 22% for wheat, pushing a large number of already vulnerable people, who depend on agriculture for their livelihoods, deeper into

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poverty and food insecurity. Without substantial measures that address the challenges caused by climate extremes such as drought, agricultural productivity losses are expected to reduce past rates of gains from technological and management improvements (De Pinto et al., 2019).

Tanzania has the second largest maize (*Zea mays*) area planted (approximately 4.12 million ha) in sub-Saharan Africa after Nigeria, with farmers allocating nearly 70% of their land to this crop (International Maize and Wheat Improvement Center [CIMMYT], 2017). However, maize productivity in Tanzania remains low, averaging 1,400 kg/ha, which is much less than the sub-Saharan African average of about 1800 kg/ha (CIMMYT, 2017), due to the limited use of improved varieties and inputs such as fertilizer, as well as to other abiotic stresses such as drought. One issue of abiotic stress-tolerant varieties is that the benefits of adoption become visible only when the specific stress, which they are tolerant to, appears (Yamano et al., 2018; Yorobe et al., 2016). The study of drought-tolerant maize adoption in Malawi demonstrates that previous early-season dry spells and access to seed subsidy increase adoption (Katengeza et al., 2019). Thus, if normal seasons continued, we could predict that farmers would tend to switch to other varieties. Therefore, Yamano et al. (2018) stress the importance of education for farmers about the benefits of stress-tolerant crop varieties through extension activities. Following recent empirical reviews on technology adoption, impact, and extension in developing countries' agriculture, Takahashi et al. (2020) noted that even if profitable technologies are potentially available, they may not be diffused widely, partly because of credit, insurance, and other market-related constraints and partly because of the ineffective information dissemination system, largely arising from the absence of effective agricultural extension systems. Moreover, a study by Kansime et al. (2022) noted that modern agricultural technologies, such as sustainable agricultural intensification practices, have been developed with the aim of increasing agricultural productivity; however, most of them are not achieving their potential because of low adoption linked to limited extension support to make them known and accessible by farmers.

In Tanzania, drought conditions are observed more frequently in the northern and central portions of the country (Arusha, Manyara, Shinyanga, Simiyu, and Dodoma), and when they occur can lead to crop failure of a significant magnitude. The effects of

maize losses are also expected to lead to other spiral effects on downstream sectors such as food-processing, including the poultry and animal feed sectors (Gbegbelegbe et al., 2014; Pauw et al., 2010), as well as causing a sharp increase in prices of maize produce. Hence, adaptation strategies that counteract the effects of drought become important. Recent years have witnessed the development of drought-tolerant maize varieties (DTMVs) designed to help smallholder farmers manage drought caused by climate change. In Tanzania, over 20 DTMVs have been released and deployed since 2007 through a collaborative effort of the CIMMYT, national research institutions, seed companies, and agro-dealers (CIMMYT, 2017; Fisher et al., 2015). In addition to drought-tolerance, these varieties often have other important traits, such as better responsiveness to inputs and good nitrogen use efficiency (Fisher et al., 2015; Seleiman et al., 2021; Simtowe et al., 2021). They are well-adapted to sub-Saharan Africa and include open-pollinated and hybrid varieties.

Despite their significant yield advantage (15-39%), DTMVs have not yet been widely adopted in Tanzania, and hence their impact is limited. However, as expressed by the United States Agency for International Development (USAID, 2017), for development interventions to yield the highest impact, programming requires a facilitative approach for the widespread adoption of improved technologies and practices at the population level, also called as scaling. The scaling of proven technologies and practices is generally defined as the process of sustainably increasing the adoption of a credible technology or practice, and achieving widespread use by stakeholders while still retaining or improving upon the demonstrated positive impact of the technology or practice (USAID, 2017). In order to complement efforts to scale drought-tolerant varieties, since 2015, CIMMYT has been implementing a Stress Tolerant Maize for Africa (STMA) project, with funding from the Bill and Melinda Gates foundation. The aim of the STMA is to reduce devastating constraints in maize production among farmers in 12 target countries in sub-Saharan Africa, including Tanzania. The project develops improved, multiple-stress-tolerant maize varieties that effectively address emerging and future production challenges, while increasing genetic gains and scaling-up and scaling-out the products developed and the knowledge gained.

The scaling strategy for DTMVs involves a number of stakeholders, including CIMMYT, the private sector

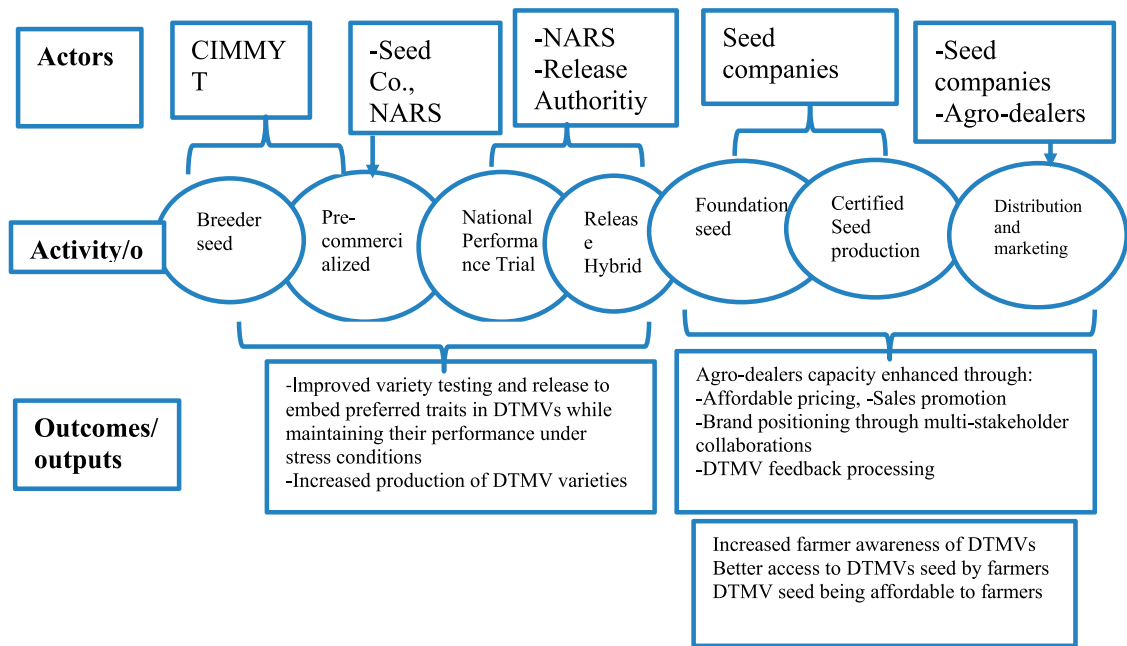
(agro-dealers and seed companies) and the public sector, as well as non-governmental organizations (NGOs). CIMMYT develops germplasm and provides pre-commercialized hybrid seeds to the National Agricultural Seed Systems (NARS) and seed companies for national performance trials (NPTs) before releasing to farmers. Once released, the NARS and seed companies can proceed with the production of foundation seed and then commercialize it through certified seed production; this is then sold to farmers through agro-dealers. To complement such scaling efforts, studies have been conducted in some countries (e.g. Amondo et al., 2019; Nord et al., 2021; Simtowe et al., 2019a; 2019b; 2021) to understand the diffusion processes of DTMVs, their adoption rates, the determinants of their adoption, and their impacts on farm productivity (Wossen et al., 2017), but little is known in Tanzania about the scalability of the DTMVs that are being promoted through the STMA project, or their potential economic benefit to the nation.

Against this background, our study seeks answers to two related questions: (1) 'what would be the potential for scaling DTMVs in Tanzania if constraints to knowledge and seed access were addressed?' This type of analysis is critical for understanding the marginal benefits from investments aimed at addressing bottlenecks in the scaling of DTMVs, and for the proper planning and building of a more concerted effort involving both public and private sectors towards expediting the widespread adoption of DTMVs. We answer this question by applying the average treatment effect (ATE) framework proposed by Diagne and Demont (2007), but follow Simtowe et al. (2019a and 2021) to also consider the availability and price affordability of seed. (2) The second question is, 'what is the potential economic benefit from scaling DTMVs to levels predicted by the econometric model?' The scaling of DTMVs requires increased investment in research and development (R&D). In sub-Saharan Africa, investment in agricultural research and development has been declining steadily since its peak in the 1980s (Pardey et al., 2007), despite the evidence of relatively high rates of return from R&D investments (Ajayi et al., 2007; Bokonon-Ganta et al., 2002; Coulibaly et al., 2004; Macharia et al., 2005). Understanding the economic benefits of scaling DTMVs and distributing them to various stakeholders (including farmers and producers) could potentially catalyze investments that are critical for the development of the maize value chain.

A study by La Rovere et al. (2010) confirms how investment in drought-tolerant maize in 13 countries of sub-Saharan Africa has brought cumulative economic and poverty-reducing benefits to producers and consumers in those countries; these benefits accrue from higher yields and reduced season-to-season yield fluctuations as a result of the adoption by farmers of improved, DTMVs. However, the study by La Rovere et al. (2010) uses an arbitrary number of potential adoption rates. The contribution of this study is in the application of adoption assumptions that are based on more realistic estimates of potential adoption rates, generated through an econometric analysis, as well as in an examination of the distribution of benefits between consumers and producers across the different regions in Tanzania. The paper first looks at the scaling strategy for the STMA project (see section 2), followed by an explanation of the analytical framework (section 3). The data sources and descriptive statistics are presented in section 4, while the results and discussions relating to the potential for scaling as well as its economic benefits, are discussed in section 5. The conclusions are presented in section 6.

## 2. Scaling strategy

CIMMYT is implementing a product-oriented breeding programme targeted at improving maize varieties for the mid-altitude areas of eastern and southern Africa that are prone to drought and other stresses. As depicted in Figure 1, the scaling strategy for the programme's products (DTMVs) involves several agents: in particular, it calls for very strong public and private partnerships at the different stages of the seed-value chain, including research institutes, seed companies, agro-dealers, and farmers. In Tanzania, the strategy for scaling DTMVs involves the provision of breeder seed by CIMMYT to the Tanzania Agricultural Research Institute (TARI) and to seed companies, who, under the oversight of the public sector institution responsible for overseeing the release of new varieties, are then expected to conduct national performance trials (NPTs) to assess the performance of the new hybrids compared to the commercial checks. Following results from the NPTs, a variety may be recommended for release or not. If the performance of the new variety is better than the commercial check, it is recommended to the national release committee for release. Once the variety is released, the seed company commercializes



**Figure 1.** Scaling strategy for drought-tolerant maize varieties in Tanzania.

it by producing foundation and certified seed. The certified seed may be sold to farmers through various distribution outlets, including the company's own channels, agro-dealers, and stockists. A major factor in the scaling of DTMVs relates to the capacity of the seed system's institutions to produce foundation seed. CIMMYT has partnered with relatively small seed companies in scaling DTMVs; such seed companies lack the capacity to produce foundation seed, and may be unable to maintain the genetic purity of seed, which can lead to seed contamination. This means they have to rely constantly on partners such as CIMMYT for their supply of breeder seed to produce foundation seed.

In order to address this constraint, and as a way of improving the sustainability of the scaling efforts, CIMMYT's interventions aim to strengthen the capacities of various actors along the seed value chain, including by offering training to breeders in the NARS and seed companies on various aspects of seed production. CIMMYT provides training to technicians and breeders on new breeding tools, to enable them to produce quality seed, maintain parental inbred lines, manage germplasm, maintain seed, and conduct hybrid male sterilization and detasseling practices. Seed companies are also trained in conducting seed estimates by applying seed road

maps, as well as in seed marketing strategies. Moreover, to increase the supply of foundation seed, a company called QualiBasic has been established; a key role of this company is to produce and supply basic seed (quality foundation seed) to seed companies in East and South Africa, with the aim of becoming their preferred supplier of foundation seed, for the ultimate benefit of Africa's farmers. This makes QualiBasic a reliable and sustainable partner in the scaling of DTMVs. The seed companies that have partnered with CIMMYT also lack the capacity to produce and market large amounts of certified seed; hence they rely on grants from donors and other partners such as CIMMYT to sustain their seed production and marketing activities. One sustainability option for such companies is to explore potential financing options with existing financial institutions within Tanzania.

Agro-dealers are also trained in seed storage, marketing, and business management. Such partnerships between seed companies, agro-dealers, the Ministry of Agriculture and other national research institutions, and NGO-based extension agents have led to a rapid scale-out of certified seed production and distribution. The demand for DTMVs is a big driver in the sustainability of the DTMV seed value chain. Demand is being generated through partnerships with extension providers, who create awareness about the existence

of DTMVs through several channels, including demonstration plots and the radio, as well as through face-to-face visits by extension agents to farmers' fields. Despite such efforts, there is a gap in understanding the potential demand for DTMVs, as well as the extent to which such efforts could lead to the sustained widespread adoption of drought-tolerant maize among the targeted farming communities. Moreover, a related question is whether or not an investment in R&D aimed at scaling the cultivation of DTMVs in Tanzania would lead to tangible economic benefits. This paper tries to address these gaps.

### 3. Conceptual and empirical framework

#### 3.1. The average treatment effects framework for estimating DTMV scalability

We begin by assessing the scalability of DTMVs in view of the constraints to access and the asymmetric exposure to information; this as an important step in estimating the parameters to be used in assessing the potential economic impact of DTMV adoption. The analysis of scalability follows a framework proposed by Diagne and Demont (2007) and Simtowe et al. (2019a & 2021), where farmers are assumed to have heterogeneous access to information about DTMVs and to seed at affordable prices.<sup>1</sup> Under this framework, we address the question of whether a potential adopter is aware of the existence of DTMVs, has access to seed, and has access to seed at a price that is affordable. In addition to identifying the households that are aware of DTMVs, we identify households with physical access to seed, and those with access to affordable seed. We then extend the ATE adoption framework proposed by Diagne and Demont (2007) to estimate three types of potential DTMV adoption rates: (i) unrestricted awareness, (ii) unrestricted awareness and access, and (iii) unrestricted awareness and access and affordability. We express the potential adoption rates in Tanzania by the percentage of the farmers that would adopt DTMVs under each of the three scenarios, and estimate the associated adoption gaps, and the determinants of DTMV awareness, access, affordability, and adoption.

#### 3.2. Economic-surplus gains of DTMV scaling

##### 3.2.1. Theoretical framework

The benefits of scaling DTMVs are both direct, at the level of adopters, and indirect, at the level of

producers and consumers. Smallholder farm households supply part of the maize that they produce to the market, hence the direct effects of adopting DTMVs lead to indirect effects on both other farmers (producers) and consumers. As such, the economic-surplus (ES) approach (Alston et al., 1995; Kostandini et al., 2013; La Rovere et al., 2010) is appropriate for estimating the change in consumer and producer surpluses. The effects of DTMV adoption for producers and consumers depend on the nature of the market. In a closed economy, indirect effects occur due to supply-induced drops in price, and all market participants are affected, with consumers benefiting at the expense of producers; however, producers can still be better off if the reduction in their per unit production cost is large enough to offset negative price effects, or if their maize sales are small (Zeng et al., 2015). In a small, open economy, the domestic price is equal to the world market price that does not change with increased domestic supply, hence direct welfare effects occur only to adopters, and no indirect effects occur. In Tanzania, only 2% of the maize produced is exported to neighbouring countries; hence a closed economy model is appropriate for estimating economic surplus, because that provides more realistic estimates of the potential benefits of DTMV scaling. Wilson and Lewis (2015) report maize exports ranging between 23,000 Metric tones and 156,000 metric tones, mainly to Rwanda, Burundi, Zambia, Malawi, the Democratic Republic of Congo, and Kenya. Nevertheless, although most smallholder producers in developing countries consume their own production (Degaldo, 1997), a substantial amount of the maize produced in Tanzania (20-35%) is traded between and within the regions (Wilson & Lewis, 2015). This implies that although it is largely a closed economy, maize moves between net-producing regions and net-consuming regions, which leads to heterogeneity in the benefits from scaling DTMVs. Wilson and Lewis (2015) indicate the following four market channels as the main routes through which maize flows between maize-surplus and maize-deficit regions:

- i. Smallholder farmers who sell to local traders and millers, mainly in the rural areas and nearby cities;
- ii. Medium-sized grain traders and millers who serve rural and urban centres;

- iii. A few well-established, large-scale millers and traders based in Dar es Salaam, who operate in both national markets and export markets;
- iv. Institutional buyers, including the World Food Programme (WFP), the National Food Reserve Agency (NFRA), the armed forces, prisons, hospitals, and schools.

Therefore, as well as understanding the differential benefits between producers, it is important to distinguish the differential benefits between different regions as well. We then adopt the horizontal multi-market model, with the initial quantity equilibrium set by balancing total production across all regions with total consumption across all regions, including exports. In the domestic market, Dar es Salaam is an important consumption region, while the southern highland regions of Iringa, Mbeya, Rukwa, and Ruvuma produce more than 40% of the maize in Tanzania. [Figure 2](#) depicts maize flows between production areas (maize-surplus regions) and maize-deficit regions.

In the economic surplus model, the major parameter affecting changes in price and economic surplus is the cost reduction per unit of output due to adoption, or the  $k$ -shift (Alston et al., 1995) expressed by:

$$K = \left( \frac{\varphi}{\varepsilon} - \frac{\theta}{1 + \varphi} \right) * A \quad (1)$$

Where  $\varepsilon$  and  $A$  are the supply elasticity, and the adoption rate (area under DTMVs), respectively;  $\varphi$  and  $\theta$  are the average change in maize yield and cost per unit of maize area due to DTMV adoption. Using the  $k$ -shift, the counterfactual output equilibrium price (the output equilibrium price without DTMV adoption) is expressed by:

$$p^0 = p^1(\varepsilon + \eta) / (\varepsilon + \eta - K\varepsilon) \quad (2)$$

Where  $p^0$  is the counterfactual maize price observed when the farmers have not planted DTMVs;  $p^1$  is the price with adoption of DTMVs; and  $\eta$  is the absolute value of the demand elasticity. Assuming linear demand and supply curves (Alston et al., 1995), and under a closed-economy assumption, changes in the producer surplus ( $\Delta PS$ ) and consumer surplus ( $\Delta CS$ ) attributed to the adoption of DTMVs are calculated

as follows:

$$\Delta PS = p^0 Q^0 (K - Z)(1 + 0.5Z\eta) \quad (3)$$

$$\Delta CS = p^0 Q^0 Z(1 + 0.5Z\eta) \quad (4)$$

Where  $Q^0$  is the equilibrium quantity of maize supplied under non-adoption of DTMVs and  $Z$  is the relative price change expressed as  $Z = \left( \frac{p^0 - p^1}{p^0} \right)$ . To find the total change in the economic surplus ( $\Delta ES$ ) resulting from the adoption of DTMVs, one has to estimate both the producer surplus (resulting from increase in yield and reduction in cost of production), and the consumer surplus resulting from price reduction. Following Zeng et al. (2015), the change in producer surplus is decomposed into the price effect and the adoption effect as follows:

$$\Delta PS = \Delta PS_{price} + \Delta PS_{adoption}$$

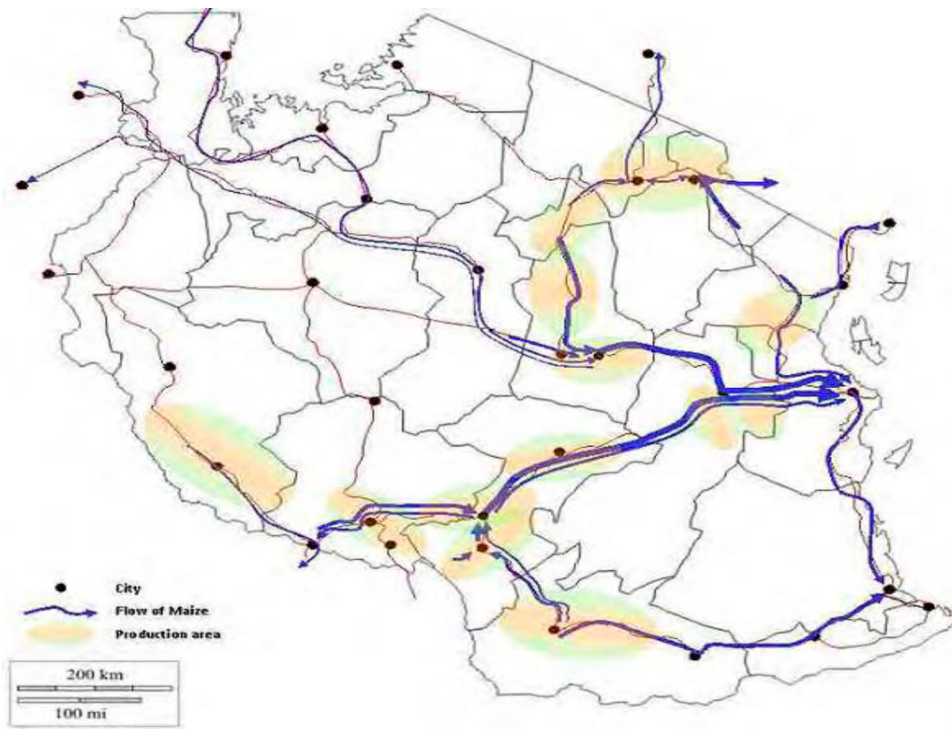
It is difficult to compute the change in producer surplus attributable to adoption ( $\Delta PS_{adoption}$ ) because households experience different changes in costs and yields. However, it is easier to compute the  $\Delta PS_{price}$  at the market level, because the change in the price is unique for all the market participants (Zeng et al., 2015). This can be expressed by:

$$\Delta PS_{price} = \left( \frac{K\varepsilon p^1 Q^0}{\varepsilon + \eta - K\varepsilon} \left( \frac{K\varepsilon p^1}{2p^0(\varepsilon + \eta - K\varepsilon)} - 1 \right) \right) \quad (5)$$

$\Delta PS_{adoption}$  is then computed as the residual between  $\Delta PS$ , evaluated through [equation \(3\)](#) and  $\Delta PS_{price}$  as computed above.

### 3.2.2. The empirical estimation using the DREAM model

The empirical approach in the estimation of the economic surpluses involves the application of the Dynamic Research Evaluation for Management (DREAM) model and computer programme (Alston et al., 1995). Initially developed at the International Food Policy Research Institute (IFPRI) (Alston et al., 1995), the DREAM software was recently improved by Biosafety Systems, in collaboration with Vitamin Software, to a new and improved version named DREAMpy, a Python version of DREAM. DREAMpy is an open-source software that allows users to input data directly and generate their output in Excel worksheets. It builds on the original DREAM software, and includes intuitive, user-friendly navigation. Because of



**Figure 2.** Market flows of maize in Tanzania. Source: Wilson and Lewis (2015).

its simplicity, the DREAM was selected for this assessment. DREAM model has been utilized to evaluate the impact assessments, including Pachico (1998), Macharia et al. (2005), and Benin and You (2007). DREAM estimates economic returns to investments in research and development under a range of market conditions, allowing price and technology spillover effects among regions due to the adoption of productivity-enhancing technologies (Benin & You, 2007). In each region, demand and supply are represented by linear equations, with market clearing enforced by a set of price and quantity identities (Benin & You, 2007). The model is based on the assumption that the adoption of the technology leads to an outward shift in the product's supply curve, which triggers a process of market-clearing adjustments in one or multiple markets that affect the flow of final benefits to producers and consumers (Alston et al., 1995). The market-clearing conditions are defined in terms of border prices, which may differ from the prices received by farmers due to transactions and other costs that are incurred within regions between the farm and the border (Benin & You, 2007). The model is parameterized by a set of demand and supply prices, quantities, and elasticities

that were measured during a defined 'base' period, and allows for exogenous shifts in supply and demand, hence allowing for a sequence of equilibrium quantities and prices to be generated in the 'without research' scenarios (Benin & You, 2007). The 'without research' outcomes and the 'with research' outcomes, obtained by simulating a sequence of supply curve shifts attributable to research are then compared. The supply shifts induced by research are defined based on the adoption pattern of the technology over time, up to some assumed maximum adoption rate in some future year. The programme then computes discounted consumer and producer surpluses and compares those in the 'with research' scenario with those in the 'without research' scenario. DREAM also computes three investment indicators that are used in assessing the impact: the net present value (NPV), the internal rate of return (IRR), and the benefit-cost ratio (BCR).

### 3.2.3. Impact on poverty reduction

Given the significance of agriculture in Tanzania's economy, it is important to understand the economic surpluses that would result from the scaling of DTMVs, and the consequential aggregate impact on poverty.



Improving maize yields through the adoption of DTMVs benefits producers directly by improving the maize supply, and the consequent reduction in the price of maize benefits net consumers by lifting them out of poverty. Moreover, as expressed by Kassie et al. (2017), agriculture has stronger growth linkages with other sectors than other economic sectors have, and thus creates employment opportunities for the poor. We follow Zeng et al. (2015), Kassie et al. (2017), and Marenya et al. (2018) to estimate the impact on poverty of the technology-induced change in the economic surplus. According to Alene et al. (2009), the number of people escaping poverty at the current level of technology adoption can be estimated as follows:

$$P = \left[ \frac{ES}{AgGDP} * \delta \right] * N \quad (6)$$

where  $P$  is the number of people who escape poverty;  $ES$  is the total economic surplus due to the adoption of DTMVs;  $AgGDP$  is the total value of the agricultural gross domestic product;  $\delta$  is the elasticity of poverty with respect to the  $AgGDP$  driven by the growth in agricultural productivity and production; and  $N$  is the total number of poor people in the country (Alene et al., 2009).

## 4. Data

The study uses both primary and secondary data. Primary data is from a household adoption survey conducted in 2018 that was supported by the STMA project, and is used for estimating the scalability of DTMVs in Tanzania. Secondary data derived from IFPRI, CIMMYT and from other secondary sources provided information on parameters for the DREAM model.

### 4.1. Household survey data for estimating the scalability of DTMVs

Maximum adoption estimates are made using household survey data collected in December 2018 in Tanzania. The survey involved 720 households in 39 villages across 17 districts and ten regions (see Figure 3). The following areas were included in the survey: Iringa region (Iringa district); Morogoro region (Morogoro rural, Kilosa, and Mvomero districts); Mbeya region (Mbeya district); Manyara (Mbulu and Babati districts); Tabora region (Nzega

district); Simiyu region (Bariadi district); Tanga region (Tanga and Korogwe districts); Dodoma region (Kondoa district); Arusha region (Meru, Arusha, and Karatu districts), and the Kilimanjaro region (Moshi rural and Hai districts).

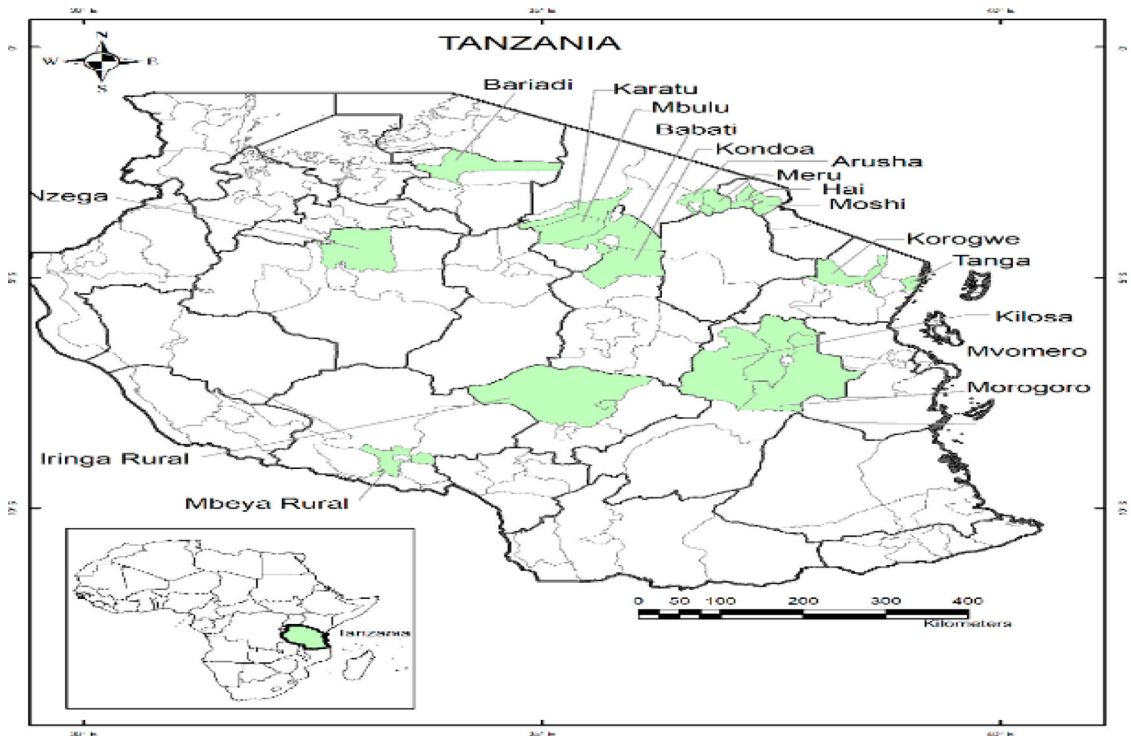
A multi-stage sampling technique was used, combining purposive and random sampling. The first stage selected regions, both project areas, and likely spillover areas. The second stage involved the selection of villages, using a probability proportional to size sample design. The third and final stage involved a random sampling of households within each village.

### 4.2. Data for the economic surplus analysis

The input data required for the economic surplus analysis in the DREAM model includes: (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 quality products where the technology has been adopted (the  $K$  factor); (3) maximum adoption rates as indicators of scalability; (4) economic parameters of the market response to change (elasticities of both supply and demand), to predict how producers and consumers will react to the new prices generated by market forces; (5) the research and extension costs incurred in obtaining the new technology. As is typical of many impact-assessment studies, no baseline data were collected for this study before the intervention. This has thus precluded the possibility of using the 'before and after' approach of comparing the same households by tracing the changes associated with the adoption of the varieties.

#### 4.2.1. Parameters for the analysis of economic surplus

Table 1 depicts the parameters used in the DREAM model estimation. We estimate the impact (benefit-cost ratio) of the STMA project, using the actual maize production and consumption data for the 2017 season to set up the baseline scenario. Our simulation period is 15 years, from 2018 to 2033. The total annual average (2000-2017) maize production is estimated to be about six million tons, while the yield is estimated to be about 1.4 tons/ha. About 90% of the maize produced in Tanzania is consumed locally, and the rest is exported. However, given the ecological diversity of Tanzania, some regions, especially in



**Figure 3.** Map showing survey sites in Tanzania.

the southern highlands, are the main maize-producing regions, while other regions rely on maize from the maize-surplus regions.

Consequently, about 20–35% of domestic consumption occurs in regions that did not produce maize, suggesting a significant maize trade between maize-surplus and maize-deficit regions. Therefore,

we estimate the overall benefits and their distribution between consumers and producers using i) a closed-economy market-clearing model; and ii) a horizontal, multimarket model. In a closed economy, the equilibrium price is entirely determined by domestic supply and demand, whereas in an open economy, equilibrium prices are determined by the domestic supply and by both the export demand and the domestic demand, and we use a horizontal multimarket model. Information on national maize prices is based on various price bulletins and the FAO Statistical Database (FAOSTAT, 2017). The potential adoption yield benefits associated with the adoption of DTMVs are based on impact assessment publications for Uganda and Zambia in 2015 (Simtowe et al., 2019b). The results from these reports show a 15%–20% yield advantage of DTMVs over local or improved varieties that are not drought-tolerant. The selling prices and the average cost of production per hectare are assumed to be the same.

In most ex-ante studies, future adoption rates are normally based on expert estimates (Hareau et al., 2006). To make plausible assessments of the maximum potential adoption rates, we use data from a household survey conducted in Tanzania in

**Table 1.** Parameters used in the DREAM model.

Parameter	Base	Source
Maize supply and demand ('1,000 tons)	5,939.7	FAOSTAT (2017)
Price of maize (\$/tonne)	150–217	FAOSTAT (2017) and various price bulletins
Price elasticity of maize supply	0.2	La Rovere et al. (2010)
Price elasticity of maize demand	−0.35	La Rovere et al. (2010)
Consumption: growth rate (%/year)	2.6	World Bank (2011)
Benefit (%)	15–19	Simtowe et al. (2019a)
Maximum adoption level (%)	39%, 46%, and 53%	Computed based on an econometric model
Discount rate (%)	10%	Gatzweiler et al. (2007)
Research costs (million US\$)	22	Bohn et al. (1997); Kate and Laird (2000), CIMMYT

Source: Various

2018, and employ an econometric model to predict potential or maximum adoption rates under heterogeneous exposure to information, physical seed access, and seed affordability, which are estimated to be 39%, 46% and 53% respectively. These potential adoption rates are the proportion of the total maize hectare area that is allocated to DTMVs. The demand estimates are based on a demand elasticity for maize in Tanzania, suggested by La Rovere et al. (2010) of  $-0.35$ . Similarly, a supply elasticity of 0.2 was also assumed based on La Rovere et al. (2010). Given the expected higher future demand for maize resulting from the growth in the Tanzanian population, an annual growth rate of 2.6% was assumed to be the growth rate in demand for maize, and a 1.85% was assumed to be the growth rate in the annual supply of maize (World Bank, 2011). The analysis is based on a planning horizon of 15 years, and a discount rate of 10% is assumed (Gatzweiler et al., 2007) to define the project costs and benefits at present values.

The costs for research, adaptation, and extension are estimated using the costs of staff for local and international research, extension, and seed multiplication. These costs are then increased by 10% of the total research costs to account for the costs of fixed factors such as land, equipment, and buildings that are shared with other projects. International research includes the cost of breeding, research materials, training, and evaluation provided by CIMMYT, while local research and extension costs are borne by the NARS partners in Tanzania. Research expenditure was calculated in terms of a full-time equivalent (FTE) scientist per year. Other sources of information about costs include Kate and Laird (2000), who estimated research costs at US\$ 1.75 million/variety. Costs for testing and for an adaptive breeding programme were estimated at US\$ 80,000/variety, based on two full-time equivalent (FTE) scientists, and the median cost per researcher was estimated at US\$ 20,000 (Bohn et al., 1997) per year for at least three years of testing. The total expenditure was then estimated at about US\$ 32 million.

## 5. Results and discussion

### 5.1. Predicted potential for scaling drought-tolerant maize varieties

The results of the predicted adoption rate with and without ATE correction for different population

awareness of DTMVs, seed availability, seed affordability, population selection biases, and adoption gaps are presented in Table 2. The awareness of DTMVs in the study area sample in Tanzania was estimated to be 27%, whereas the sample adoption was 10%. The predicted adoption rate for the full population after correcting heterogeneity in awareness of DTMVs was 39%. This is higher than the observed sample adoption rate because of the low levels of diffusion of DTMVs among the farming community. This indicates that if the entire population of maize farmers were aware of DTMVs, the effective demand for DTMV seed would have increased from 10% to 39%, resulting in an adoption gap due to the lack of DTMV exposure of 29%.

Correcting for heterogeneity in awareness and availability of physical seed combined, the predicted adoption rate for the full population is 46%. This means that if, in addition to being aware of DTMVs, all farmers had DTMV seed physically available to them, the effective demand for DTMV seed would have been 46%. The corresponding estimate of the adoption gap of 34% resulting from the non-availability of seed can, therefore, be interpreted as the seed-access gap, which is the potential demand loss due to non-access to seed (Donstop et al., 2013), and which also suggests that there is scope for scaling the cultivation of DTMVs in Tanzania if seed companies can increase the supply of seed to the farming community after increasing farmers' awareness.

The cost of seed can prevent potential adopters from adopting DTMVs. After correcting for heterogeneity in awareness, seed availability, and access to affordable seed combined, the predicted DTMV adoption rate for the full population is 52%. The corresponding estimate of the adoption gap resulting from lack of awareness, access to seed, and access to seed at an affordable price combined is 43% and is significant at the 5% level. These adoption gap estimates imply that there is still potential for scaling DTMVs adoption once awareness and seed accessibility constraints are addressed.

### 5.2. Economic surpluses

Estimates of the economic benefits of scaling the cultivation of drought-tolerant maize varieties in Tanzania, with an optimistic yield benefit of 19%, and considering the three levels of potential adoption rates, are presented in Table 3. In the first scenario,

**Table 2.** Predicted DTMV potential adoption rates.

	Parameter with awareness unconstrained			Parameter with awareness + access unconstrained			Parameter with awareness + access + affordability unconstrained		
	Est	S.E	Z	Est	S.E	Z	Est	S.E	Z
ATE-Corrected population estimates									
Predicted adoption rate in full population (ATE)	0.39*	0.37	10.29	0.46*	0.04	11.82	0.52*	0.04	12.33
Predicted adoption rate in treated subpopulation (ATT)	0.37*	0.03	12.51	0.46*	0.03	13.86	0.53*	0.03	15.39
Predicted adoption rate in untreated sub-population (ATU)	0.39*	0.04	8.96	0.46*	0.04	10.66	0.52*	0.04	11.16
Joint treatment and adoption rate (JTA)	0.10*	0.01	12.51	0.10*	0.01	13.86	0.10*	0.01	15.39
Population adoption gap (GAP)	-0.29*	0.03	-8.96	-0.36*	0.03	-10.66	-0.43*	0.04	-11.16
Population selection bias (PSB)	-0.02	0.02	-0.68	-0.00	0.03	-0.03	0.00	0.03	0.14
<b>Observed sample estimates</b> Rate of treated ( $N_e/N$ )	0.27*	0.02	16.23	0.21*	0.02	13.99	0.19*	0.01	12.82
Adoption rate ( $N_a/N$ )	0.10*	0.01	8.87	0.10*	0.01	8.87	0.10*	0.01	8.87
Adoption rate among the treated subsample	0.37*	0.04	8.87	0.46*	0.05	8.87	0.53*	0.06	8.87

\* denote statistical significance at 5% level

Source: (Survey data, 2018)

assuming symmetric exposure of the population to drought-tolerant maize varieties, the total benefits from the scaling of DTMVs have a present value of about US\$ 373 million when summed over the 15-year period of the simulation, of which producers capture about 60%. The total amount of the benefits is about twice the amount spent on research into maize improvement, including extension. The internal rate of return (IRR) of 89% can be said to be very high because the return is above the prevailing discount rate during the same period (10%). The findings suggest that the STMA project in Tanzania, with its associated R&D and scaling strategy for DTMVs is very beneficial for the maize sub-sector. In the second scenario, assuming universal physical access to seed for drought-tolerant maize varieties in addition to symmetric population exposure, the total benefits from the scaling of DTMVs would have a present value of about US\$ 441 million when summed over the 15-year period of the simulation. Producers still capture about 60% of the benefits, and the IRR of 118% remains attractive and is much higher than in the first scenario. The higher return is attributable to higher marginal benefits from the increased maximum adoption rate of DTMVs from 39% in the first scenario to 46%.

The third scenario assumes symmetric exposure and universal access to seed that is at an affordable price. Under this scenario, the government would incur additional expenditure due to offering seed price support to those unable to purchase seed at prevailing seed market prices. Under this scenario, the total benefits from the scaling of the DTMVs have a present value of about US\$ 499 million. The consistently higher benefits are attributable to

the yield benefits accruing from scaling the cultivation of DTMVs from 46% in the second scenario to 52% in the third scenario. Producers' benefits increase by 1% to 61% due to the price support that they enjoy from the government, while the internal rate of return, though high, declines from 118% in the second scenario to 96% in the third scenario due to the cost incurred by the government in administering a targeted smart seed-subsidy programme.

Assuming that the estimates hold true in the best-case scenario of 19% yield increase, and considering the change in total economic surplus gains as additional income for the AgGDP, the poverty impacts show that up to 1.6 million people would escape poverty over the period of 15 years.

### 5.3. Sensitivity analysis

With a conservative assumption that the yield benefit is 15% (instead of 19%), under the 39% maximum-adoption scenario, the total benefits would amount to US\$ 294 million, with a benefit/cost ratio of 1.9 (Table 4). With a more optimistic scenario of a 46% maximum adoption rate, which could be achieved if all farmers had physical access to the seed, the economic surplus would be reduced from US\$ 441 million to US\$ 348 million, with a 19% yield-benefit assumption. With the most optimistic scenario of a 52% maximum potential adoption rate, which could be achieved if farmers had access to affordable seed, the economic surplus would be reduced from \$499 million to US\$ 393 million, with a 19% yield-benefit assumption.

**Table 3.** Economic surplus expected under the assumption of 19% yield benefits from DTMVs.

Assumed adoption level	Producer surplus	Consumer surplus	Total economic surplus	Costs discounted (million US\$)	Benefit/Cost ratio	Internal rate of return (%)	People impacted (millions)
39% max.adoption	226	147	373	153	2.4	89	1.178
46% max.adoption	267	173	441	153	2.8	118	1.393
52% max.adoption	302	196	499	195	2.6	96	1.577

**Table 4.** Economic surplus expected under the assumption of 15% yield benefit from DTMVs.

Assumed adoption level	Producer surplus	Consumer surplus	Total economic surplus	Costs discounted (million US\$)	Benefit/Cost ratio	Internal rate of return (%)	People impacted (millions)
39% max.adoption	178	116	294	153	1.9	58	0.563
46% max.adoption	211	137	348	153	2.3	78	0.667
52% max.adoption	238	155	393	198	2.2	63	0.752

**Table 5.** Benefit-cost analysis of the DTMV scaling programme in Tanzania by region.

Region	Present Value of R&D Benefits			Costs (C) ('1000 US\$)	Returns		IRR %
	Producer ('1000 US\$)	Consumer	Total (B)		B-C ('1000 US\$)	B/C (ratio)	
Arusha	22410.8	8236.4	30647.2	9932.7	20714.4	3.1	80.9
Dar es Salaam	943.7	21275.3	22219.0	1665.8	20553.2	13.3	--
Dodoma	4980.2	10128.7	15108.9	3292.1	11816.8	4.6	149.4
Geita	3557.3	8456.2	12013.5	2750.0	9263.5	4.4	138.3
Iringa	14435.5	4575.5	19011.0	8170.9	10840.1	2.3	52.9
Kagera	16007.7	11948.9	27956.6	7493.3	20463.3	3.7	108.3
Katavi	3557.3	2744.7	6301.9	2750.0	3551.9	2.3	51.7
Kigoma	16007.7	10344.3	26352.0	7493.3	18858.7	3.5	98.9
Kilimanjaro	18142.1	7972.8	26114.8	8306.4	17808.4	3.1	83.3
Lindi	5691.6	4203.2	9894.9	3563.1	6331.8	2.8	69.0
Manyara	17786.3	6927.8	24714.2	8170.9	16543.3	3.0	78.5
Mara	11383.3	8477.1	19860.4	5731.5	14128.9	3.5	96.6
Mbeya	28871.0	13161.3	42032.2	14947.1	27085.1	2.8	70.3
Morogoro	16007.7	10784.5	26792.2	7493.3	19298.9	3.6	101.4
Mtwara	16007.7	6177.9	22185.6	7493.3	14692.3	3.0	76.0
Mwanza	22410.8	13477.7	35888.5	9932.7	25955.8	3.6	103.1
Njombe	7114.5	3413.0	10527.6	4105.2	6422.4	2.6	61.2
Pwani	7549.9	5355.5	12905.4	3563.1	9342.3	3.6	103.4
Rukwa	35572.7	4883.3	40455.9	14947.1	25508.8	2.7	66.4
Ruvuma	24900.9	6693.3	31594.2	10881.4	20712.8	2.9	73.8
Shinyanga	9248.9	7461.0	16709.9	4918.4	11791.5	3.4	93.8
Simiyu	5691.6	7700.9	13392.5	3563.1	9829.4	3.8	109.5
Singida	3557.3	6662.9	10220.2	2750.0	7470.2	3.7	107.7
Tabora	18142.1	11140.0	29282.1	8306.4	20975.7	3.5	99.2
Tanga	17786.3	9942.2	27728.5	8170.9	19557.6	3.4	93.6
<b>Total</b>	<b>347764.6</b>	<b>212144.6</b>	<b>559909.2</b>	<b>170392.0</b>	<b>389517.2</b>	<b>3.3</b>	<b>89.1</b>

#### 5.4. Economic surplus analysis based on region (horizontal multimarket model)

As earlier expressed, about 35% of the maize produced in Tanzania is traded between maize-surplus

and maize-deficit regions, with Dar es Salaam being the major maize-deficit region. The results for the horizontal multimarket model are presented in Table 5.

The largest benefits occur in the major maize-producing regions of Mbeya, Rukwa, Ruvuma, Mwanza, Arusha, and Kagera. Consumers in Dar es Salaam also benefit significantly from the price reductions resulting from increased production. The largest returns on investment occur in Dodoma, Geita, Simiyu, Singida, and Kagera.

## 6. Conclusions

The Tanzanian maize sector plays an important role in the economy and livelihoods of rural Tanzanians; however, it continues to face challenges from both biotic and abiotic stresses that affect productivity. The promotion of drought-tolerant maize varieties is expected to improve productivity and yield stability. In order to achieve this, CIMMYT, in collaboration with the government of Tanzania and the private sector, is implementing a project aimed at scaling the cultivation of DTMVs.

This paper examines the scalability of DTMVs in Tanzania under three scenarios: (i) scalability conditional on knowledge of DTMVs; (ii) scalability conditional on (physical) seed availability in addition to awareness; and (iii) scalability conditional on seed affordability in addition to awareness and (physical) seed availability. We find that DTMVs in Tanzania could be scaled out to 39% of the farming population if the whole population were made aware of them. Conditional on DTMV awareness and physical seed availability, DTMVs are scalable out to 46% of the farming community and to 52% if in addition to awareness and seed availability, the seed were also made affordable. The findings suggest huge potential for scaling DTMVs, which would also require substantial investment in Research and Development targeted at the DTMVs value chain.

Using the predicted scalability levels, we estimate the economic returns of the DTMVs scaling initiative in Tanzania by applying an economic surplus analysis both under closed market and horizontal multimarket model assumptions. Overall, results indicate that the scaling of DTMVs is highly viable, with estimated benefits of US\$ 373–499 million and potential to lift up to 1.6 million people out of poverty. The internal rates of return are above 60%, and the benefit–cost ratio above 3 under the different assumptions. Consumers are estimated to get 40% of the benefits due to price reductions, while producers would get 60% of the benefits arising from improvements in maize

productivity. Moreover, DTMV scaling can also reduce poverty, suggesting that benefits from the scaling of DTMVs are beneficial for the maize sub-sector and the whole economy. The largest benefits occur in the major maize-producing regions of Mbeya, Rukwa, Ruvuma, Mwanza, Arusha, and Kagera. Consumers in Dar es Salaam also benefit significantly from the price reductions accruing from increased production. The largest returns on investment occur in Dodoma, Geita, Simiyu, Singida, and Kagera. These findings provide a glimmer of hope for maize farmers and governments that strive to identify solutions to drought and other stresses. The results also strongly justify continued investment in drought-tolerant maize research and scaling. Furthermore, the findings also contribute to the realization of the importance of investing in innovations that support farmers' access to improved technologies, such as the use of input subsidies to scale the technology and reduce poverty.

## Note

1. A detailed explanation of the identification of different categories of households, and their status in terms of access to information and seed, the assumptions about the distributions of the treatment status variables (exposure, and access to seed at affordable prices) and their relationship to the adoption outcomes as well as to the estimation strategy for potential for scalability is discussed in Simtowe et al. (2019a and 2021).

## Acknowledgments

We would like to express our sincere gratitude to the International Maize and Wheat Improvement Centre (CIMMYT) for supporting our study through the Stress Tolerant Maize for Africa (STMA) project funded by the Bill and Melinda Gates Foundation (grant number OPP1134248).

## Availability of data and material

Authors do not have the right to share the data. However, it will be made available to the reader upon request.

## Consent to participate

Each questionnaire of this study had a front-page section that required informed consent for interview and publication before the interview could proceed. Interviewers were trained and under instructions to read aloud the consent statement to each interviewee

before the interview could advance. Participants were informed that they were under no obligation to answer any questions, or they could stop the interview at any time without giving any reasons and ask that any partial data recorded to be removed from the records. This way, the survey was consistent with CIMMYT-IREC policies and those generally applied in low-risk social science research.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

## Funding

This work was supported by Bill and Melinda Gates Foundation [grant no OPP1134248].

## Ethics approval

This study is based on survey methods involving interviewing farmers to answer questions about their socioeconomic and farming activities. Like all socioeconomic surveys (or any data collection that involves collecting data from family or community representatives) Institutional Research Ethics Committee (IREC) of the International Maize and Wheat Improvement Centre (CIMMYT) classified it as low risk study. Entire research methods were performed in accordance with the relevant guidelines and regulations issued by CIMMYT institutional research ethics committee (IREC).

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