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The International Maize and Wheat Improvement Center, known by its Spanish acronym, CIMMYT® (www.cimmyt.org), is an international, not-for-profit research and training organization. With partners in over 100 countries, the center applies science to increase food security, improve the productivity and profitability of maize and wheat farming systems, and sustain natural resources in the developing world. The center's outputs and services include improved maize and wheat varieties and cropping systems, the conservation of maize and wheat genetic resources, and capacity building. CIMMYT belongs to and is funded by the Consultative Group on International Agricultural Research (CGIAR) (www.cgiar.org) and also receives support from national governments, foundations, development banks, and other public and private agencies.

The Drought Tolerant Maize for Africa (DTMA) Project is jointly implemented by CIMMYT and the International Institute for Tropical Agriculture (IITA), and is funded by the Bill & Melinda Gates Foundation and the Howard G. Buffett Foundation. The project is part of a broad partnership also involving national agricultural research and extension systems, seed companies, non-governmental organizations (NGOs), community-based organizations (CBOs), and advanced research institutes, known as the DTMA Initiative. Its activities build on longer-term support by other donors, including the Swiss Agency for Development and Cooperation (SDC), the German Federal Ministry for Economic Cooperation and Development (BMZ), the International Fund for Agricultural Development (IFAD), the United States Agency for International Development (USAID), and the Eiselen Foundation. The project aims to develop and disseminate drought tolerant, high-yielding, locally-adapted maize varieties and to reach 30–40 million people in sub-Saharan Africa with these varieties within 10 years.

Abstract: This study was conducted in collaboration with HarvestChoice (IFPRI) and evaluates the potential impacts of the Drought Tolerant Maize for Africa (DTMA) project run by CIMMYT and the International Institute for Tropical Agriculture (IITA) in 13 countries of eastern, southern and West Africa, describing cumulative economic and poverty-reduction benefits to farmers and consumers in those countries over 2007-16, from higher yields and from diminished season-to-season yield fluctuations, through the adoption by farmers of improved, drought tolerant maize varieties. At the most likely rates of adoption drought tolerant maize can generate US$ 0.53 billion from increased maize grain harvests and reduced risk over the study period, assuming conservative yield improvements. Assuming more optimistic yield gains, the economic benefit is nearly US$ 0.88 billion in project countries. If all current improved varieties were replaced with drought tolerant ones, this could help more than 4 million people to escape poverty and many millions more to improve their livelihoods. If as expected farmers who adopt drought tolerant maize continue to grow it beyond 2016, the returns on investments to this work will become even more significant.

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Abstract

The study evaluates the potential impacts of the Drought Tolerant Maize for Africa (DTMA) project run by CIMMYT and the International Institute for Tropical Agriculture (IITA) in 13 countries of eastern, southern and West Africa: Angola, Benin, Ethiopia, Kenya, Malawi, Mali, Mozambique, Nigeria, Tanzania, Uganda, Zambia, and Zimbabwe and Ghana. It describes cumulative economic and poverty-reduction benefits to farmers and consumers in those countries over 2007-16, from higher yields and from diminished season-to-season yield fluctuations, through the adoption by farmers of improved, drought tolerant maize varieties. At the most likely rates of adoption, based on several recent studies and expert advice, drought tolerant maize can generate US$ 0.53 billion from increased maize grain harvests and reduced risk over the study period, assuming conservative yield improvements—that is, a yield advantage over normal, improved maize of 3-20%, depending on the site and seasonal conditions. Assuming more optimistic yield gains—a range of 10-34% over non-drought tolerant improved maize—the economic benefit is nearly US$ 0.88 billion in project countries. Optimistic yields plus full replacement of current improved varieties with drought tolerant ones could help more than 4 million people to escape poverty and many millions more to improve their livelihoods. The most striking economic and poverty benefits will accrue in Nigeria, Kenya, and Malawi, based on the amounts of maize sown in those countries, the importance of maize in inhabitants' diets and livelihoods, and their historical levels of adoption of improved maize. In comparison, the benefits will be more modest in Angola and Mozambique and moderate in Uganda and Mali. However, even if most DTMA project resources were allocated to the countries where the benefits are highest, the other countries would still benefit from the research spillovers that could be facilitated by cross-border seed market exchanges. Crucial components in this multi-disciplinary study included geographic information system data, data on the probability of failed crop seasons (PFS), yield data from breeders, projected maize adoption rates mainly from seed experts, and poverty data from socioeconomists. The drought tolerant varieties considered are the product of conventional breeding—that is, they are not transgenic. Follow-up research will address potential benefits from such factors as area expansion effects, increased cropping diversity (households can meet their maize requirements from a smaller portion of their land, freeing up space to sow other crops), and increased investment in fertilizer and other improvements, owing to reduced risk. Moreover, if as expected farmers who adopt drought tolerant maize continue to grow it beyond 2016, the returns on investments to this work will become even more significant.

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Acronyms

AgGDP	Agricultural Gross Domestic Product (total value of agricultural production)
CIA	Central Intelligence Agency
CIMMYT	International Maize and Wheat Improvement Center
CIESIN	Center for International Earth Science Information Network
CS	Consumers
CV	Coefficient of variation
DSSAT	Decision Support System for Agrotechnology Transfer
DTMA	Drought Tolerant Maize for Africa
FAO	Food and Agriculture Organization
FAOSTAT	FAO Statistical Database
FEWSNET	Famine Early Warning Systems Network
GIS	Geographic information systems
IIASA	International Institute for Applied Systems Analysis
IITA	International Institute for Tropical Agriculture
IFPRI	International Food Policy Research Institute
MSU	Michigan State University
NARS	National agricultural research systems
NGO	Non-governmental organization
OPVs	Open-pollinated varieties
PCA	Principal components analysis
PFS	Probability of failed season
PR	Producers
SSA	sub-Saharan Africa
SPAM	Spatial Production Allocation Model
USA	United States of America

1. Introduction

Maize is life to more than 300 million of Africa's most vulnerable people and is the most important cereal crop in Africa. It is grown in a wide range of agro-ecologies and with a wide range of complementary crops. When, as frequently happens, sub-Saharan Africa's recurrent droughts depress harvests, rural livelihoods are threatened. The development, deployment and cultivation of drought tolerant maize varieties are highly relevant interventions to reduce household vulnerability and food insecurity at all levels. Consequently, research on drought has been the subject of significant investments, especially during the last decade. Building on previous breeding successes and on-going research, the Drought Tolerant Maize for Africa (DTMA) project accelerates the development of new maize varieties with significantly improved drought tolerance. The vision of this project is to generate, by 2016, drought tolerant maize that provides a 1 ton/ha yield increase under drought stress conditions, increase the average productivity of maize under smallholder farmer conditions by 20–30% on adopting farms, reach 30–40 million people in sub-Saharan Africa (SSA,) and add an annual average of US$ 160–200 million of additional grain. This vision will be accomplished by distributing open-pollinated (OPVs) and hybrid varieties with increased drought tolerance to small-scale farmers. Farmers adopting drought tolerant maize will have less need to resort to damaging coping strategies such as reducing food consumption, selling assets or withdrawing children from school. There are a range of other benefits to reducing farmers' harvest risk. These include boosting their confidence to adopt other productivity-enhancing cultural practices, such as weeding and application of (higher levels of) fertilizer. Such actions will augment the effects of drought tolerant maize adoption and the currently low proportion of small-scale farmers who regularly sell surplus maize. This is of particular benefit as maize grain prices in drought-affected areas and years tend to rise, hence farmers can gain more.

The present ex-ante study is a component of the DTMA project and a joint activity of the CIMMYT and the International Institute for Tropical Agriculture (IITA)[1]. It is closely linked to the DTMA breeding and other socioeconomic activities, which provided the essential primary data underpinning the assessment. The outputs of the study are expected to inform investors, stakeholders, and partners on future research and dissemination strategies for achieving the greatest drought tolerant maize impacts in drought zones of Africa, and CIMMYT and IITA on where to invest (i.e. countries, farmer types and risk zones), so as to achieve the highest returns from drought tolerant maize. The focus of the ex-ante research is the estimation of the future returns from drought tolerant maize, in terms of aggregate economic benefit and poverty reduction. Usually, ex-ante research related to drought has focused on the country level—mainly on the benefits of mean yield increases related to drought varieties. This study differs from the conventional ex-ante impact evaluation in three main ways. Firstly, it uses a geo-referenced framework based on the probability of failed season concept (PFS; introduced in the data and methods section) and spatial production data, to better account for different drought levels. Secondly, it uses geo-referenced farm level data from several countries and estimates the benefits for different household types under each PFS zone, and thirdly the model takes into account the benefits from yield stabilization (risk or variance reduction) related to drought tolerant varieties. This is in addition to benefits derived from yield and production increases, thus providing a better estimate of the potential impacts of drought tolerant maize.

1 Corresponds to Milestone 8.3.2 of the DTMA project, see: http://dtma.cimmyt.org

2. Key scenarios and outline of the study

The main stakeholders of the DTMA project are project partners and policymakers in SSA. Based on their perceived primary interests elicited during the DTMA project and other meetings, the scenarios aim to explore **how benefits are achieved over different countries and drought zones, and how resources can be allocated most effectively.** Also to be studied are the expected maize production volumes and values in US dollars (US$), changes in poverty reduction, and the number of farmers who can be reached by investing in drought tolerant maize in Africa. The study explores the anticipated cumulative gains to be achieved over a 10-year period (2007–16). The counterfactual of the study is represented by non-availability of improved drought tolerant maize varieties. The key idea is to gain insights on where greatest impacts may be achieved by investing in drought tolerant maize in Africa.

The report is organized as follows: the present section outlines the key scenarios. The data and materials used in the models are illustrated in Section 3. Section 4 describes the economic methodology used to evaluate the benefits of mean yield increases and of yield stability as they translate into income stability at the aggregate PFS level and at the household level. The results are reported and discussed in Section 5 for the aggregate levels (nationally, and by PFS zone), the household level and the potential impacts on poverty. Section 5.1 reports the benefits of what would potentially happen in the case of a full replacement of all improved varieties with drought tolerant maize varieties, under both conservative and optimistic yield improvement scenarios, in terms of mean yield increases and yield variance reductions, as well as in terms of total production gains per failed season zone. All results are cumulative for 2007-16; not yearly. Also reported are the impacts on poverty in terms of the number of poor expected to escape poverty due to the adoption of drought tolerant maize and poverty reduction expressed as the percentage of the poor for each country by 2016. In Section 5.2 the potential benefits from the DTMA project are explored under conservative and optimistic scenarios of expected yield improvements. Potential yield gains and expected adoption rates are the critical data for the analysis. These parameters originate from a process of close consultation with breeders and other experts working closely with the seed companies, field studies, and household surveys in each project country. The results of these scenarios represent the vision of success of the project. In Section 5.3 the scenarios are disaggregated by household typology based on a wealth criterion classification (i.e., among poor, medium and prosperous farms) derived from the recent DTMA household field surveys.[2] As a case study, these scenarios illustrate the potential benefits expected from the adoption of drought tolerant maize in medium drought risk zones, as defined by using a 20–40% PFS, to explore the likely impacts in areas where drought risk is relatively higher (but not highest) and where significant vulnerable portions of the population live and maize production is located. Section 5.4 explores the results of a sensitivity analysis on the main parameters used in this study. Section 6 concludes by underlining the main results and some possible policy implications and provides a forward-looking view of improvements to the methodology and additional scenarios of interest that may be required in the future.

By 2011, a planned fine-tuning of the present assessment will enable the identification of the potential impact of investments that are alternative or complementary to drought tolerant maize and the most cost-effective scaling up zones for achieving the highest impact. Policymakers and local NGOs will also be informed on the most effective ways to overcome the institutional bottlenecks that limit or delay the impact of drought tolerant maize nationally.

2 To disaggregate and target the assessment among poverty groups, the data collected by the DTMA project in 2007–2008 on household assets was used to construct wealth indices using the principal components analysis (PCA) method used by Langyintuo and others. The PCA is used to extract from a set of variables the combinations that capture best the common information. Based on constructed wealth indices, the communities were segregated according to meaningful groups and factors affecting adoption and impact of technologies by wealth group.

3. Data

The study uses several layers of data: new breeding data from baseline household adoption and seed supplier surveys from the DTMA project, published breeding data, secondary information and expert opinion (mainly adoption rates), and primary data from the updated spatial characterization (GIS data) derived from the International Food Policy Research Institute (IFPRI) and CIMMYT, as well as other secondary sources. The data are differentiated in terms of agro-ecologies and risk zone areas and, in some cases, in terms of household typologies.

3.1 GIS data – maize production and drought risk

A GIS-based Africa Maize Research Atlas database (Hodson et al. 2002) provided some data for this study, updated with recent data from CIMMYT-IITA and IFPRI. Socioeconomic (community and household) data generated by the DTMA project from specific project areas, and remote sensing data on livelihoods by the Famine Early Warning Systems Network (FEWSNET, 2006) was also included. Data layers for probability and severity of drought across maize producing areas in Africa were developed using methods by Hodson et al. (2002) for southern Africa and the PFS by Thornton et al. (2006). The updated environmentally and socioeconomically defined drought zones served as a framework to target the DTMA household surveys in 2008; these are important sources of data.

An important aspect of this study is the spatial characterization of maize production with regard to the incidence of drought across the 13 DTMA countries. For this purpose, spatially distributed harvested area and production data disaggregated to 10km × 10km pixels were obtained from IFPRI (SPAM, 2000 version 2). To characterize drought risk through the PFS concept, Thornton et al. (2006) reflect the probability of growing season failure as a result of insufficient soil water availability (either a too-short growing season, or a too-severe level of water stress within the growing period). Soil water availability is assessed using 100 years of rainfall, potential evapotranspiration, and soil profile data. The PFS indicates the percentage of years in which harvest is likely to fail. For example, an area with a 100% PFS indicates no possible production in any year in that area. Another dimension of the DTMA project is to improve the livelihoods of at least 30–40 million people. Thus, it is important to know where the distribution of population falls within each country. Gridded data on rural and urban population density for all countries were available from the Center for International Earth Science Information Network (CIESIN) at Columbia University. To distinguish among geographical areas in which new DTMA varieties would likely have different levels of yield enhancing potential, the PFS was divided into five classes (0–5%, 5–10%, 10–20%, 20–40% and 40–100%). Areas of different drought intensity, hence of different potential drought impact, are shown in Figure 1.

Maize area and production within the geographic extent of each PFS class were then estimated. Given the spatial complexity of known maize production patterns across the countries of the DTMA project, different estimation approaches were tested and applied. Grid cell (pixel) scale yield estimates are available from three yield estimations at the pixel level: the Spatial Production Allocation Model (SPAM), the rescaled FAO yield potential surface, and the Decision Support System for Agrotechnology Transfer (DSSAT) crop simulation model, all of which are explained below.

i. Average farmer yield (2005): from SPAM (Figure 2).
ii. Potential yields for high- and low-input rainfed systems (crop suitability surfaces) from FAO / International Institute for Applied Systems Analysis (IIASA 2001); see Figure 3. These crop suitability layers are used as input into the SPAM model. Potential yields are calibrated to expectations about yield attainable using best farming practices under specified input conditions. Yields are determined via expert-based rules conditioned by growing season (thermal and rainfall) conditions, average slope and soil properties. Given that FAO yield potential data contain both high-level and low-level management inputs, low management is picked as default. If all of the models (SPAM, FAO yield potential low-input and crop model) do not work well in certain counties, FAO high yield potential input data is added for evaluation. However, since the FAO layer is a yield potential estimation, its yield value is not applied in the study directly. Yields are rescaled

based on country yield tables based on expert opinion. The FAO yield potential layers (high and low input) are only applied to identify spatial patterns in different PFS zones.

iii. Potential yield for low input rainfed systems estimated by the DSSAT crop simulation model (Figure 4).

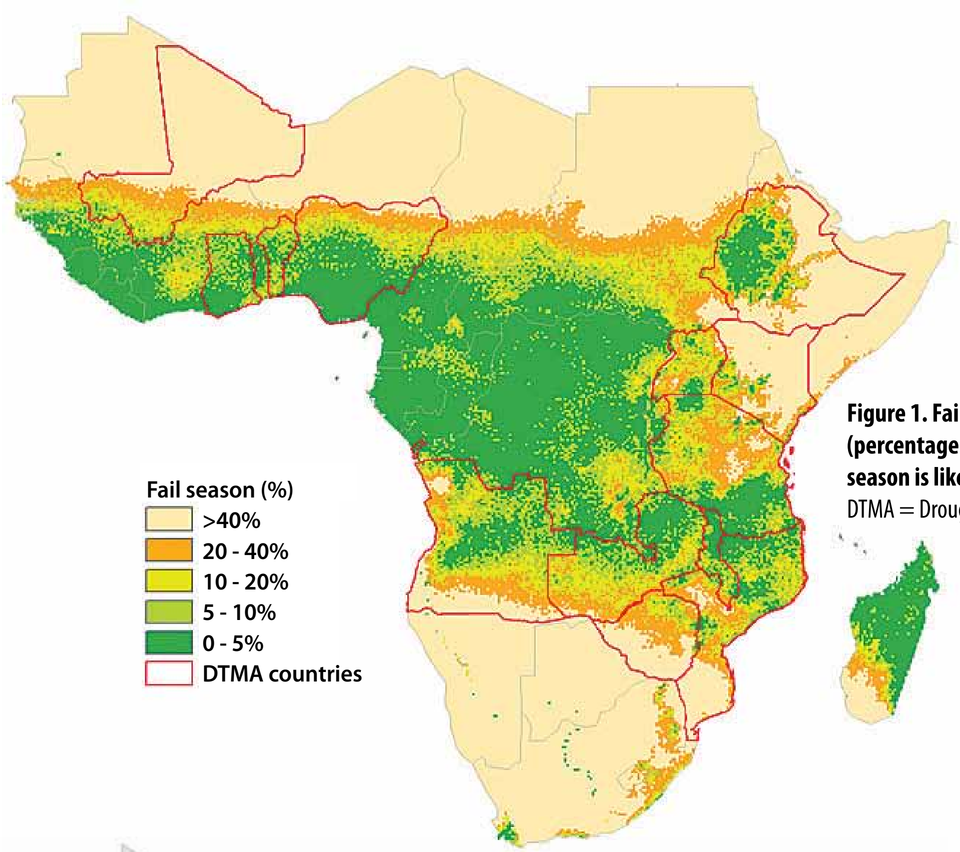

Figure 1. Failed season distribution (percentage of years in which growing season is likely to fail).
DTMA = Drought Tolerant Maize for Africa.

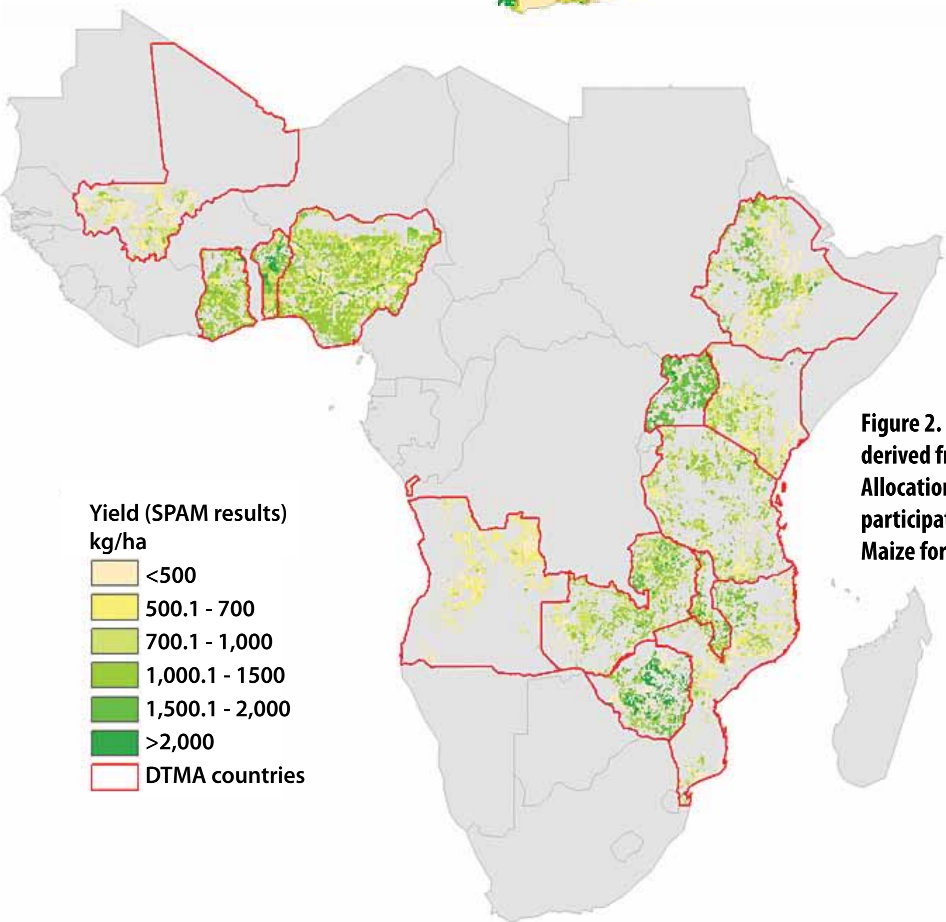

Figure 2. Average farm maize yield derived from the Spatial Production Allocation Model (SPAM), for countries participating in the Drought Tolerant Maize for Africa (DTMA) project.

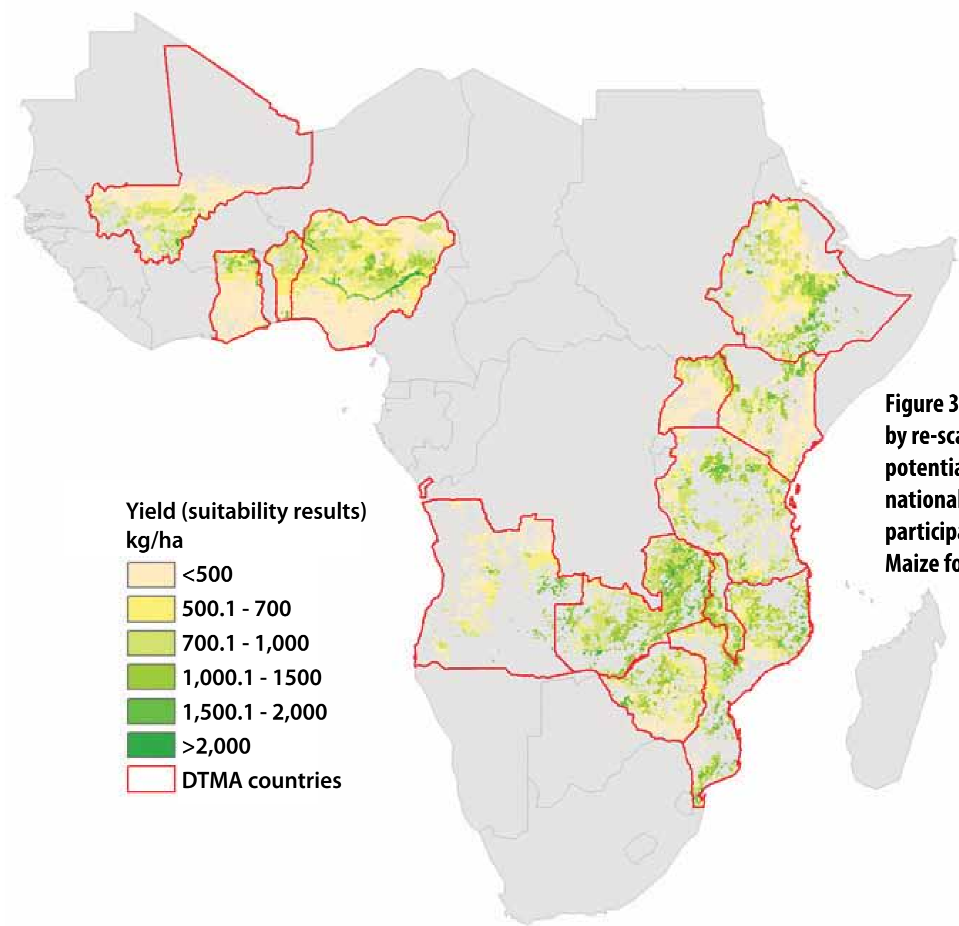

Figure 3. Maize yield map derived by re-scaling FAO low-input maize potential yields using expert-based national farm level yields, for countries participating in the Drought Tolerant Maize for Africa (DTMA) project.

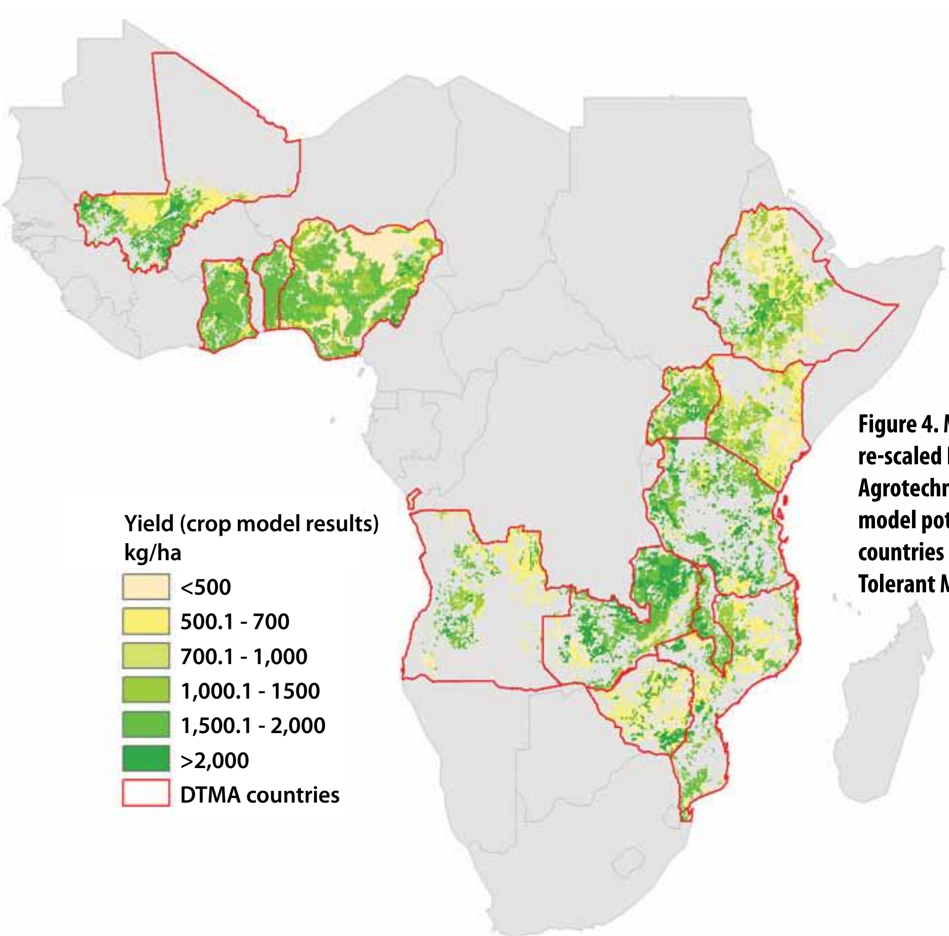

Figure 4. Maize yield derived from re-scaled Decision Support System for Agrotechnology Transfer (DSSAT) crop model potential yield estimates for countries participating in the Drought Tolerant Maize for Africa (DTMA) project.

After evaluating three yield estimations at the pixel level in all DTMA focused countries, we found that none of the models could be used for yield in all DTMA countries. In fact, due to the inherent complexity of the spatial conditions, each model works in certain countries but not in the rest. After evaluating all three models in each country, the best fit model for yield estimation was applied in the country specific studies.

Maize production and yield for each PFS class are presented in Table 1 for each country, validated against FAO 2001–06 yield data and CIMMYT 1997–99 yield data. Clearly, most of the maize production takes place in areas with a PFS lower than 40% (i.e., with more reliable rainfall). However, there is still considerable maize production in areas with higher rainfall variability, most notably in Zimbabwe and Kenya, as well as in Nigeria. Overall, Nigeria is the country with the most maize production followed by Ethiopia and Kenya.

Population distribution across the different areas in each country is another important factor; especially where transport networks are under-developed and transportation is very costly. Table 2 illustrates the population distribution in urban and rural areas across each PFS in each country. Farming is the main occupation for most people, with more people living in rural areas. Many live in areas with PFS lower than 20% but a large proportion of people live in higher drought risk areas.

3.2 Price data

Most of the information on national and household maize prices comes from the FAO Statistical Database (FAOSTAT) and from household surveys, respectively. In some cases (e.g. in Tanzania), the relevant information was received from bulletins published by the national agricultural research centers. These often take into account both the

Table 1. Production (000 t) and yield (t/ha) by probability of failed season (PFS), cumulative values for 2007-16.

	PFS 0–5%		PFS 5–10%		PFS 10–20%		PFS 20–40%		PFS 40–100%			
	Maize prod.	Yield	Maize prod.	Yield	Maize prod.	Yield	Maize prod.	Yield	Maize prod.	Yield	Total prod.	Avg. yield
Kenya	200	2.17	353	1.58	587	1.36	547	1.49	410	1.08	2,098	1.4
Ethiopia	1,014	2.31	442	1.92	409	1.85	382	1.78	409	1.5	2,656	1.93
Uganda	138	1.71	172	1.68	457	1.66	230	1.64	50	1.5	1,047	1.66
Tanzania	498	1.63	276	1.62	502	1.5	628	1.33	131	1	2,034	1.44
Angola	14	0.78	19	0.72	56	0.64	129	0.61	182	0.35	400	0.46
Malawi	884	1.19	1,044	1.2	505	1.11	157	0.97	0	0	2,590	1.16
Mozambique	267	1.14	285	1.09	257	0.98	263	0.86	218	0.75	1,290	0.95
Zambia	156	2.07	316	1.93	514	1.65	185	1.4	14	1.28	1,185	1.71
Zimbabwe	50	0.82	205	0.8	290	0.74	1,006	0.77	447	0.68	1,997	0.75
Nigeria	2,585	1.8	925	1.81	387	1.48	92	0.98	4	0.9	3,994	1.73
Ghana	306	1.6	631	1.45	100	1.41	0	–	4	1.35	1,041	1.49
Benin	229	1.18	341	1.14	117	0.96	1	0.83	7	0.7	694	1.11
Mali	15	1.6	49	1.56	125	1.29	54	1.29	1	0.9	244	1.35

Source: International Food Policy Research Institute (IFPRI), GIS data, and Drought Tolerant Maize for Africa (DTMA) project data.

Table 2. Rural and urban population ('000 of people in 2000).

	PFS 0–5%		PFS 5–10%		PFS 10–20%		PFS 20–40%		PFS 40–100%		
	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Total
Kenya	489	3,165	2,576	5,364	1,619	6,705	1,228	4,811	296	3,755	30,610
Ethiopia	3,572	19,933	1,394	10,757	521	8,228	828	7,383	1,051	9,136	62,802
Uganda	244	2,038	272	3,562	2,162	8,885	204	5,489	6	459	23,322
Tanzania	2,028	5,438	3,568	4,288	3,720	6,898	704	5,210	331	971	33,158
Angola	357	3,817	844	2,422	681	1,550	1,217	662	431	799	12,779
Malawi	722	3,254	1,014	3,519	124	1,801	3	581	–	–	11,018
Mozambique	358	2,432	1,224	3,392	1,004	2,938	475	1,842	2,237	2,388	18,291
Zambia	550	2,028	1,288	1,659	1,774	2,161	123	841	80	81	10,586
Zimbabwe	–	248	75	744	748	1,225	1,118	2,791	2,713	2,864	12,526
Nigeria	29,212	40,725	2,985	7,337	2,294	10,167	4,928	11,880	287	3,210	113,026
Ghana	4,793	7,990	1,642	3,570	252	469	–	–	45	42	18,803
Benin	1,804	889	421	2,055	175	919	1	54	–	2	6,321
Mali	28	178	85	800	1,465	2,474	503	2,676	643	2,567	11,418

PFS = probability of failed season. Source: International Food Policy Research Institute (IFPRI), GIS data, and Drought Tolerant Maize for Africa (DTMA) project data.

large seasonal variation in prices by normalizing the data over the year, and the fact that different prices are obtained at the producer and consumer levels. This is relevant given that the adoption of drought tolerant maize seed can help stabilize prices annually during those years when climate risk and drought might otherwise cause large variations and risk.

3.3 Expected yield gains and yield variance reductions

Expected yield gains and yield variance reductions are among the most important components of this analysis. Two main studies were utilized to estimate potential mean yield gains and yield variance reductions among drought tolerant maize varieties, improved varieties and landrace varieties. The first two sources are the comprehensive studies by Bänziger et al. (2006) and Magorokosho (2006), where the performance of hybrids of drought tolerant maize was compared with that of released and pre-released improved private sector varieties and landrace varieties in multiple locations across eastern and southern Africa. More specifically, the projected yield increases are based on field trials including 273 trials in eastern and southern Africa over three years, conducted across a wide range of input and yield levels (Bänziger et al. 2006; Magorokosho, 2006). To evaluate potential yield variance reductions, data from the field trials by Bänziger et al. (2006) and Magorokosho (2006) were used to determine the yield stability among drought tolerant varieties and other improved and landrace varieties in multiple locations. When translating yields from trial sites to farmers' fields, yield gains were estimated with caution, since farmers' fields usually deliver lower yields than trial sites. Two scenarios were examined in this study. The first is a more conservative scenario with gains based on average yield gains observed among new drought tolerant maize hybrids as compared to hybrids from conventional breeding efforts (which do not select for drought tolerance), taken from Bänziger et al. (2006). The second is a more optimistic (best case) scenario, with gains based on yield increases of best drought tolerant maize hybrids, as compared to hybrids from conventional breeding. Data on yield gains and yield variance reduction used here for conservative and optimistic scenarios, for each of the yield levels, under each class of PFS are presented in Table 3. These mean yield gains and yield variance reductions are also used in the household level studies. The gains are cumulative over 2007-16, rather than yearly.

3.4 Yield advantage of improved varieties over landraces

Country, regional, and household level data are a mix of the improved maize varieties and landraces. Thus a careful evaluation of average yields between improved maize varieties and landrace varieties is warranted. Data on the yield advantage of non-drought tolerant improved varieties over landraces mainly came from household data and previous studies (e.g. Magorokosho, 2006) that document the yield advantage complemented by expert (breeders') opinion. An important factor in the yield advantage of improved varieties is the additional fertilizer use associated with using improved varieties, as outlined, for example, in Table 4 (data from DTMA household surveys). Improved varieties obviously perform significantly better than landraces. However, for this study, a conservative yield advantage of 50% is considered because breeders familiar with the improved and landrace varieties indicated that a 50% yield advantage (net of additional effects of fertilizer use) would be a typical average for all countries in all production areas. This yield advantage between landrace and improved varieties is used to calculate the benefits for each PFS and the related benefits for different household types. The yield advantage data in Table 4 average 47.5%, despite significant variation over survey sites. Thus, overall, a 50% yield advantage for non-drought tolerant improved varieties is confidently used in this study.

Table 3. Expected mean yield gains and yield variance reductions of drought tolerant improved varieties over landraces cumulative values for 2007-16.

	Mean yield gains of drought tolerant over normal improved varieties		Yield variance reductions	
Yield level (t/ha)	Conservative	Best	Conservative	Best
0–1	13.0%	20.4%	10%	15%
1–2	18.7%	33.9%	10%	15%
2–3	19.5%	29.4%	10%	15%
3–4	12.7%	20.8%	10%	15%
4–5	13.6%	23.0%	10%	15%
5–6	6.9%	21.1%	10%	15%
6–7	4.2%	16.0%	10%	15%
7–8	2.9%	15.1%	10%	15%
8–9	6.0%	20.5%	10%	15%
9–10.5	3.2%	10.4%	10%	15%

Source: Yield gains data based on Bänziger et al. (2006); variance reduction based on expert opinion.

3.5 Adoption rates

Information on current and potential adoption rates originates from the DTMA seed sector study (Langyintuo et al. 2008) and the household data collected in 2007 for five eastern and southern Africa countries, while for West Africa, some estimates are based on a recent paper by Alene et al. (2009). The adoption rates from the household surveys provide the basis for assessing the potential adoption rates for the project from primary data. Experts working closely with seed distributors provided invaluable information, especially on potential adoption rates. A summary of the current and potential adoption rates used in this report is provided in Table 5. The expected adoption rates of drought tolerant germplasm from 2006 to 2016 are used to estimate the potential benefits of drought tolerant varieties for each PFS in each country. They are also used to determine the area under landrace and improved varieties for the household level case studies in Section 5.3 for four countries.

Adoption of improved germplasm is the sum of the adoption rate of open-pollinated varieties (OPVs) and hybrids. It is clear that among the countries in eastern Africa, Kenya is expected to make substantial progress compared to the rest of the countries. It has an impressive adoption rate of 85%. In southern Africa, Zambia and Zimbabwe have the highest adoption rates for improved varieties (85% and 81%, respectively).

3.6 Demand and supply elasticities

Country specific demand and supply elasticities, along with the source for each estimate, are presented in Table 6. In the absence of country specific demand estimates, the demand elasticity for all crops in SSA is used, and a supply elasticity of 0.2 estimated by Gabre-Madhin et al. (2002).

3.7 Research costs

Research costs (Table 7) are extracted from the DTMA 2007–11 project budget which includes institutional overheads, is available per year, and is differentiated per allocation to CIMMYT and IITA. It is assumed that all project costs contribute in different ways and at different stages to the final impact, hence project breeding, genetic research, socioeconomic studies, delivery and dissemination costs are included. However, the national costs of research and extension are

Table 4. Advantage of improved varieties (IVs) over landraces (LRs) and associated rates of fertilizer use.

	Fertilizer used		Fertilizer not used			Fertilizer use (kg/ha)		
Location	Yield IV/LR	Yield IV/LR	LR – NPK	LR – Urea	IV – NPK	IV – Urea	IV/LR NPK rate	IV/LR Urea rate
Kenya – Machakos	1.89	1.86	17.76	13.36	34.79	27.90	1.96	2.088
– Makueni	1.44	2.08	28.34	18.72	48.41	36.49	1.708	1.948
Zambia – Monze	1.04	1.29	25.1	25.1	113.9	120.2	4.538	4.789
– Kalomo	1.23	1.37	73.8	49.6	273.8	271.9	3.709	5.478
Nigeria – Malunfashi	1.70	1.58	66.8	41.1	124.2	86.1	1.86	2.09
– Rano	1.28	0.94	26.5	17.0	105.3	64.3	3.97	3.78

Source: Drought Tolerant Maize for Africa (DTMA) household surveys, averaged across different environments.

Table 5. Past, current, and potential assumed adoption rates (%) for improved and drought tolerant (DT) maize.

	Adoption improved germplasm 1997	Adoption improved germplasm 2006	Adoption improved germplasm 2016	Adoption increase 2007-2016	Proportion DT germplasm 2006	Proportion DT germplasm 2016
Ethiopia	8	19	37	18	10	48
Kenya	71	72	85	13	10	46
Tanzania	4	18	38	20	10	49
Uganda	9	35	48	13	10	40
Angola	12	5	17	12	10	43
Malawi	14	22	43	21	20	50
Mozambique	9	11	27	16	10	48
Zambia	23	73	85	12	10	44
Zimbabwe	82	60	81	21	10	55
Benin	10	15	20	5	15	25
Ghana	22	25	40	15	15	35
Mali	10	15	30	15	15	30
Nigeria	20	25	45	20	20	40

Sources: Drought Tolerant Maize for Africa (DTMA) project documents and expert opinion (DTMA and partners, mostly by John MacRobert, CIMMYT Zimbabwe). West African estimates are based on the results of the seed systems study, as well as on Alene et al. 2009.

excluded at this stage. Institutional overheads and management costs are all included as they are an integral part of the effort.

These costs are used to estimate the potential returns to the investments from the DTMA project. However, the results should be interpreted with caution since the costs related to breeding for DTM, which started before 1996, are not included in these calculations. These costs will be included in future versions of the model when the respective role of earlier projects by CIMMYT and other research centers, as well as the contribution by national partners and by the extension systems in the dissemination and delivery of seeds and innovations, will be factored in. Because of the close partnership between CIMMYT/IITA and their national agricultural research systems (NARS), no attempt is being made to differentiate their separate contributions for attributing impacts or the returns to their individual investments.

3.8 Household data

The household data sets were collected in 2007 as part of DTMA project activities in Kenya, Ethiopia, and Nigeria, with 350 households interviewed per country and 100 in Zimbabwe. The households were selected in these four countries in districts falling within the 20–40% PFS, to represent a case study of disaggregated potential household impacts of drought tolerant maize. The districts and exact PFS range where they fall within each country are given in Table 8. The areas are located mostly below a 30% PFS, although in Kenya the PFS is relatively higher (up to 60%) and relatively lower in Mozambique and Zambia.

The parameters of interest from these surveys are illustrated in Table 9. They come mainly from the DTMA household surveys although a few parameters from FAO are also used. The table introduces the categorization of three household types (representative poor, average, and prosperous farms), coinciding with the categories derived from the household surveys in the study districts, to allow disaggregating the results and drawing the implications for different users (and consumers) of DTMA maize. In addition to the cross sectional data, panel data are also needed to derive the coefficients of variation (CV) for yield, the maize income, and total household income for each household type. However, panel data for each country were not available at the time of developing these scenarios and will be available by 2011, according to the DTMA project milestones. Hence, the only datasets available were the Rural Household Surveys of Kenya in 1997, 1998, 2000 and also the Rural Indicators Survey in 2002, both collected from a collaboration of Egerton University and the Tegemeo Institute-Michigan State University (MSU). For that study, out of more than 5,000 households included in the study from 1997 to 2002, 454 were interviewed. The datasets have detailed data on crop production. The CVs of yields for poor, average, and prosperous households were 0.59, 0.59, and 0.57, respectively, while the CVs for total income were 0.43 for poor households and 0.4 for average and prosperous households. In the absence of other panel data sets, the CV is used for the rest of the countries. Homogeneous household maize price data from the DTMA study were used, for both buyers and sellers.

The current yield, annual maize income, total household area, and maize area planted are used in equations (11) and (12) in Section 4.4 in the subsequent section on methodology, along with the CV of yield and the CV of income from the Kenya panel dataset mentioned above.

Table 6. Demand and supply elasticities.

	Demand	Supply	Source
Kenya	−0.53	0.173	Omamo et al. 2007
Ethiopia	−0.53	0.2	Omamo et al. 2007
Uganda	−0.53	0.157	Omamo et al. 2007
Zimbabwe	−0.075	0.45	Cutts and Hassan, 2003
All other DTMA countries	−0.35	0.2	Gabre-Madhin et al. 2002

DTMA = Drought Tolerant Maize for Africa.

Table 7. Research cost (US$) data for Drought Tolerant Maize for Africa (DTMA), 2007– 2011.

	Year 1	Year 2	Year 3	Year 4	Year 5
IITA		1,905,125	1,940,338	2,016,351	2,026,302
CIMMYT	5,800,000	5,934,100	5,677,811	5,795,466	6,153,782
Total	5,800,000	7,839,225	7,618,149	7,811,817	8,180,085

Source: DTMA project documents.

Table 8. Household locations for case studies.

Country	District	PFS	Maize mega-environment
Kenya	Makueni	40–60% (80%) <30% (20%)	Dry mid altitude (50%) Dry lowland (50%)
Kenya	Machakos	40–60% (80%) <30% (20%)	Dry midaltitude
Ethiopia	Adama	<30% (50%) 30–40 (50%)	Wet upper midaltitude (90%) Dry midaltitude (10%)
Ethiopia	Kombolcha	<30% (90%) 30–40% (10%)	Dry midaltitude
Zimbabwe	Masvingo	10–40% (40%) >40% (60%)	Dry midaltitude, Dry lowland
Zimbabwe	Vikita	20–40% (60%) > 40% (40%)	Dry lowland Wet upper midaltitude
Nigeria	Malumfashi	<30% (80%) 30–40% (20%)	Wet lowland
Nigeria	Rano	<30%	Wet lowland

Source: Drought Tolerant Maize for Africa (DTMA) and GIS-based probability of failed season (PFS) classification.

Table 9. Household parameters for four major countries used as case studies.

	Kenya	Ethiopia	Zimbabwe	Nigeria
Current yield (t/ha)				
Representative poor farms	0.97	1.61	0.2	1.3
Representative average farms	1	1.92	0.325	1.4
Representative prosperous farms	1.35	2.5	0.55	1.6
Annual maize income (US$)				
Representative poor farms	196	583	109	164
Representative average farms	231	644	176	258
Representative prosperous farms	316	882	298	619
Total household income (US$)				
Representative poor farms	1,188	814	1,099	767
Representative average farms	1,255	861	2,234	1,060
Representative prosperous farms	1,612	1,132	3,010	1,744
Maize planted area (ha)				
Representative poor farms	0.48	1.1	0.49	1.34
Representative average farms	0.68	1.7	0.55	2.7
Representative prosperous farms	1.12	2.75	0.61	2.19
Total farm area (ha)				
Representative poor farms	1.42	1.3	1.1	6.03
Representative average farms	1.44	2.7	1.55	6.5
Representative prosperous farms	1.45	6.2	1.86	6.3
Annual maize price (2006) (US$/t)				
Representative farms (all types)	138	96	346	360
Maize price CV (5 years)				
Representative farms (all types)	118	51	59	27

Source: Drought Tolerant Maize for Africa (DTMA) project household survey, 2008–2009; and FAOSTAT, used as comparison for producers' prices (US$/ton) as well as other national sources (Ethiopia: Central Statistical Agency, http://www.csa.gov.et; Kenya: Regional Agricultural Trade Intelligence Network, http://www.ratin.net/; Nigeria and Zimbabwe: http://www.fews.net. CV = coefficient of variation.

4. Methods for the ex-ante assessment

This study was implemented by a team of mainly social scientists from CIMMYT, IITA, and the University of Georgia, USA, in collaboration with breeders and GIS specialists from CIMMYT, IITA, and IFPRI. The focus is to estimate—in an ex-ante fashion—the economy-wide potential impact of investing in drought tolerant maize in Africa, on total maize production, on household income, and on poverty reduction. An economic surplus framework based on Alston et al. (1995) is used, along with models to evaluate the additional benefits of increased yield stability (Gollin 2006; Kostandini et al. 2009) and differentiate the results by agro-ecology, drought risk areas, and household wealth typology. Increased production of grain from drought tolerant maize varieties is valued by means of established methods (Hassan et al. 2001). Within an analytical framework for linking micro-economic data to national and regional assessments, the study builds upon data from the household baseline surveys developed in 2007–2008 in the DTMA project, to underpin the projections based on econometric models. The tools used build on those developed by Kostandini et al. (2009). An attempt is made to limit the number of assumptions that are often used in such methods, by using better socioeconomic data from surveys, GIS, and secondary breeding data from CIMMYT and from the DTMA project. Nevertheless, some important assumptions, as discussed in this chapter, remain. To improve the accuracy and disaggregation of the results, in terms of the incidence of drought risk, the approach uses the PFS method to characterize maize drought tolerance risk. The simulations use a spatial framework that takes into account the yield levels under the five different PFS classes in each country, and matches them with the potential gains under drought based on several drought tolerant maize field trial data. This framework allows the identification of cumulative potential benefits for the study time frame not only at the national level but also within different areas of each country. This is useful in helping to pinpoint regions where breeding has the highest likelihood of generating impact in terms of monetary and poverty levels. As introduced in the data section, the analysis is also carried out at the household level, as a case study to shed light on the potential impacts of drought tolerant maize on different household types. A subset of countries—Ethiopia, Kenya, Nigeria, and Zimbabwe—is studied as these have better DTMA project data. The household level assessment focuses on medium drought risk areas, areas along the lines of the DTMA community and household surveys. It thus differentiates the households by type, associated with some specific recommendation domains. It also uses mean yield, as well as yield variability reductions (that is, yield stability improvements), in line with the emphasis on reducing production risk. Although in the medium-term market linkages between regions can affect welfare impacts from adopting improved technology, the effects are greater after 5–10 years than at project implementation.

4.1 The surplus analysis model and drought risk assessment

The framework to evaluate the potential impact of technologies that increase mean yield is developed in Alston et al. (1995). This partial equilibrium approach is based on consumer and producer surplus changes at the market level. To maintain consistency with the benefit measures of research-induced variance reduction, an extension of the approach is applied in this study. The benefits of mean yield increases as changes in producer and consumer income for rainfed areas with uniform levels of drought risk are measured. Specifically, the changes in producer and consumer income are estimated for producers and consumers under each PFS interval. Thus, the model does not take into account market interactions between PFS zones but rather the markets are based on the spatial occurrence of drought. Furthermore, there are no spatially disaggregated price data or transaction costs to account for trade between agro-ecological drought risk zones. In addition, it is difficult to capture spillovers across zones for variance reductions. Under this setup, the production of maize under each PFS is composed of a representative producer and consumer. The drought tolerant varieties result in yield increases translated into a unit cost reduction in producer costs. Thus, the producer experiences a change in income due to a lower production cost and lower prices due to market induced responses. The consumer experiences a gain in income by buying at lower prices. The changes in producer and consumer income can be approximated as:[3]

(1) $Pr.\ Y = KPQ_p - \Delta PQ_p$

(2) $Cs.\ Y = \Delta PQ_c$

where *Pr.Y* is the change in producer income, *Cs.Y* is the change in consumer expenditure in the market, ΔP is the change in price, Q_p is the quantity produced, Q_c is the quantity consumed, and *K* is the unit cost reduction, assuming a parallel supply curve shift, calculated as:

$$K + \left[\frac{E(G)}{\varepsilon} - \frac{E(C)}{1 + E(G)} \right] A_t$$

where *E (G)* is the expected increase in yield per hectare, *E (C)* is the proportionate change in variable costs per hectare, A_t is the expected adoption rate, and ε is supply elasticity at the farm level.[4] There are estimates (Bänziger et al. 2006; Magorokosho 2006) of improved yields of drought tolerant maize varieties compared with (a) other improved maize varieties and (b) landrace varieties. In order to estimate the potential benefits of drought tolerant maize adoption for 2006–16, both factors need to be considered, i.e., a substitution effect where farmers switch from other improved maize varieties to drought tolerant maize varieties, and an increase in drought tolerant maize adoption as farmers replace landraces with drought tolerant varieties. Under these conditions the overall unit cost reduction can be calculated as:

$$K = K_1 + K2 = \left[\frac{E(G)_1}{\varepsilon} - \frac{E(C)_1}{1 + E(G)_1} \right] A_{t1} + \left[\frac{E(G)_2}{\varepsilon} - \frac{E(C)_2}{1 + E(G)_2} \right] A_{t2}$$

where K_1 indicates the unit cost reduction from drought tolerant maize substituting other improved maize varieties, and K_2 indicates the unit cost reduction from drought tolerant maize substituting landrace varieties.

Detailed information on yield advantages and adoption of other improved, drought tolerant and landraces maize varieties needed to estimate the model is presented in the data section. Changes in price after the introduction of new technology can be calculated from elasticities of consumer demand (η), producer supply elasticity at the market level (ψ), and the initial prices and quantities sold in each drought risk zone. More specifically, assuming linear supply and linear demand, the new equilibrium price is:

$$P_1 = (\lambda - \delta + KP_0)/(Q_0/P_0)(\eta + \psi)$$

where λ and δ are the intercepts of the linear supply and the linear demand curves, respectively, and Q_0 is the initial equilibrium quantity, P_0 is the initial equilibrium price, and P_1 is the new equilibrium price.

4.2 Benefits from yield variance reduction

Yield variance reduction has been a priority for some crop improvement programs (Heisey and Morris 2006) and evaluated at the global level for CIMMYT maize germplasm by Gollin (2006). Methods for quantifying risk and transferring the benefits associated with price variance reductions were developed by Newbery and Stiglitz (1981). Kostandini et al. (2009) modified this framework to incorporate changes in yield variance reductions and their model is outlined in this section and the next. Under this framework, risk averse producers and consumers benefit from reductions in yield variability which lead to reductions in the variation of income and therefore less risk. The framework essentially finds the monetary value associated with reduction of risk benefits. However, the risk analysis does not distinguish between the variance of landrace varieties and improved varieties. Under this framework, maize production areas under each PFS are considered to consist of a representative producer and consumer exposed to price and quantity variability at the market level. The individual producer facing this risk has a Von-Newman Morgenstern utility function of income *U(Y)* with:

(3) $R = -YU''(Y)/U'(Y)$

where *R* is the coefficient of relative risk aversion. Producers are risk averse with respect to variations in income, while changes in yield variations influence income variation. The reduction in yield variance will change the distribution of income from $\tilde{Y}_0$ with mean $\bar{Y}_0$ and CV σ_{y0} to distribution $\tilde{Y}_1$ with mean $\bar{Y}_1$ and CV σ_{y1}. The money value B for this reduction in income variation can be found by equating:

(4) $EU(\tilde{Y}_0) = EU(\bar{Y}_1 - B)$

[3] Equations (1) and (2) are simplifications of the classic consumer and producer surplus calculation and essentially ignore small second round benefits associated with individual price responses which may potentially underestimate the total benefits. However, this simplification leads to an upper boundary of at most 0.5% of the total benefit estimates.

[4] Following Alston et al. (1995), the elasticity of supply in the formulae for calculating K is assumed to be 1 at the farm level for the adopting farmers. This is different from the elasticity at the market level that accounts for overall production including adopters and non-adopters.

Expanding both sides of this equation using a Taylor series approximation, dividing both sides by $\bar{Y}_0 U'(\bar{Y}_0)$, neglecting terms of order higher than σ_{y1} the equation reduces, and focusing solely on yield variance reductions, producer risk benefits are measured as:

$$(5) \quad \frac{B}{\bar{Y}_0} = \frac{1}{2} R\{\sigma^2_{y1} - \sigma^2_{y1}\}$$

Consumers may also benefit from a yield variance reduction through changes that variance of prices in each zone have on their expenditures. These consumer risk benefits can be measured as:

$$(6) \quad \frac{B}{\bar{X}_0} = \frac{1}{2} R\{\sigma^2_{p0} - \sigma^2_{p1}\}$$

where $\bar{X}_0$ is the mean consumer expenditure, σ^2_{p0} and σ^2_{p1} are the squared CV of prices before and after the yield variance reduction, respectively, as price variability is the only way by which yield variability affects consumers. Simplifying the assumptions on equations (5) and (6) are that prices in other markets and producer and consumer income from other sources stay constant. Specific assumptions are needed on the shape of the supply and demand curves to determine the effects of yield variance reductions on price variability and, thus, producer income and consumer expenditure variability. Results are sensitive to the specification of the source of risk (Newbery and Stiglitz 1981). In this study, the focus is on the impact of technologies that reduce the variance of yields and the source of risk lies on the supply side. Additive supply risk is then assumed with linear demand and supply curves. Demand and supply are thus specified as:

$$(7) \qquad Q_d = \theta - \gamma P \ (\gamma > 0)$$

$$(8) \qquad Q_5 = \alpha - \beta P \ (\beta > 0)$$

where Q_d and Q_5 are quantity demanded and supplied, respectively. P is price, θ is a constant, and α is a normally distributed random variable with mean μ_α and variance σ_α.[5] Thus, demand is stable and supply fluctuates due to weather, technology and other factors.

The yield variance reduction can be incorporated in the analysis as a reduction in the variability of supply (i.e. as a reduction in σ_α). Specifically, if the coefficient of yield variation is reduced by a fraction z and the adoption rate of the technology is Λ, then, the new supply variability is $(1-z)\Lambda\ \sigma_\alpha$.

4.3 Benefits from income stability

Newbery and Stiglitz (1981) discuss the appropriate value of the coefficient of relative risk aversion. Based on experimental evidence, they assume a value of 1.2 for producers' R and they use a value of 1 for consumers' R. Considering that producers in this study are located in drought prone areas, the study employs a value of 1.2 for producers' R . Consumers are assumed to have an R equal to 1. These are very conservative estimates, as other studies have found high risk aversion coefficients. For example, Barret et al. (2004) found a minimum R of 1.28 among Malagasy farmers and Yesuf and Bluffstone (2009) indicated that 28% of farmers in their experiment in Ethiopia had relative risk aversion coefficients as high as 15. Changes in the CV of income can be found by comparing the difference of income variation with and without the yield variance reduction. Specifically, given the demand and supply specifications in equations (7) and (8), we can express P and Q in terms of slope and intercept and find the variance in terms of these parameters by (9), shown at the bottom of this page.

Market level changes in the coefficient of variation in income are simulated by applying a reduction of (1–z) in the CV for the zones under intermediate drought risk. Adoption rates are borrowed from available studies for each country. The shares of each crop on producer total income and consumer expenditure are based on household data. Producer risk benefits for each PFS can be calculated by equation (5). Consumers also experience changes

[5] Given the equilibrium price and quantity for each PFS in each country, it is straightforward to calculate the values of the intercept and slope of the supply and demand curves.

$$(9) \quad Var(PQ) = Var\left[\left(\frac{\theta\beta+\gamma\alpha}{\gamma+\beta}\right)\left(\frac{\theta-\alpha}{\gamma+\beta}\right)\right] = E\left[\left\{\left(\frac{\theta\beta+\gamma\alpha}{\gamma+\beta}\right)\left(\frac{\theta-\alpha}{\gamma+\beta}\right)\right\}^2\right] - \left\{E\left(\frac{\theta\beta+\gamma\alpha}{\gamma+\beta}\right)\left(\frac{\theta-\alpha}{\gamma+\beta}\right)\right\}^2$$

$$Var(PQ) = \left[\frac{\theta^4\beta^2 - 2\theta^3\mu\beta^2 + \theta^2\beta^2(\mu^2_\alpha + \sigma^2_\alpha) + 2\theta^3\gamma\beta\mu_\alpha - 4\theta^2\gamma\beta(\mu^2_\alpha + \sigma^2_\alpha) - 2\theta\beta\gamma(\mu^3_\alpha + 3\mu_\alpha\sigma^2_\alpha)}{(\gamma+\beta)^4}\right] +$$

$$\left[\frac{\theta^2\gamma^2(\mu^2_\alpha + \sigma^2_\alpha) - 2\gamma^2\theta(\mu^3_\alpha + 3\mu_\alpha\sigma^2_\alpha) + \gamma^2(\mu^4_\alpha + 6\mu^2_\alpha\sigma^2_\alpha) + 3\sigma^4_\alpha}{(\gamma+\beta)^4}\right] - \left[\frac{\sigma^2_\alpha\beta - \mu_\alpha\theta\beta + \mu_\alpha\theta\gamma - \gamma(\mu^3_\alpha + \sigma^2_\alpha)}{(\gamma+\beta)^2}\right]^2$$

in the variation of their expenditures from yield variance reductions through changes in the coefficient of price variation. For the normal distribution, the variance in prices is:

$$(10) \quad Var(P) = \left[\left(\frac{1}{\gamma + \beta} \right)^2 \right] \sigma^2_\alpha$$

Changes in the coefficient of prices are easily recovered from changes in yield variance, and the consumer risk benefits for each PFS can be calculated from equation (6).

4.4 Economic impact of changes in agricultural productivity and risk

Expected changes in mean yields and yield variance can also be computed for the representative producing household types (poor, average and prosperous) by using the household data described below and accounting for supply shock-induced market-level price variance. It is important to re-emphasize that the households are not representative at the national level; they represent particular PFS regions in each country. The potential benefits for representative households that replace all their maize area with drought tolerant varieties have been estimated. Households may plant both landraces and improved maize varieties; thus, area under landraces and improved, and yield advantage of drought tolerant over improved and landrace are taken into account. The benefits from expected mean yield increases per adopting household type are:

$$(11) \quad Pr_{ij}\,Y. = P_j\omega_j(\phi_j + 1)\zeta_{ij} + P_j\varphi_j(\delta_j + 1)\rho_{ij} - \Delta PQ_i$$

(i = poor farm, average farm or prosperous farm; j = PFS)

where $Pr_{ij}.Y$ is the producer benefit from the crop, P_j is the new equilibrium price at market level, ω_j is the yield of improved maize varieties, ϕ_j is the expected mean yield increase of drought tolerant over improved varieties, ζ_{ij} is the area under improved varieties, φ_j is the yield of landrace varieties, δ_j is the expected mean yield increase of drought tolerant over landrace varieties, ρ_{ij} is area under landrace varieties, and ΔPQ_i is the product of price and quantity produced before adopting the technology.

The risk benefits at the household level for each type of household are calculated as:

$$(12) \quad Pr_{ij}.RB = 0.5RY_js_{ij}(\varphi_{ij}\,\sigma^2 + \Delta\sigma^2_p)$$

(i = poor farm, average farm or prosperous farm; j = PFS)

where $Pr_{ij}.RB$ is producer risk benefits, R relative risk aversion coefficient, Y_j total household income, s_{ij} share of crop income on total income, φ_{ij} reduction in variation, σ^2_k a squared CV of crop yield, and $\Delta\sigma^2_p$ is the change in CV of prices at the market level.

4.5 Poverty reduction impacts

Poverty impacts are reported as the number of poor who escape poverty and poverty reduction expressed as the percentage of the poor for each country. To estimate the number of poor who escape poverty we use the methodology by Alene et al. (2009):

$$(13) \quad \Delta N + \left(\frac{ES}{AgGDP} \text{x}100\% \right) \frac{\delta\ln\,(N)}{\delta\ln(AgGDP)} \text{ x } N$$

where ΔN is the number of poor who escape poverty, ES is the total benefits from the introduction of drought tolerant maize, AgGDP is the agricultural GDP (total value of agricultural production), δln is the elasticity of poverty reduction with respect to agricultural GDP growth, and N is the total number of poor. As AgDGP data are not readily available for each country, we used the 2008 GDP for each country from the Central Intelligence Agency (CIA) Country Fact Book[6] and then utilized the latest shares of AgGDP for each country provided by Fan et al. (2008) to derive the AgGDP. These figures along with the poverty rate for each country are illustrated in Table 1 of the Annex. The other important parameter is the elasticity of poverty reduction with respect to AgGDP growth. Fan et al. (2008) review several studies on the elasticity of poverty reduction with respect to AgGDP growth and argue that this elasticity is different for each country in Africa, depending on whether the country is low income or middle income. They provide values ranging from –0.83 for middle-income countries to –1.76 for low income countries. Alene et al. (2009) on the other hand use an elasticity of –0.72 for West African countries, which are among the low-income countries in Africa. We use the poverty index from the World Bank for our 13 countries to rank them from low-income (those with a high poverty index) to middle-income (those with a lower poverty index) and use the range suggested by Fan et al. (2008) to assign elasticities as shown in Table 2 of the Annex.

6 Information online at https://www.cia.gov/library/publications/the-world-factbook/index.html.

5. Results and discussion

The potential cumulative benefits from drought tolerant maize breeding are presented in different ways, so as to allow interpreting the impacts by means of a range of different economic and poverty reduction indicators. One way is in terms of their monetary value (US$): the monetary benefits from mean yield increases and variance reductions are calculated and then reported separately, first in terms of benefits to producers (PR) and to consumers (CS) for each PFS class in each country, and then for each type (poor, medium, and prosperous) of farm household. In addition, the benefits from mean yield increases and benefits from yield variance (drought risk) reduction are reported separately: benefits from yield variance (drought risk) reduction are expressed in terms of additional grain production as well as in terms of percentage of current maize production, at the country level. Finally, the results are being compared with poverty indicators: US$/capita in 2016 (in 2016 US$), number of people expected to be out of poverty due to additional maize production (with 'the poor' considered to be those living on less than US$1/day), and percentage of poverty reduction. A summary of the assumptions made is given in Annex Table 3, while the agricultural GDP data used in the analysis are illustrated in Annex Table 1. All benefits represent cumulative gains through 2016.

There are a total of four scenarios included in the analysis (see also note in Annex Table 3). The first scenario assumes maximum adoption (i.e. 100%) and conservative yield gains. The second assumes maximum adoption and optimistic yield gains. The third combines conservative yield gains with DTMA adoption projections. The fourth combines optimistic yield gains with DTMA adoption projections.

Before presenting the monetary benefits under the case of a potential full replacement of improved varieties with drought tolerant maize varieties, the initial yield is presented, broken down by landrace and improved maize varieties and production for each country for 2006—the base year—in Table 10. Average yield at the country level, yield under improved drought tolerant maize, and production gains by 2016 are also given in Table 10. To calculate the yield gains for each PFS in each country, the information on yields of landrace varieties, existing improved maize varieties, advantage of existing improved maize varieties over landrace varieties and advantage of drought tolerant maize varieties over improved varieties are crucial. The analysis therefore takes these factors into consideration and projects the final yields for each PFS in each country, along with the production gains in 2016. Information on adoption rates for each country in 2006 and the 50% yield advantage (of improved varieties over landraces) is used to derive the yields for landrace and improved varieties for each PFS. To derive the national average, weighted averages are used for each PFS. Then, given the advantage of drought tolerant maize over improved varieties, the production and national average yields under the case of a full replacement of improved varieties by means of a maximum adoption of drought tolerant maize varieties is calculated, with weighted averages for each PFS.

5.1 Potential benefits with maximum adoption of drought tolerant maize

The maximum potential benefits from a potential full replacement of improved maize varieties with drought tolerant varieties plus the projected adoption increases (Table 5) are given in Table 11 with conservative yield gains and in Table 12 with optimistic yield gains, for each PFS in each country.

Table 10. Yield and production (t) in 2006 and 2016 under the case of a full replacement with drought tolerant maize

	2006			2016		
	Yield landrace	Yield improved	Production	Yield DT	Average yield	Production
Kenya	1.03	1.55	2,097,818	1.84	1.65	2,465,207
Ethiopia	1.03	1.55	2,097,818	1.84	1.65	2,465,207
Uganda	1.46	2.17	1,184,789	2.60	1.89	1,308,586
Tanzania	1.32	1.98	2,034,328	2.35	1.56	2,207,867
Angola	0.45	0.68	399,545	0.77	0.49	423,534
Malawi	1.04	1.57	2,589,758	1.86	1.28	2,859,784
Mozambique	0.90	1.36	1,289,887	1.61	1.01	1,370,139
Zambia	1.25	1.88	1,184,789	2.24	2.00	1,389,285
Zimbabwe	0.58	0.86	1,997,457	0.97	0.85	2,286,487
Nigeria	1.54	2.30	3,993,608	2.73	1.89	4,368,641
Ghana	1.32	1.99	1,041,026	2.36	1.61	1,125,507
Benin	1.03	1.55	694,316	1.84	1.17	728,206
Mali	1.26	1.89	243,824	2.24	1.45	260,930

Source: GIS data for 2006 and model analysis for 2016.

The results in Table 11 suggest that a total of US$ 907 million will be generated from the use of drought tolerant maize varieties in the 13 countries between 2007 and 2016. These cumulative benefits are distributed almost equally, with US$ 490 million to maize producers and US$ 417 million to maize consumers. The risk reduction benefits constitute about 34% of the total benefits. Under this scenario, and with maximum adoption, Nigeria and Kenya have the highest benefits followed by Zimbabwe and Malawi. Most of the benefits accrue in agricultural areas with PFS of 0–5%, followed by PFS 5–10% where most of the maize production takes place. In countries such as Kenya, Uganda, and Zambia, most benefits will be derived at the PFS 10–20%, whereas in Nigeria it is in the PFS 0–5% and in Zimbabwe in the PFS 20–40%. In terms of production gains, Kenya and Zambia would have the highest production gains (17.5% and 17.3%, respectively, by 2016) followed by Zimbabwe (14.5%). Angola, Mali, and Benin would have very low production gains. The main reason for high production gains is that maize yields in Kenya and Zambia are greater than the 0–1 t/ha yield level, and as suggested by expected yield gains in Table 3, high yields are expected at such levels.

Potential poverty impacts from the conservative scenario are shown in Table 13. It is important to note that population growth rates for each country were taken into consideration when estimating the poverty impacts in 2016. The first column reports benefits in terms of the number of poor who escape poverty in 2016. The second column reports the percentage drop in the number of poor in each country as a result of the adoption of drought tolerant maize varieties. The poor in Zimbabwe appear to benefit the most from drought tolerant maize varieties with 0.8 million poor escaping poverty by 2016 and a national reduction of 9% in the number of the poor. However, as Zimbabwe has experienced hyperinflation in recent years, these results should be interpreted with caution. Malawi and Nigeria are the second and third countries that would benefit the most in numbers of poor escaping poverty, while Malawi and Zambia experience the largest decrease in poverty after Zimbabwe, with 5% and 4%, respectively. The country that benefits the least in terms of people escaping poverty is Angola with a 0.02% reduction in poverty by 2016. Clearly, the number of people lifted out of poverty depends on the total benefits, the size of the agricultural GDP, the poverty reduction elasticity

Table 11. Maximum benefits from full adoption of drought tolerant maize varieties, with conservative estimates of yield improvement in 2016 ('000 US$).

	PFS 0–5%		PFS 5–10%		PFS 10–20%		PFS 20–40%		PFS 40–100%			Total production	
Benefits from mean yield increases in 2016													
	PR	CS	PR	CS	PR	CS	PR	CS	PR	CS	Total	Gains (t)	Gains (%)
Kenya	5,593	1,826	9,820	3,205	16,661	5,438	15,316	4,999	12,110	3,953	78,922	367,388	17.5
Ethiopia	7,494	2,828	3,329	1,256	3,119	1,177	2,954	1,115	3,386	1,278	27,937	201,931	7.6
Uganda	1,822	540	3,749	1,111	6,286	1,862	2,341	693	190	56	18,649	123,797	10.4
Tanzania	6,276	3,587	3,479	1,988	6,552	3,744	8,685	4,963	2,091	1,195	42,560	172,537	8.5
Angola	35	20	51	29	163	93	395	226	886	506	2,406	23,989	6.0
Malawi	11,939	6,822	14,070	8,040	7,062	4,036	1,627	930	–	–	54,527	270,026	10.4
Mozambique	1,085	620	1,185	677	796	455	883	504	798	456	7,458	80,252	6.2
Zambia	3,543	2,024	7,249	4,143	11,489	6,565	4,212	2,407	325	186	42,144	204,496	17.3
Zimbabwe	346	2,076	1,435	8,609	2,083	12,496	7,123	42,737	3,335	20,011	100,251	289,029	14.5
Nigeria	47,593	27,196	37,006	21,146	16,648	9,513	3,275	1,872	153	87	164,490	375,033	9.4
Ghana	3,969	2,268	8,361	4,778	1,340	766	–	–	54	31	21,565	84,481	8.1
Benin	3,881	2,218	5,842	3,339	1,454	831	12	7	99	57	17,739	33,890	4.9
Mali	321	183	1,082	618	2,987	1,707	1,296	740	14	8	8,955	17,106	7.0
Subtotal	93,897	52,208	96,658	58,939	76,640	48,683	48,119	61,193	23,441	27,824	587,603	2,243,955	
Benefits from yield variance reductions in 2016													
	PR	CS	PR	CS	PR	CS	PR	CS	PR	CS			
Kenya	1,138	1,452	2,010	2,565	3,338	4,260	3,110	3,969	1,138	1,452	24,430		
Ethiopia	1,815	2,195	791	957	733	886	684	827	733	887	10,508		
Uganda	570	593	1,158	1,204	1,884	1,959	676	703	52	54	8,853		
Tanzania	3,261	3,476	1,806	1,925	3,290	3,507	4,117	4,388	857	914	27,539		
Angola	17	18	23	24	68	71	157	166	221	233	999		
Malawi	5,334	5,699	6,304	6,735	3,051	3,260	946	1,010	–	–	32,338		
Mozambique	474	503	505	535	456	484	467	495	386	409	4,715		
Zambia	1,810	1,971	3,677	4,004	5,982	6,514	2,147	2,338	164	178	28,785		
Zimbabwe	550	531	2,256	2,177	3,191	3,078	11,076	10,685	4,926	4,752	43,221		
Nigeria	37,811	43,533	13,531	15,578	5,667	6,524	1,343	1,546	60	69	125,662		
Ghana	1,075	1,230	2,215	2,535	353	404	–	–	1,075	1,230	10,118		
Benin	160	181	238	271	81	93	1	1	5	6	1,036		
Mali	40	46	135	155	344	394	149	171	2	2	1,438		
Total	147,952	113,636	131,307	97,604	105,077	80,117	72,991	87,492	33,060	38,010	907,245		

PR = producers; CS = consumers; PFS = probability of failed season.

with respect to agricultural GDP growth and the total number of poor. For example, in the case of Angola, the total benefits are relatively small with respect to the agricultural GDP, which translates into a relatively low number of poor lifted out of poverty. Overall, these estimates suggest that the adoption of drought tolerant maize has the potential to help 2.4 million of the poor escape poverty by 2016. This is significant because it comes from a conservative scenario and most poor people in these countries are very poor and food insecure.

The benefits from the full replacement of all improved varieties by drought tolerant varieties and the projected yield increases in each country until 2016 with optimistic yield gains, are given in Table 13. Obviously, the benefits are greater than the conservative yield gains in Table 11. A total of US$ 1.534 billion can be generated in all 13 countries by 2016 with the projected adoption increases and the replacement of all improved maize varieties. The allocation of benefits among producers is almost equal and the share of risk benefits over total benefits is more than 30%. Nigeria benefits the most from drought tolerant maize varieties, mainly due to a higher area planted with maize. Compared with the conservative case, a full replacement of all improved varieties with drought tolerant maize varieties is expected to determine the highest additional gains in Kenya (13.7%, from 17.5% to 31.2%) and Zambia (12.9%), while in Angola, Benin and Mozambique the additional gains are around 4% or less. The additional total production gains in tons of grain over all countries are 1.672 million in 2016, from the conservative to optimistic scenarios.

Table 13. Poverty impacts from the conservative scenario in 2016.

	Number of people escaping poverty	Poverty reduction (%)
Kenya	278,755	1.41
Ethiopia	220,345	0.64
Uganda	54,114	0.50
Tanzania	129,200	0.88
Angola	1,399	0.02
Malawi	448,605	5.03
Mozambique	88,317	0.72
Zambia	360,026	4.03
Zimbabwe	505,932	9.33
Nigeria	249,211	0.52
Ghana	23,433	0.35
Benin	30,528	1.00
Mali	55,945	0.62

Table 12. Maximum benefits from full adoption of drought tolerant maize varieties, with optimistic expected yield improvements in 2016 ('000 US$).

	PFS 0–5%		PFS 5–10%		PFS 10–20%		PFS 20–40%		PFS 40–100%			Total production	
Benefits from mean yield increases in 2016													
	PR	CS	PR	CS	PR	CS	PR	CS	PR	CS	Total	Gains (t)	Gains (%)
Kenya	8,476	2,767	17,912	5,847	30,387	9,919	27,935	9,119	22,083	7,208	141,652	655,060	31.2
Ethiopia	11,323	4,273	6,045	2,281	5,664	2,137	5,365	2,024	6,150	2,321	47,583	343,200	13.0
Uganda	2,876	852	6,815	2,019	11,426	3,385	4,254	1,260	331	98	33,316	220,420	18.6
Tanzania	11,394	6,511	6,316	3,609	11,895	6,797	15,768	9,010	3,798	2,171	77,268	312,544	15.4
Angola	55	31	80	46	255	146	619	354	1,388	793	3,767	37,494	9.4
Malawi	21,686	12,392	25,556	14,604	12,829	7,331	2,547	1,455	–	–	98,401	485,994	18.8
Mozambique	1,969	1,125	2,151	1,229	1,245	711	1,381	789	1,248	713	12,562	134,969	10.5
Zambia	5,369	3,068	12,663	7,236	20,956	11,975	7,682	4,390	593	339	74,270	358,049	30.2
Zimbabwe	542	3,249	2,246	13,474	3,260	19,558	11,148	66,889	5,220	31,320	156,906	451,745	22.6
Nigeria	86,518	49,439	67,236	38,421	30,250	17,286	3,276	1,872	153	87	294,539	672,862	16.8
Ghana	7,209	4,119	15,186	8,678	2,433	1,390	–	–	98	56	39,169	153,034	14.7
Benin	7,042	4,024	10,601	6,058	2,275	1,300	19	11	155	88	31,572	60,222	8.7
Mali	582	333	1,963	1,122	5,422	3,098	2,351	1,344	21	12	16,249	30,977	12.7
Subtotal	165,041	92,183	174,770	104,624	138,297	85,033	82,345	98,517	41,238	45,206	1,027,254	3,916,570	
Benefits from yield variance reductions in 2016													
	PR	CS	PR	CS	PR	CS	PR	CS	PR	CS			
Kenya	1,623	2,129	2,867	3,762	4,762	6,248	4,436	5,821	3,330	4,369	39,347		
Ethiopia	2,663	3,262	1,161	1,422	1,075	1,317	1,004	1,229	1,076	1,317	15,526		
Uganda	830	878	1,686	1,784	2,744	2,903	985	1,042	75	79	13,006		
Tanzania	4,802	5,163	2,660	2,860	4,845	5,209	6,062	6,518	1,262	1,357	40,738		
Angola	25	27	34	36	101	107	234	248	329	348	1,489		
Malawi	7,836	8,454	9,260	9,991	4,482	4,836	1,389	1,499	–	–	47,748		
Mozambique	702	750	747	798	676	721	691	737	702	750	7,274		
Zambia	2,605	2,890	5,293	5,872	8,612	9,554	3,091	3,430	236	261	41,845		
Zimbabwe	808	779	3,312	3,196	4,683	4,520	16,257	15,689	7,231	6,978	63,451		
Nigeria	62,202	72,431	22,259	25,919	9,322	10,856	2,209	2,572	99	115	207,984		
Ghana	2,201	2,548	4,535	5,249	722	836	–	–	2,201	2,548	20,841		
Benin	920	1,064	1,372	1,588	469	543	4	4	29	34	6,027		
Mali	60	69	199	230	508	587	220	254	3	3	2,134		
Total	252,318	192,627	230,154	167,331	181,298	133,270	118,927	137,560	57,811	63,365	1,534,665		

PR = producers; CS = consumers; PFS = probability of failed season.

The poverty impacts in case of a full replacement of improved varieties with drought tolerant maize varieties under the optimistic yields scenario are reported in Table 14. This case suggests that Zimbabwe, again, will have the largest number of poor people escaping poverty (1.2 million), followed by Nigeria with 0.9 million and Malawi with more than 0.7 million. Zimbabwe also has the most drastic reduction in poverty with a decrease of 14% by 2016. As compared with the conservative scenarios, a full replacement of all improved varieties with drought tolerant maize varieties over all 13 countries would result in almost 5 million poor escaping poverty. However, even if a full replacement of improved varieties were to take place, Angola would not improve significantly.

5.2 DTMA projections

The expected benefits from the DTMA project, under the most likely scenario in terms of yields and adoption rates, are given in Table 15. The estimated benefits from conservative yield gains accruing in all countries add up to US$ 532 million, or a gain of 1.2 million metric tons of additional maize during 2007–16. Total production gains range from 1.6% in Benin to 9.5% in Zimbabwe, and 8.0% in Kenya. Differences among countries in terms of production gains are mainly due to projected adoption rates which—among other factors—depend on the quality of the seed markets in each country. Half of the benefits are generated in agricultural areas under PFS 0–5% and 5–10% and the other half in areas with higher PFS. Producers would gain slightly more than

Table 14. Poverty impacts from the optimistic scenario in 2016.

	Number of people escaping poverty	Poverty reduction (%)
Kenya	488,180	2.47
Ethiopia	361,704	1.05
Uganda	91,145	0.84
Tanzania	217,498	1.48
Angola	2,160	0.03
Malawi	754,771	8.46
Mozambique	143,913	1.17
Zambia	589,383	6.60
Zimbabwe	777,056	14.33
Nigeria	431,616	0.90
Ghana	44,384	0.67
Benin	61,155	2.00
Mali	98,955	1.10

Table 15. Benefits from Drought Tolerant Maize for Africa (DTMA) projections under the conservative scenario for expected yield improvements in 2016 ('000 US$).

	PFS 0–5%		PFS 5–10%		PFS 10–20%		PFS 20–40%		PFS 40–100%			Total production	
Benefits from mean yield increases in 2016	PR	CS	PR	CS	PR	CS	PR	CS	PR	CS	Total	Gains (t)	Gains (%)
Kenya	2,577	557	4,752	1,028	8,276	1,790	7,486	1,619	6,289	1,360	35,733	167,226	8.0
Ethiopia	4,280	1,615	1,988	750	1,877	708	1,795	677	2,144	809	16,643	120,458	4.5
Uganda	803	238	1,612	477	2,810	832	1,093	324	91	27	8,308	55,309	4.7
Tanzania	4,103	2,345	2,275	1,300	4,361	2,492	5,946	3,398	1,523	870	28,613	116,071	5.7
Angola	29	17	44	25	140	80	343	196	812	464	2,151	21,436	5.4
Malawi	7,516	4,295	9,431	5,389	4,817	2,752	1,143	653	–	–	35,995	178,381	6.9
Mozambique	798	456	880	503	603	345	686	392	635	363	5,661	60,919	4.7
Zambia	1,424	814	2,822	1,612	4,786	2,735	1,806	1,032	142	81	17,253	84,221	7.1
Zimbabwe	223	1,339	931	5,587	1,371	8,223	4,651	27,904	2,236	13,413	65,878	190,101	9.5
Nigeria	37,151	21,229	17,225	9,843	8,364	4,779	1,909	1,091	92	52	101,734	177,382	4.4
Ghana	1,921	1,098	4,236	2,421	687	392	–	–	28	16	10,799	42,384	4.1
Benin	1,198	684	1,839	1,051	501	286	4	3	40	23	5,629	10,769	1.6
Mali	157	90	537	307	1,600	914	695	397	8	5	4,711	9,004	3.7
Subtotal	62,180	34,777	48,572	30,293	40,193	26,328	27,557	37,686	14,040	17,483	339,108	1,233,661	
Benefits from yield variance reductions in 2016													
	PR	CS	PR	CS	PR	CS	PR	CS	PR	CS			
Kenya	550	681	972	1,203	1,614	4,260	1,504	1,861	1,129	1,397	15,169		
Ethiopia	1,255	1,505	547	656	507	608	473	567	507	608	7,232		
Uganda	288	294	584	597	951	971	341	349	288	294	4,956		
Tanzania	2,343	2,485	1,298	1,376	2,364	2,507	2,958	3,138	616	653	19,740		
Angola	14	14	19	20	55	57	127	134	178	188	804		
Malawi	3,475	3,687	4,107	4,357	1,988	2,109	616	654	–	–	20,992		
Mozambique	357	377	380	402	343	363	351	371	290	307	3,542		
Zambia	821	875	1,669	1,778	2,715	2,893	975	1,038	74	79	12,918		
Zimbabwe	332	320	1,360	1,312	1,924	1,855	6,678	6,440	2,970	2,865	26,057		
Nigeria	22,791	26,062	8,156	9,326	3,416	3,906	809	925	36	41	75,469		
Ghana	598	681	1,231	1,402	196	223	–	–	8	9	4,347		
Benin	119	135	177	201	61	69	0	1	4	4	771		
Mali	24	27	78	89	200	228	87	99	1	1	834		
Total	95,147	71,920	69,151	53,011	56,525	46,379	42,476	53,264	20,141	23,930	531,940		

CS = consumers; PR = producers; PFS = probability of failed season.

consumers from mean yield increases, whereas consumers would get slightly higher gains from the benefits derived from risk reduction. Potential benefits in the optimistic yield gains case are given in Table 16. Projected adoption rates of drought tolerant varieties and adoption increases to 2016 are similar to those in the previous case. Obviously, benefits with optimistic yield gains are higher than the conservative gains; they total US$ 876 million in all DTMA countries. The distribution of the gains between producers and consumers depends on the elasticities of demand and supply that are used in the analysis. The risk benefits are about 34% of the total benefits, indicating that yield stability may be a crucial contributing factor for the well-being of the poor. The results for the individual countries follow patterns that, overall, are similar to those discussed in Section 5.1 and are not discussed again in great detail.

As a matter of initial discussion on the returns over investment, given that the DTMA project will have invested by 2011 (over a 5-year period) a total of more than US$ 38 million (and assuming that the investment stays the same until 2016, hence up to US$ 76 million in 10 years—not including the earlier investments in drought tolerant maize research made by other donors), and that expected returns will be (over 10 years) US$ 532 million under the conservative scenario and US$ 876 million under the optimistic scenario, the ratio of returns over investment will be between 7 and 11 times the investment. The returns over the investment will be calculated in more detail in the next updates of the model, as further discussed in the concluding section.

5.3 Household level country case studies

Another important dimension of the study is the micro aspect, exploring what impacts will occur at the farm household level, who will benefit most among different types of farms, and what the gains will be. The farm level analysis uses mostly household data collected by the DTMA project. The analysis includes poor, medium, and prosperous farms from four countries where the results of Section 5.1 indicate that significant gains can be obtained and significant maize production exists. These countries are Ethiopia,

Table 16. Benefits from Drought Tolerant Maize for Africa (DTMA) projections from the optimistic scenario for expected yield improvements in 2016 ('000 US$).

	PFS 0–5%		PFS 5–10%		PFS 10–20%		PFS 20–40%		PFS 40–100%			Total production	
Benefits from mean yield increases in 2016	PR	CS	PR	CS	PR	CS	PR	CS	PR	CS	Total	Gains (t)	Gains (%)
Kenya	3,570	1,165	7,909	2,582	13,775	4,497	12,460	4,067	10,468	3,417	63,909	298,481	14.23
Ethiopia	5,496	2,074	3,059	1,154	2,888	1,090	2,761	1,042	3,292	1,242	24,096	174,261	6.6
Uganda	1,207	357	2,908	861	5,070	1,502	1,973	584	158	47	14,667	97,534	8.2
Tanzania	7,444	4,254	4,128	2,359	7,912	4,521	10,791	6,166	2,765	1,580	51,920	210,259	10.3
Angola	46	26	68	39	220	126	536	307	1,273	727	3,368	33,504	8.4
Malawi	13,644	7,797	16,053	9,173	8,229	4,702	1,692	967	–	–	62,258	307,872	11.9
Mozambique	1,448	828	1,597	912	944	539	1,074	614	994	568	9,518	102,266	7.9
Zambia	2,152	1,230	5,123	2,927	8,688	4,964	3,278	1,873	257	147	30,640	149,256	12.6
Zimbabwe	349	2,095	1,457	8,740	2,144	12,864	7,275	43,651	3,497	20,984	103,056	297,122	14.9
Nigeria	67,401	38,515	31,243	17,853	15,176	8,672	1,909	1,091	92	52	182,003	295,319	7.4
Ghana	3,485	1,991	7,683	4,390	1,245	712	–	–	51	29	19,586	76,777	7.4
Benin	2,171	1,240	3,333	1,905	783	447	7	4	63	36	9,989	19,100	2.8
Mali	286	163	975	557	2,903	1,659	1,260	720	13	7	8,543	16,303	6.7
Subtotal	108,699	61,735	85,536	53,452	69,977	46,295	45,016	61,086	22,923	28,836	583,553	2,078,054	
Benefits from yield variance reductions in 2016	PR	CS	PR	CS	PR	CS	PR	CS	PR	CS			
Kenya	806	1,011	1,425	1,786	2,366	2,966	2,204	2,764	1,654	2,074	19,057		
Ethiopia	5,962	2,244	2,599	978	2,407	906	2,246	845	2,408	906	21,501		
Uganda	425	438	864	890	1,406	1,448	505	520	38	40	6,574		
Tanzania	3,469	3,702	1,922	2,051	3,500	3,735	4,380	4,674	912	973	29,319		
Angola	20	21	28	29	81	86	189	200	265	280	1,200		
Malawi	5,144	5,491	6,078	6,489	2,942	3,141	912	973	–	–	31,171		
Mozambique	530	563	564	599	510	542	521	554	431	458	5,273		
Zambia	1,210	1,300	2,459	2,642	4,001	4,298	1,436	1,543	109	118	19,117		
Zimbabwe	491	474	2,015	1,944	2,850	2,749	9,892	9,542	4,400	4,244	38,601		
Nigeria	33,812	38,858	12,100	13,905	5,068	5,824	1,201	1,380	54	62	112,263		
Ghana	891	1,017	1,835	2,096	292	334	–	–	12	13	6,490		
Benin	164	187	245	278	84	95	1	1	5	6	1,065		
Mali	35	40	117	134	298	341	129	148	2	2	1,244		
Total	161,657	117,081	117,787	87,274	95,782	72,759	68,632	84,230	33,213	38,013	876,429		

CS = consumers; PR = producers; PFS = probability of failed season.

Kenya, Nigeria, and Zimbabwe. The analysis focuses on households residing in areas which fall mostly within a PFS 20–40%. These are not representative at the country level but provide a good case study of disaggregated impacts in maize producing areas under significant risk of drought. Targeting research in such areas could improve the livelihoods of many farmers by reducing the maize production or consumption risk, economically as well as in terms of hunger and food security.

Two sets of results are presented in this section: the first, in Table 17, indicates potential annual benefits under the conservative yield scenario for representative households and the potential impacts on poverty at the household level. The assumption underlying the results is that representative poor, medium, and prosperous households fully adopt drought tolerant maize varieties and plant all of the current maize area with drought tolerant maize varieties, accounting for the yield and planted area of landraces and improved varieties. We use the shares of landrace varieties over improved maize and the total maize area (adoption rates of improved varieties) from Table 5 (with landraces covering 28%, 81%, 40% and 75% of total maize area in Kenya, Ethiopia, Zimbabwe, and Nigeria, respectively, in 2006) in each of the countries to derive the area and yield under landraces and improved varieties, and estimate the consequent household level benefits.[7]

Based on the household level analysis, prosperous farmers in Nigeria's PFS 20–40% zone gain the most from the adoption of drought tolerant varieties due mainly to higher maize planted areas, followed by Ethiopian farmers. In general, every maize farmer benefits from mean yield increases at the household level, but the magnitude depends on maize planted area by each household type as well as the share of landraces and improved varieties by the households. Typically, a larger share of landrace varieties would generate larger benefits for a household that fully adopts drought tolerant maize, since the yield advantage of drought tolerant over landrace varieties is very high. However, poor and medium farmers in Nigeria and in the other countries also gain significant benefits from drought tolerant maize varieties. Thus, the benefits generally increase with farm size and with the share of landrace varieties. Poor farmers in Kenya and Zimbabwe gain slightly lower benefits by adopting drought tolerant maize varieties, with cumulative gains of US$ 33 and US$ 17, respectively, mainly due to a smaller area planted to maize, lower share of landrace varieties, and lower yields compared to Nigeria and Ethiopia. Benefits from mean yield increases are higher than the benefits from yield variance reductions, but the latter are still a significant part of the total benefits. In addition to the monetary gains, at the household level under the conservative yield gain scenario, the magnitude of the accumulated benefits in 2016 (in terms of rate of improvement over the poverty line[8]) are more significant in Nigeria (based on Amaza et al. 2007), and secondarily in Ethiopia, based on Jayne et al. (2003). The results (not reported here in detail) are indicative of the likely poverty effects of adopting drought tolerant maize, yet should be interpreted with caution since the poverty line is at the country level—it does not differentiate by household type and does not necessarily represent the rural households. Yet the benefits from adopting drought tolerant maize are considerable when compared to the poverty lines. Even for the poor farmers in Kenya, the accumulated benefits of US$ 33 from adopting drought tolerant varieties by 2016 represent 7% of the household poverty line (estimated at US$ 461/year for Kenyan households). This means that in Kenya, a poor family will gain with respect to the poverty line an additional US$ 33 by 2016—that is 7% of the household poverty line—by using DTMA maize. For medium and prosperous farmers in Nigeria, the gains from adopting DTMA maize are more than double the Nigerian household poverty line.

Estimated benefits at the household level from the optimistic yield gain case are shown in Table 18. As expected, these are higher than those from the conservative scenario. The distribution among the different household types and the relative magnitude of benefits from mean yield increases and yield variance reductions is very similar to the one from the conservative yield gain scenario.

Table 17. Annual benefits for adopting households—conservative scenario.

	Annual benefits from mean yield increases (US$/year)		
	Poor farms	Medium farms	Prosperous farms
Kenya	2.5	3.7	8.3
Ethiopia	16.5	30.4	64.7
Zimbabwe	1.2	2.1	4.0
Nigeria	55.4	120.3	111.5
	Annual benefits from yield variance reductions (US$/year)		
Kenya	0.8	0.9	1.2
Ethiopia	2.0	2.1	2.9
Zimbabwe	0.5	0.7	1.2
Nigeria	0.6	1.0	2.3

7 It is worth noting that the analysis, at this stage, does not take into consideration any area expansion.

8 Poverty line is defined as minimum amount of annual income necessary for a family to afford an adequate living.

The household data that were collected for this study comes from specific PFS 20–40% areas selected in each country. In most cases, there is a correspondence between areas where most benefits occur and where the household data for this study were collected. This makes the household disaggregation of the study relevant as it represents areas where most gains also take place. This is particularly the case with Ethiopia, where data were collected mostly in PFS <30% (with most gains in PFS 0–5%), Zimbabwe in PFS 20–40% (with most gains in areas with PFS >20%), Zambia in PFS <30% (with most gains between 5–20% PFS), and in Nigeria in PFS <30% (with most gains between 0–5% and 0–20% PFS).

5.4 Sensitivity analysis

Sensitivity analysis was conducted on the main parameters used: mean yield increases, yield variance reductions, adoption rates and elasticities of demand and supply. In addition, a 25% increase and 25% decrease from the initial 50% yield advantage of improved versus landrace varieties were also tested in this analysis. The results of the simulations are discussed in terms of changes in monetary values and poverty indicators from the baseline scenario (the DTMA projections). To run the sensitivity analysis, each parameter of interest was first increased by 50% from the baseline values and then decreased by 50%.

Generally, the benefits from mean yield increases and yield variance reductions increased (or decreased) by almost 50% from increases of 50% in both mean yields and yield variance reductions at both the PFS zone and household levels. A similar proportional effect was found from increases and decreases by 50% in the adoption rate at the PFS zone level. Thus benefits increased (or decreased) proportionally with increases (or decreases) in mean yields, yield variance reduction, and adoption rates.

Table 18. Adopting households' annual benefits—optimistic scenario.

	Annual benefits from mean yield increases (US$/year)		
	Poor farms	Medium farms	Prosperous farms
Kenya	3.4	4.8	8.7
Ethiopia	30.6	36.3	49.3
Zimbabwe	1.2	2.2	4.1
Nigeria	67.9	147.3	136.5
	Annual benefits from yield variance reductions (US$/year)		
Kenya	1.2	1.4	1.8
Ethiopia	2.9	3.2	4.3
Zimbabwe	0.7	1.1	1.9
Nigeria	1.0	1.5	3.5

Sensitivity analysis was also conducted on the demand and supply elasticities, which were found to have a significant impact on the distribution of the producer and consumer risk benefits. Specifically, an increase in the elasticity of supply resulted in greater producer benefits and smaller consumer benefits; the converse was also true. A higher demand elasticity results in higher consumer benefits and smaller producer benefits; the converse was also true. However, the total benefits from mean yield increases did not change with the changes in the elasticities of demand and supply. A different situation was found for the case of risk benefits. When the supply elasticity was reduced by 50%, benefits increased by more than half at the household level and the PFS zone level. A 50% more elastic demand resulted in risk benefits which were smaller than one half of the base estimates. The results from the sensitivity analysis confirm that the estimates of demand and supply elasticity should be carefully selected – they are an important factor in this type of analysis, especially when it comes to estimating the risk benefits deriving from yield variance reduction at both the aggregate (PFS zone) and household levels.

Another set of sensitivity analyses considered the yield advantage of existing improved versus landrace varieties. A 25% change (increase/decrease) generated a 4–9% increase (or decrease) from the original total benefits, depending on the initial maize yield level in each country. Such results warrant a careful evaluation of the yield advantage between landraces and improved varieties. Finally, producer and consumer benefits are sensitive to the risk aversion coefficient. From equations (5) and (6) it is clear that any change in R will produce a change of similar size in consumer and producer risk benefits.

6. Summary and conclusions

This study provides an ex-ante evaluation of the potential impacts of the DTMA project and where to achieve greatest impacts by investing in drought tolerant maize in Africa. The analysis covered 13 countries: Angola, Benin, Ethiopia, Kenya, Malawi, Mali, Mozambique, Nigeria, Tanzania, Uganda, Zambia, and Zimbabwe. Household level impacts from household surveys in Kenya, Ethiopia, Nigeria and Zimbabwe were also estimated for representative poor, average and prosperous farms. The analysis used a novel simulation approach that evaluates not only mean yield gains but also the additional benefit derived from yield stability gains. Furthermore, the benefits from the adoption of drought tolerant maize varieties are also presented in terms of their potential impacts on poverty. Several crucial components were estimated by scientists from different disciplines, such as GIS data from GIS experts by PFS zone, yield data from breeders, projected maize adoption rates by seed experts and socioeconomists, and poverty data by socio-economists.

When looking at the impacts derived from the DTMA project, it appears that adoption of drought tolerant maize can generate substantial cumulative benefits to both producers and consumers in all countries, with US $532 million under conservative yield improvements and US $876 million with optimistic yield improvements between 2007 and 2016. One of the goals of the DTMA project is to generate US $160–200 million in increased value of maize grain. These benefits translate into significant reductions in poverty when considering that they are due to using DTMA varieties, leading to higher and more stable yields. The household level results shed light on the distribution of potential impacts given country level household poverty lines and indicate their potential contribution in alleviating poverty. The division by PFS zone is useful in terms of matching the population data with the drought risk zones. The figures presented in this study, aggregated over all 13 countries translate into 22–25% yield increases achievable in PFS 0–10%, where drought may be less likely in climate probability terms, but can hit most crops, and still have high yield increases in the 10–40% range (about 20%), whereas when the PFS is higher than 40% the yield increase benefits are limited to 7–10%. A similar range of benefits would be experienced across PFS also in terms of yield risk (variance reduction), except for PFS 0–5% where the benefits are 34–35%. Given the range of yields and adoption rates, largest gains accrue in the 0–10% PFS zone. The poverty impacts are mainly driven by the total drought tolerant maize benefits to agricultural GDP ratio (the higher the ratio, the more people out of poverty). The largest impacts in terms of people out of poverty are in Zimbabwe and Malawi, followed by Nigeria. These benefits are even more important when taking into consideration the depth of poverty and that the majority of those people will also be free from hunger; the results, consequently, must be carefully interpreted if used in a policy context.

In case of a potential full replacement of improved varieties with drought tolerant maize varieties, there would be substantial benefits to producers and consumers by 2016, with a total US $907 million over all DTMA countries with conservative yield improvement and US $1,535 million with optimistic improvement, in the same period. Kenya, Malawi, Zambia and Zimbabwe will obtain the greatest aggregate benefits.

In terms of investments over countries, it appears that the adoption of DTMA varieties will generally create striking benefits in terms of most indicators in Nigeria, as well as in Kenya and Malawi. This is very significant for Malawi given the relatively small size of the country, and can be explained by the major role that maize plays as a food and source of livelihoods (as shown by Heisey and Smale 1995; Smale 1995; Smale and Heisey 1997). In Malawi, Zambia, and Zimbabwe, use of drought tolerant maize will result in the most notable poverty impacts (although here the data may be to some extent affected by hyperinflation and the fact that a significant part of maize farmers in Zimbabwe are commercial/large farmers, as opposed to all the other countries where small farmers are the vast majority). Based on the data used for this study, benefits will be generally modest or even negligible in Angola and Mozambique, and often moderate in Uganda and Mali. In terms of targeting, investing most of the DTMA project resources (for instance for delivery, seed systems work, socioeconomics, some management costs, and possibly some breeding activities) in only eight to ten of the current 13 countries, would generate roughly the same benefits as for investing in all 13 countries. A reduction and refocusing of some activities where most benefits can be obtained should thus be considered; countries where activities may be downsized would still benefit from research spillovers and the cross-border facilitation of seed markets that can most effectively be handled by the private sector.

The scenarios under maximum adoption suggest that more than 4 million people, both among producers and consumers, would have their poverty level significantly reduced in all countries by year 2016, principally due to the role of drought tolerant maize. In other words, about 15% of all people targeted by the DTMA project will benefit directly and significantly in terms of poverty reduction, with many millions more having their livelihoods improved. About 95% of them will come from 8 to 10 countries where the benefits are largest.

An important point not factored into the present impact estimates: the benefits due to adoption of drought tolerant maize will continue after 2016, as long as farmers continue to use drought tolerant maize, and the benefits may even increase, if farmers take up newer, more productive (and drought tolerant) DTMA project-derived varieties.

6.1 Discussion on future data and methods improvements

Several other factors influence people's livelihoods, together with and besides drought. Therefore, the present study will be upgraded using socioeconomic adoption panel data and new breeding data generated by the project, including explorations on other traits, as well as further refinements of the model. One important policy and management covariate that largely affects the results is the level of fertilizer use—which is implicitly considered in this study. However, the analysis of the advantage of fertilizer use with improved and landrace varieties is planned for year 2011 during the next phase of this assessment, also using detailed data from the project household surveys. Other investments often associated with drought tolerant maize are the expansion of the seed sector and the enhanced supply of water and pest management, the use of conservation agriculture, and different policies in agriculture, including those on fertilizer use. The diverse situations likely to occur due to the expected effects of climate change in coming years will be analyzed using updated climate data. Further scenarios will explore the comparative advantages of drought tolerant maize breeding vis-à-vis substitution with other cereals in high drought risk zones, especially in lower potential zones where other crops (e.g. sorghum) are more prevalent. While the current scenarios simply factor in yield increases, a future possible scenario could consider that because of the reduced risk inherent in drought tolerant maize, farmers may intensify, for instance by using more fertilizer. This would increase the yield and income gains and the marketable surplus, enabled by higher yields from using drought tolerant maize. Similarly, it is possible to assume that the drought tolerant adoption rate exceeds the normal improved variety adoption rate because of drought tolerant varieties' underlying advantages, hence enhancing the adoption of high-yielding maize varieties.

During the project, and in view of the updated ex-ante study planned for 2011, the GIS database will be upgraded with key monitoring indicators (on variety release, seed production/sales, adoption and productivity increase) and variables (e.g. grain and seed prices). The household level analysis will also be expanded, as more household data are collected and processed in all countries. Important methodological improvements include consideration of higher amounts of yield, trade of maize seed and grain between countries, different moments of yield distribution,[9] and different types of utility functions. Given the range of yield gains and the adoption rates employed in the study, the results suggest that the highest production gains will accrue to producers in the 0–10% PFS zones (although the same adoption rates are assumed for all PFS zones within the country). PFS-specific adoption rates and poverty indicators will further refine the results and provide better guidance on investment decisions within countries and among countries, in terms of production, monetary gains, and impacts on poverty. Finally, an important aspect of adopting drought tolerant maize varieties that currently is not fully captured by the model is the area expansion effect of the improved varieties. Often, successful new varieties replace existing varieties and farmers may expand the area planted, including substitution for other crops. A careful analysis will be conducted on the area expansion effect and included in the model to better capture any additional benefits (or losses) from the adoption of drought tolerant maize varieties.

[9] Meaning that besides mean and variance, skewness and kurtosis effects may need to be considered.

The results of current on-farm trials in West Africa through the DTMA project will be used in future upgrades of the study, to improve the estimation of the effects attributable to drought tolerant maize varieties.

One typical indicator resulting from economic surplus models is the rate of return on investment. While this was calculated by straightforward means in this study, it will be enhanced in the future as the benefits derived from the adoption of drought tolerant varieties are better quantified, and the understanding of the attribution of costs and benefits increases. This will allow modeling scenarios to include benefits from the DTMA investment in addition to those from earlier and other simultaneous investments from the public, NARS, and private sectors in terms of research, development, and seed delivery.

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Annexes

Annex Table 1. Agricultural GDP and poverty rate.

	All GDP (billion US$)[2]	Percent of agricultural GDP (2004)[3]	Poverty rate (%)[1]
Kenya	29.564	25	52.0
Ethiopia	26.393	38	44.2
Uganda	14.565	35	37.7
Tanzania	20.668	42	5.7
Angola	84.945	35	54.3
Malawi	4.268	34	65.3
Mozambique	9.897	27	54.1
Zambia	14.654	15	68
Zimbabwe	3.145	17	34.9
Nigeria	207.116	36	34.1
Ghana	16.654	41	28.5
Benin	6.712	42	39
Mali	8.774	35	63.8

1 http://hdr.undp.org/en/media/HDI_2008_EN_Tables.pdf (Human Development Indices from the United Nations Development Programme -UNDP).

2 CIA Factbook (https://www.cia.gov/library/publications/the-world-factbook/rankorder/2001rank.html), 3Fan et al. 2008.

3 Compiled based on data from http:// mdgs.un.org/unsd/mdg/SeriesDetail.aspx?srid=583 (Last updated: 14 Jul 2009) last accessed in October 2009.

Annex Table 2. Elasticity of poverty reduction with respect to agricultural GDP.

	Human poverty index (HPI-1) rank 2007	Poverty reduction elasticity based on agricultural GDP growth and growth index
Mali	133	1.83
Ethiopia	130	1.67
Mozambique	127	1.58
Benin	126	1.50
Angola	118	1.42
Nigeria	114	1.34
Zambia	110	1.25
Zimbabwe	105	1.17
Tanzania (United Republic of)	93	1.09
Kenya	92	1.01
Uganda	91	0.92
Malawi	90	0.84
Ghana	89	0.76

Source: http://hdrstats.undp.org/en/indicators/97.html

Annex Table 3. Assumptions on the scenarios related to the calculation of benefits (2006–2016).

	Maximum replacement scenario under conservative yield improvement				Maximum replacement scenario under optimistic yield improvement			
	Adoption rate (%)	**Yield adv. 0–1 t/ha (%)**	**Yield adv. 1–2 t/ha (%)**	**Yield adv. 2–3 t/ha (%)**	**Adoption rate (%)**	**Yield adv. 0–1 t/ha (%)**	**Yield adv. 1–2 t/ha (%)**	**Yield adv. 2–3 t/ha (%)**
All countries	100	13.0	18.7	19.5	100	20.4	33.9	29.4
	DTMA projections under conservative yield improvement				**DTMA projections under optimistic yield improvement**			
	Effective DT maize adoption rate (%)	**Yield adv. 0–1 t/ha (%)**	**Yield adv. 1–2 t/ha(%)**	**Yield adv. 2–3 t/ha (%)**	**Effective DT maize adoption rate (%)**	**Yield adv. 0–1 t/ha (%)**	**Yield adv. 1–2 t/ha(%)**	**Yield adv. 2–3t/ha(%)**
Kenya	39	13.0	18.7	19.5	39	20.4	33.9	29.4
Ethiopia	25	13.0	18.7	19.5	25	20.4	33.9	29.4
Uganda	27	13.0	18.7	19.5	27	20.4	33.9	29.4
Tanzania	24	13.0	18.7	19.5	24	20.4	33.9	29.4
Angola	14	13.0	18.7	19.5	14	20.4	33.9	29.4
Malawi	28	13.0	18.7	19.5	28	20.4	33.9	29.4
Mozambique	20	13.0	18.7	19.5	20	20.4	33.9	29.4
Zambia	37	13.0	18.7	19.5	37	20.4	33.9	29.4
Zimbabwe	48	13.0	18.7	19.5	48	20.4	33.9	29.4
Nigeria	35	13.0	18.7	19.5	35	20.4	33.9	29.4
Ghana	20	13.0	18.7	19.5	20	20.4	33.9	29.4
Benin	30	13.0	18.7	19.5	30	20.4	33.9	29.4
Mali	24	13.0	18.7	19.5	24	20.4	33.9	29.4

DTMA = Drought tolerant maize for Africa; Yield adv. = Yield advancement.

Note: There are two types of assumptions in this table that make a total of four scenarios: Assumptions on adoption rates and assumptions on yield improvements. The first three rows indicate the assumptions associated with the two Maximum Adoption Scenarios: (1) Maximum DT adoption (i.e. 100% in each country) with the conservative yield improvement and (2) Maximum adoption under optimistic yield improvement. The rest of the table illustrates the assumptions associated with the two DTMA Projection Scenarios: (1) Effective DTMA maize adoption rates (i.e. those based on Langyintuo et al. 2008 and household surveys) for each country under conservative yield improvement and (2) Effective DTMA adoption rates. The yield advantages are broken down by yield level.

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