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The Potential Economic Impacts of Herbicide-tolerant Maize in Developing Countries: A Case Study

Nicholas Kalaitzandonakes
University of Missouri

John Kruse
World Agricultural Economic and Environmental Services

Marnus Gouse
Gates Foundation and University of Pretoria

In this study, we evaluate the potential economic impact of herbicide-tolerant (HT) maize in Kenya. HT maize is essentially a new weed-control approach. The potential agronomic changes from the use of HT maize are multidimensional and subtle and must be understood within the context of Kenya's maize farming systems and the inherent crop-weed competition. We therefore begin by analyzing the current status of weed-control systems in the Kenya maize sector and review what is known about their relative effectiveness, constraints, and impact on yields and farm profitability. Next, we discuss how HT maize can change the weed-control systems of maize production, in general, as well as their economics. We also examine the accumulated experience from the adoption of HT maize in countries with many subsistence farmers and draw useful parallels for Kenya. Against this background, we then discuss how weed control, yields, and farm economics in Kenyan maize production can change from the introduction of HT maize and estimate the potential aggregate economic impacts of the technology for a 10-year period.

Key words: herbicide tolerance, maize, economic impact, Kenya.

Introduction

The purpose of this study is to evaluate the potential economic impact of herbicide tolerant (HT) maize in Kenya. To do so, the farm-level agronomic changes from the introduction of HT maize need to be understood first. HT maize is essentially a new weed-control method. But as we describe in the opening sections of this paper, the potential agronomic changes from HT maize are multidimensional and subtle and can only be properly understood within the context of Kenya's maize farming systems and constraints.

We therefore begin by reviewing what is known about crop-weed competition and associated impacts in Africa and especially Kenyan maize production. We then analyze the current status of weed-control systems in the Kenyan maize sector and review what is known about their relative effectiveness, constraints, and impact on yields and farm profitability. Next, we discuss how HT maize can change the weed-control systems of maize production, in general, as well as their economics. We also examine the accumulated experience from the adoption of HT maize in countries with many subsistence farmers and draw useful parallels for Kenya. Against this background, we then discuss how weed control, yields, and farm economics in Kenyan maize production can change from the introduction of HT maize and estimate the potential aggregate economic impacts of the technology for a 10-year period.

Literature on Crop-weed Competition

Weeds are a significant crop pest—especially in hot and humid places in sub-Saharan Africa—and favor fast and vigorous weed growth (Akobundu, 1980; Gianessi, 2009; Gleason, 1956). Unlike insect pests and diseases, weeds are present in every African farm and occur every year. Due to the enabling environment and history of poor control, weed populations in African fields are rich (Chikoye & Ekeleme, 2001), dense (Tanner & Sahile, 1991), and have an extensive seed reservoir to draw from in any given year (Gianessi, 2009).

Weeds compete with crops for moisture, nutrients, light, and space, and as a result they can cause significant yield losses, increase production costs, and reduce crop quality (Benson, 1982). Additional costs are incurred for manual, chemical, or mechanical weed control and for cleaning the harvested crop. Crop quality is reduced from the presence of weed seeds; this leads to lower nutritional value and prices (dockage).

Over several decades, weed scientists have produced an expansive set of literature that documents the intricacies of the competition for scarce resources between crops and weeds. Among other matters, these studies have analyzed the critical periods of weed/crop competition, the associated yield losses, and the efficacy of alternative weed-control methods for different crops and environments.

The concept of a "critical period for weed control" has been formalized to define how long weeds may be allowed to compete with the crop before yields are impacted (Hall, Swanton, Anderson, 1992; Nieto, Brondo, & Gonzalez, 1968). To obtain maximum crop yields, weeds must be managed before the critical period begins. Hundreds of studies have measured the critical period and associated yield losses in maize and other crops (e.g., Benson, 1982; Knezevic, Evans, Blankenship, Van Acker, & Lindquist, 2002; Zimdahl, 2004). While the results vary by crop, weed flora, population densities, soil type, level of soil moisture, and fertility and other conditioning factors, there is overwhelming experimental and field evidence that confirms that if weeds are not effectively controlled during the critical period, crop yield losses can be staggering.

Benson (1982) reviewed almost 500 such studies published over a 30-year period (1950s-1980) that examined the impacts of weeds on tropical crops—including maize—in Africa and similar growing environments. The studies reviewed by Benson generally showed that grasses and sedge weeds can cause losses up to 92% of the potential yield of maize, while losses from broadleaves can approach 85%. Periods of competition as short as 10 days were found to cause losses of 10% of a potential maize yield, especially when competition occurred within the first four weeks of crop growth. Based on all the experimental evidence accumulated at that time, Benson concluded that for effective control, maize fields must be weeded two or more times during the early weeks of crop growth. Benson's general conclusions have since been confirmed by numerous studies in every part of the world.

A number of the studies reviewed by Benson (1982), but also many other studies published since, have investigated the conditioning effects of various factors on the yield impacts of weeds (for instance, see Kropff, Van Keulen, Van Laar, & Schenieders, 1993; Zimdahl, 2004; and literature therein). These studies have found that weeds often uptake nutrients (e.g., nitrogen) faster than crops to the point that, in some instances, increasing nutrients through fertilization benefits weeds more than the crops and may even lead to yield losses. Competition for soil moisture has been found to be even more pressing and damaging by some studies. Because of their widespread root system, some weeds were found to withdraw up to 80% of moisture from the soil, causing serious water deficits for the maize crop. This highlights the significance of effective weed control in areas where droughts are frequent. Finally, crop and weed population densities have been determined to be important, and low crop populations have been found to compete less effectively against weeds.

While soil moisture, soil fertility, crop and weed population densities, and other relevant conditioning factors matter, the chief conclusion in the literature remains that if weeds are not sufficiently controlled at the right time, weed infestations can have devastating impacts on crop yields. Indeed these impacts are particularly pernicious because farmers cannot easily discern them while they occur and hence they cannot always appreciate their cause.

Given the inherent difficulties in appreciating the importance of timely and effective weed control, insufficient investment in relevant inputs, especially by resource-poor farmers, is a possibility. Indeed, a few studies have argued that subsistence farmers in Africa systematically allocate insufficient and mistimed labor and capital resources to weed control, thus resulting in significant yield losses (e.g., Chikoye, Schultz, & Ekeleme, 2001; Gianessi, 2009).

Weed Control in Kenya Maize Production

Current Weed Control Practices

Weed species in East Africa have been described by Terry (1984) and Terry and Michieka (1987), while several studies reviewed in Nderitu (1997) have described the weed flora in Kenya. Most recently, Ngome, Mussgnug, and Becker (2010) conducted field studies in Kakamega, Western Kenya, during the short rains of 2008 and long rains of 2009 and cataloged weeds in maize smallholdings. They identified 55 weed species, 84% of which were broadleaved, 12% were grasses, and 4% were sedges.

Weeds are typically controlled in Kenyan maize production through tillage prior to planting (generally referred to as "land preparation") and through occasional weeding after crop emergence. Given the significant heterogeneity in rainfall, soils, landscape, labor and capital resources, and other factors, weed-control systems vary significantly across Kenyan regions, farm types, and even growing seasons. Nevertheless, land preparation in Kenyan maize production generally involves plowing the field (through tractor, oxen, or hoe) to loosen and aerate the soil, control weeds, and mix organic matter. One or two tillage operations might be done prior to planting, and the second might be followed by harrowing to prepare the seed bed. Because tillage and harrowing operations are expensive, most Kenyan maize producers—especially smallhold-

Table 1. Production costs by activity and production intensity in Kenya maize production (in KSH).*

	High-intensity hybrids	High-intensity hybrids	Medium-intensity hybrids	Low-intensity recycled hybrids	Lowest-intensity local hybrids	Lowest-intensity OPV
Output (bags)	57.5	50	35	15	13.75	5
Labor inputs			Total cost (KSH/hectare)			
Planting	200	300	1,000	400	750	425
Gapping	200	125	175	125	125	
Weeding	3,250	3,800	3,825	4,125	3,500	2,500
Topdressing	400	350	250	-	-	-
Dusting	250	150	-	-	-	-
Harvesting	1,313	2,250	1,750	1,000	375	350
Loading	250	-	-	-	-	-
Hand shelling	-	1,500	1,300	788	625	175
Sub-total: total labor costs	5,863	8,475	8,300	6,438	5,375	3,450
Other intermediate inputs						
Seed	3,300	3,300	3,300	375	375	750
Land preparation	5,000	4,000	4,000	3,000	3,750	3,000
Planter hire	1,750					
Fertilizers - DAP/MAP	3,375	3,125	3,300	1,000	-	-
CAN/NPK	3,000	3,000	-	800	-	-
Insecticides	1,813	750	-	-	-	-
Herbicides	563	-	-	-	-	-
Sub-total	18,800	14,175	10,600	5,175	4,125	3,750
Total production costs	**24,663**	**22,650**	**18,900**	**11,613**	**9,500**	**7,200**
Weeding as % of labor costs	**55.4%**	**44.8%**	**46.1%**	**64.1%**	**65.1%**	**72.5%**
Weeding and land preparation as % of total costs	**40.5%**	**34.4%**	**41.4%**	**61.4%**	**76.3%**	**76.4%**

** Figures in Nyongesa et al. (2004) are in Kenyan Shillings (KSH) and are transformed to USD with an average 2004 exchange rate of 77.55 KSH to 1 USD. Source: Nyongesa et al. (2004)*

ers—till once and may plant their maize crop at the same time. Such land preparation is typically done by hoe and requires significant amounts of labor. Mechanical tillage and the use of pre-emergence herbicides are less frequent and used mostly by larger commercial maize farms.

The timing of land preparation is important and early preparation (relative to the onset of the rainy season) is recommended to Kenyan maize farmers. Tillage is then typically performed after the initial flush of weed emergence. This tends to reduce crop/weed competition when maize emerges and minimizes later weeding requirements during the critical period (Mwanda, 2000). A standard recommendation to Kenyan maize farmers is that at least part of the cropland should be dry-planted and that planting should be completed within one week of the onset of the rains (Muhammad & Partont, 1992).

After the emergence of maize, weeds must be controlled to minimize yield losses during the critical growth period of the crop (3^{rd} to 10^{th} leaf) and two weeding operations are typically recommended. Most Kenyan maize farmers, especially smallholders, weed their fields by hand. Labor requirements vary with the level of weed infestation and other factors but often exceed 50 man-days for weeding one hectare of maize by hand.

While there are significant differences in the degree of intensification of Kenyan maize farms and their weed-control systems, they all tend to spend a large share of their labor and capital resources on land preparation and weeding. For instance, Nyongesa et al. (2004)[1] presented detailed labor and other input costs by agronomic activity and showed that for medium and high-intensity maize farmers, weeding represented 45-55% of total labor costs, while for low intensity maize

Table 2. Hired and family labor used by Kenya households by activity.

Activity	Mean	Median	STDV
Family labor (hours per activity per household)			
1st plowing	34.3	18.0	50.7
2nd plowing	29.7	20.0	31.6
Harrowing	13.0	6.0	17.2
Planting	29.0	20.0	35.0
1st weeding	50.0	30.0	69.1
Top-dressing	12.0	6.5	20.0
2nd weeding	42.3	28.0	54.0
Field dusting	15.7	8.0	26.8
Stoking	32.8	15.0	55.3
Harvesting	41.4	26.0	60.0
Hired labor (days per activity per household)			
1st plowing	3.0	2.0	2.9
2nd plowing	5.0	4.0	4.5
Harrowing	4.0	1.5	5.4
Planting	1.6	1.0	1.1
1st weeding	2.9	2.0	1.9
Top-dressing	1.4	1.0	0.7
2nd weeding	2.9	2.0	2.0
Field dusting	1.6	1.0	0.9
Stoking	2.3	2.0	1.6
Harvesting	2.1	2.0	1.7

Source: A. Jones, Kansas State University (2011)

farmers it represented 65-73% (Table 1). Taken together, land preparation and weeding were 35-42% of all variable production costs for the more intensive maize farmers, while for the low-intensity farmers they were a dominant 61-76% of all such expenses. Other studies that have reported maize production expenditures by activity also show similar allocations and find that land preparation and weeding dominate labor use while they represent a significant share of production costs (e.g., Micheni, Amboga, & Mbogo, 2010a; Micheni, Karuri, Amboga, 2010b; Tittonell, vanWijk, Rufino, Vrugt, & Giller, 2007).

Detailed labor data from Kenyan households similarly confirm significant resource allocations to land preparation and weeding in maize production. Jones (2011) reported detailed family and hired-labor use from a 2007 survey of 1,397 households across 24 districts in Kenya,[2] and once again land preparation and weeding were found to represent a dominant share of family and hired-labor resources used by Kenyan maize producers (Table 2).

A robust conclusion from these and other studies is therefore that a large share of the scarce labor and capital resources of Kenyan maize farmers goes to land preparation and weeding activities. While the total amounts of such resources appear to be significant, however, little is known about how timely their allocations are. There is some indirect evidence, however, that suggests they might not be timely.

A number of studies have identified labor as the main limiting factor for adequate land preparation and weed control in Kenyan maize production (e.g., Muhammad & Partont, 1992; Mwanda, 2000).[3] Not only does the household supply of labor among Kenyan maize producers appear constrained overall, but its availability at critical periods may be even more limited because of competition with other household and farm activities. Muhunyu (2008) for instance noted that—for smallholder maize producers he surveyed in Eastern Kenya—delays in land preparation and planting were due mainly to over-reliance on family labor. Mwanda (2000) similarly reported that animal draft and mechanical power were also in short supply during critical periods of land preparation and weed control.

A difficulty with assessing the relevance of potential labor and capital shortages during critical periods in the growing season is that most studies report the total quantities of inputs used throughout the season and do not concern themselves with their temporal allocation and constraints. An exception is Muhunyu (2008), who specifically examined the timing of land preparation, planting, and weeding activities in Kenyan maize production.

1. *The purpose of the study was to assess how pricing affected the farmers' use of certified maize seed in 13 districts east and west of the Rift Valley in 2004. Here we present only variable production costs and an abstract from other reported costs such as land rent, interest payments, costs of seed packaging, storage, and others.*

2. *The survey was carried out by Egerton University's Tegemeo Institute of Agricultural Policy and Development and Michigan State University, and these have presented several similar surveys in the last 15 years that provide useful benchmarks on maize production factors and associated costs.*

3. *For instance, in their research on early land-preparation practices by smallholders in Eastern Kenya, Muhammad and Partont (1992) noted that "...although well over half of the farmers in the sample were implementing the recommendation on time of planting, …complaints about lack of sufficient labor were almost unanimous. Hence, availability of labor was seen as a constraint to adoption of this practice."*

Table 3. Timing of cropping practices of maize production in Nakuru.

Cropping practice		Number of farmers	% of farmers
Land preparation time (in relation to onset of rainy season)	> 2 weeks before	6	0.7%
	1-2 weeks before	201	23.1%
	1-2 weeks after	411	47.3%
	> 2 weeks after	251	28.9%
Planting time (in relation to onset of rainy season)	Up to 1 week before	121	13.9%
	During	367	42.2%
	Up to 1 week after	233	26.8%
	> 2 weeks after	146	16.8%
Weed control	Once	383	44.1%
	Twice	116	13.3%
	Once late	276	31.8%
	None	92	10.6%

Source: Muhunyu (2008)

In 2007, Muhunyu surveyed small-scale maize producers in the Nakuru District in order to analyze their agronomic practices and productivity levels. In this context, he organized farmers by the time they plowed and planted (relative to onset of the rainy season). He also recorded the number of times these maize producers weeded after planting and whether such weedings were done late or on time (Table 3). Data presented by Muhunyu (2008) therefore suggests that most smallholders prepared their land late, planted late, and only 13% weeded the recommended two times after planting. Thirty-two percent of the maize producers weeded late and did so only once, while almost 11% did not weed at all. Muhunyu also found that maize farmers who prepared their land late had significantly lower yields.

There is also some indirect statistical evidence in the literature that points to the potential yield losses from untimely use of labor and capital in land preparation and weed control. Kirimi and Swinton (2004) measured the level of cost inefficiency of maize farms in Kenya and Uganda and attempted to attribute measured inefficiencies (lower levels of output per unit of inputs used) to various potential factors, including the use of recycled and open-pollinated maize seeds, low levels of fertilizer, and late planting. From their analysis, Kirimi and Swinton found that the key source of cost inefficiency in their sample was late planting. Similarly, Keating, Wafulat, and Watikit (1992) estimated that delayed land preparation and planting—presumably due to labor constraints—in Eastern Kenya resulted in losses of 1.2% of the grain yield per day of delay when both growing seasons were considered and 2.5% per day delay when only the long rains season was accounted for.

Use of Herbicides

Use of herbicides for pre-emergence control of weeds prior to planting as well as post-emergence treatments for control of weeds after planting could help ease potential temporal labor constraints in Kenyan maize production, especially during critical periods of weed control. Indeed, there have been numerous herbicide trial studies in Kenya that have generally concluded that herbicide use in maize (and other crop) production would control weeds effectively, overcome labor constraints and, in many instances, be profitable. Nderitu (1997), reviewed hundreds of herbicide trial studies mainly from research work recorded in the proceedings of the East African Weed Science Society, theses from the University of Nairobi, Annual Reports of the Ministry of Agriculture (Research Division), Kenya Agricultural Research Institute (KARI), the Kenya Coffee Journal, the East African Forestry and Agricultural Research Organization Journal (EAAFRO), and conference reports held mainly in the African region. Most such research on weed control has been done in sole maize crops, mixed maize crops, coffee, and wheat, but also in other crops like rice, barley, oats, sorghum, millet, beans, peas, tea, sugarcane, cotton, tubers, and even pyrethrum.

Despite a general agreement on the potential usefulness of herbicides, however, only a small minority of maize farmers in Kenya uses them today. A number of factors seem to contribute to their slow uptake. Herbicides can be costly and require upfront cash or credit resources that are often unavailable to smallholders. Herbicides may not always be locally available. Herbicides may be packaged in larger amounts, which are not relevant to smallholders. The agronomic knowledge needed for effective use (e.g., to correctly identify the type of weeds in a field, choose appropriate herbicide[s] to control them, and know when and how to use), which is demanding and not widely available (e.g., Micheni et al., 2010a, 2010b; Muthamia et al., 2001).

Potential Yield Losses from Ineffective Weed Control

If untimely and ineffective weed-control efforts are frequent in Kenyan maize production, what sort of yield losses should be expected? While direct evidence is, once again, not plentiful, there is some indirect empirical evidence that provides initial indications. Herbicide

Table 4. Average maize grain yields from different weed management systems during the first and second seasons of kick-out efficacy trials.

Weed management treatment	Herbicide rate (ha-1)	Maize grain yields (t^{-1})	
		1st season	2nd season
Kick-out	1.5	3.7	4.3
Kick-out	2	4	4.5
Kick-out	2.5	3.8	4.1
Weedall	2	4.3	3.9
Un-treated control	N/A	0.6	1.2
Hand weeding	N/A	3.9	4.2
Mean	-	3.4	3.7
CV	-	2.22	1.34

Source: Micheni and Mbogo (2011)

Table 5. Average maize grain yields from different weed management systems during three seasons of glyphonut efficacy trials.

Weed management treatment	1st season	2nd season	3rd season	Mean
Glyphonut, 1.5 liters/ha	5.1	5.6	4.8	5.2
Glyphonut, 3.0 liters/ha	4	5.2	4.6	4.6
Glyphonut, 4.5 liters/ha	5.1	5.4	4.9	5.1
Touchdown, 1.5 liters/ha	4.2	5	4.5	4.6
Weedall, 2.0 liters/ha	3.6	4.9	4.2	4.2
No weeding (control)	1.3	1.4	0.8	1.2
Conventional tillage	4.1	4.8	4.4	4.4
Mean	3.9	4.6	4	4.2

Source: Micheni et al. (2010a)

efficiency trials, for instance, can help quantify the upper bounds of potential yield losses from ineffective weed control in Kenya. To be sure, herbicide efficiency trials are not representative of actual farm conditions, as they are of small scale and weed-control inputs are not applied at cost/profit-optimizing levels as they would be on a farm. Still, they do provide measures of potential yields from fields that have been prepared, planted, and weeded adequately and in a timely fashion as well as measures of maize yields from fields that have not been weeded at all. They also provide useful information on weed populations and densities in Kenyan maize fields.

Because of their usefulness, we present here results from three recent herbicide efficiency trials in Kenya and draw inferences about potential yield losses in maize production and about the types of weed populations that can cause them.[4] The first trial compared the efficiency of a post-emergence glyphosate herbicide (“Kick-out”) applied at different rates to that of another broadly used herbicide (“Weedall”) and to the efficiency of hand weeding over two production periods (Table 4). The second trial compared the performance of another glyphosate herbicide (“Glyphonut”) used under conservation tillage in humid areas of Central Kenya against the performance of two alternative herbicides and to the use of conventional tillage (Table 5).

As illustrated in Tables 4 and 5, maize yields under all alternative herbicide treatments as well as under conventional tillage and hand weeding were similar in all locations and seasons. This is expected as all such alternative weed-control methods are practiced by experts with no consideration to costs and, as such, they represent maximum and effective weed control. More informative therefore are the reported yields for the unweeded parcels, which were 70%-90% lower than the yields of those parcels where weeds were controlled. These yield losses are in line with those reported in the literature for maize produced under poor weed-control conditions in various countries. They are also only slightly lower than the average yields achieved by smallholder maize farmers in Kenya under normal production conditions (approximately 1.1 to 1.4 metric tons per hectare).

Participatory field trials on smallholder farms have also confirmed the results from herbicide efficiency trial studies. For instance, Mwanda (2000) found that uncontrolled weed growth could reduce maize yields by up to 60% in smallholder fields of Eastern Kenya. Similarly, Micheni et al. (2010a, 2010b) carried out participatory herbicide trials in the Central Kenya highlands from April 2003 to October 2005 where they compared minimum-tillage production systems that used pre- and post-emergence herbicide treatments with conventional-tillage production systems that used hoeing and hand weeding. They found that production of maize with conservation tillage and herbicide use yielded 40% more than those based on conventional tillage. They also found that use of minimum tillage and herbicide use resulted in lower labor use, 25-40% ($20-35 USD per hectare) in variable cost savings, and improvements in farm profitability.

The third herbicide efficiency trial we review here evaluated a selective broad spectrum post-emergence herbicide (“AUXO”) for controlling both the broad- and narrow-leafed weeds (Table 6). In this context, the weed

4. *It should be noted that the herbicide efficiency trial data reported here are representative of many others that have been carried out in Kenya over the years. Hence, the inferences drawn are general.*

Table 6. Weed species and their percent occurrence during April 2009, October 2009, and April 2010 rainy seasons.

		% weed occurrence within the trial site		
	Weed species	1st season	2nd season	3rd season
1	***Bidens pilosa*** **(Black jack)**	75.8	20.1	56.6
2	***Setaria spp.***	34.6	15.4	56.4
3	***Tagetes minuta***	53.4	14.9	23.9
4	***Nicandra physalodes***	12.2	5.4	9.5
5	***Galinsoga parviflora***	65.1	28.5	73.1
6	***Euphorbia hirta***	12.8	4.0	26.0
7	***Richardia scabra***	36.7	96.4	42.1
8	***Eleusine Indica***	43.0	2.5	54.2
9	***Lionotis mollisma***	46.7	9.2	3.8
10	***Amaranthus spp.***	28.9	6.6	11.3
11	***Portulaca spp.***	5.5	0.0	4.2
12	***Oxalis spp.***	34.9	2.5	25.1
13	***Cyperus spp.***	40.9	6.8	16.4
14	***Camelina bengalensis***	14.2	2.9	6.4
15	***Digitania spp.*** **(Couch grass)**	11.2	24.4	12.7
16	***Datura stramonium***	6.9	1.8	3.1
17	***Digitaria velutina***	3.2	1.2	2.2
18	***Eragrostis tenuifolia***	3.2	1.4	1.8
19	***Portulaca oleraceae***	1.5	1.0	0.5

Source: Micheni et al. (2010b)

populations and densities encountered in the small fields were recorded and we present this data here.

The information in Table 6 illustrates the significant weed flora that can be found in maize fields in Kenya as well as the radical shifts that can be observed in weed populations from one season to another. These radical shifts illustrate a key constraint on the adoption of herbicides in Kenyan maize production: to effectively use them farmers must have enough knowledge to properly identify varying weed populations early in the season, choose the correct herbicide to apply (in the right proportion and time), and have easy and timely access to proper supplies. It is unlikely that most of these conditions could be met for the majority of Kenyan maize producers.

In all, there is limited direct empirical evidence about the timeliness and efficiency of current weed-control methods in Kenyan maize production and the associated yield losses from weed competition. Nevertheless, indirect evidence suggests that because of the persistent constraints in labor supply as well as limited access to mechanical and chemical means for timely land preparation and weed control, large yield losses may be consistently realized in most Kenyan maize farms. Under such conditions, improvements in land preparation and weed control during critical periods of maize production could lead to both yield increases and cost reductions. In this context, the use of HT maize is of interest.

HT Maize and Potential Agronomic Impacts

HT maize is a novel weed-control system. At this time, the dominant technology is the glyphosate tolerant maize (GTM), though other systems are also commercialized and under development. GTM is genetically modified to withstand direct contact with the broad-spectrum herbicide glyphosate which provides effective control for both grasses and broadleaf weeds. As such, the GTM is designed to allow over-the-top applications of the herbicide, eliminating weeds around the maize plants.

GTM can be used within a conventional or a minimum-tillage system. In the first instance, the maize producer can control weeds and prepare the maize field for planting by tilling the field as described above. Planting of GTM then allows the replacement of subsequent hand weeding with an over-the-top post-emergence application of glyphosate any time prior to the weeds growing taller than 10 cm. Depending on the weed density and type of weeds present in the farmer's field, an application rate of 0.9-1.8 kilograms of active ingredient (1-2 liters, depending on the formulated product) per hectare is recommended.[5] In the second instance, the maize producer can replace the land preparation operations with a pre-emergence (burn down) spray and glyphosate (but also other non-selective herbicides like gramoxone as well as tank mixes with 2,4-D, Dicamba, and other herbicides) can be used to control weeds prior to planting without the need for tillage.

Because spraying with glyphosate controls effectively a very broad spectrum of weeds and it does not harm the HT maize crop, maize producers do not need much specialized knowledge to use the technology. And because applying herbicide in a field planted with HT maize is a quick operation (one hectare of HT maize can be meticulously sprayed in less than one man-day), it is generally possible to manage weeds prior to the critical

5. *Note that the application rates used in HT maize systems are an important determinant of its cost efficiency as increased rates imply larger amounts of herbicide and higher costs.*

period even in the presence of labor constraints or of poor weather which, at times, can restrict access to the field. Finally, because of the low cost of glyphosate, its broad availability in most markets, and its superior safety profile, GTM technology can be readily implemented at relatively low cost in most places. Given these features, adoption of GTM should, in principle, lead to one or more of the following: ease and flexibility of weed management, timely and effective weed control, increased yields, improved cost efficiency, improved environmental and human safety, as well as increased adoption of reduced- and minimum-tillage production systems. So what has been the practical experience with the technology so far?

Potential Yield Benefits and Cost Efficiency Gains—A Review of Evidence

GTM has proved yield-neutral in technologically advanced maize sectors. For instance, GTM adoption in the United States and Canada has not been associated with any yield gains (Brookes & Barfoot, 2011). This is not surprising as crop yield is a function of both genetics and effectiveness of weed control (and other factors). GTM uses the same germplasm base as conventional maize and has the same yield potential under equally effective weed-control alternatives (other conditions being equal). Since weed-control practices in North America are generally timely and effective, the most direct advantage of GTM has been an economic one. Substitution of multiple and more costly herbicides for the broad spectrum and inexpensive glyphosate has been found to reduce the costs of weed control by $15-25 per hectare in the United States, after accounting for increased seed costs and other expenses (*ibid*).

When weed-control practices are not timely or effective and weed competition causes large yield losses, gains in yields from the use of GTM are, however, possible. Significant yield gains from the use of GTM have also been reported in the Philippines, Indonesia, and South Africa, where large numbers of subsistence farmers grow maize. Field tests of GTM conducted by Syngenta over two seasons in six different locations in the Philippines showed that GTM provided, on average, an 8% yield advantage over conventional maize and 35% over unweeded fields.[6] As with all herbicide efficiency trials, this type of experimental data should be used with caution since both GTM and conventional maize receive maximum weed control and hence yield differences are not expected to be large or representative of potential yield differences achieved on the farm.

Information on potential yield gains in the Philippines is available from participatory (split-plot demonstration) field trials compiled during the wet season of 2005. In the aggregate, the trials showed that GTM provided up to 15% yield advantage over standard producer weed-control programs. Yield gains were also observed in field trials in Indonesia. In multiyear field trial data performed by Monsanto, GTM was found to provide up to a 13% yield advantage in dry seasons and up to a 25% average yield gain during wet seasons.[7]

The most extensive empirical evidence on the performance of HT maize adopted by smallholders under normal farm conditions, however, comes from South Africa. Gouse and collaborators from the University of Pretoria have studied the adoption and performance of HT (as well as Bt) maize, effectively, for the same group of subsistence maize farmers in Hlabisa, South Africa over multiple years.

HT maize was first introduced in South Africa in the 2004/05 season and stacks of HT with Bt maize were introduced in 2007/08. Smallholders in Hlabisa have historically used hired tractors or oxen-drawn plow for land preparation. After the introduction of HT maize, however, HT adopters seem to find that the most cost- and labor-effective way to plant is to just “open plant and close” using a hoe without tilling the soil (Gouse, Piesse, & Thirtle, 2006; Gouse, Piesse, Thirtle, & Poulton, 2009; Gouse, Pray, Kirsten, & Schimmelpfennig, 2005; Gouse, Pray, Schimmelpfennig, & Kirsten, 2006). This is in line with the no-tillage practices known as “planting without plowing” (PWP) that is recommended by the Agricultural Research Council to limit soil erosion (Gouse, Piesse et al., 2006; Gouse, Pray et al., 2006).

Yield increases between HT and conventional maize were also consistently observed among smallholders in Hlabisa. Overall, in three out of four seasons, 9-10% yield gains were observed from the adoption of HT maize (Table 7). In 2006/07, yield differences between HT and conventional maize were 94% and Gouse reported that during that season HT producers in the sample applied significantly more fertilizer than they had in the past. Whether this large yield gain is attributable to increased fertilization alone, to the combined

6. *Data provided by Syngenta to the authors through personal communication.*

7. *Data provided by Monsanto to the authors through personal communication.*

Table 7. Yield comparison between conventional, HT, and Bt/HT maize achieved by smallholders in Hlabisa, South Africa (various years).

Season		Conventional	HT	Bt/HT stack
2005/06	Number of farms	61	21	
	Average yield	440	481	
	Difference to conventional		9%	
2006/07	Number of farms	38	35	
	Average yield	451	875	
	Difference to conventional		94%	
2007/08	Number of farms	28	38	19
	Average yield	1,869	2,062	2,263
	Difference to conventional		10%	21%
2009/10	Number of farms	16	67	15
	Average yield (grain MT/hectare)	1,707	1,880	1,910
	Difference to conventional		10%	12%

Source: M. Gouse, University of Pretoria

effect of increased fertilization and improved weed control, or other factors is unclear.

In many publications, Gouse and coauthors have also estimated the expenses paid by smallholder maize producers in Hlabisa for land preparation, hand weeding, and herbicide use according to their use of conventional, HT, and stacked HT/Bt maize. In the three periods between 2005/06 and 2007/08, maize producers growing HT maize in Hlabisa experienced $23-81 USD/hectare lower costs due to substitution of labor and capital for herbicides. These represented 7-26% reductions in relevant expenses. In 2009/10, however, expenses associated with land preparation and weed control were higher in HT maize than in conventional maize production due to low labor use for cultivation and higher herbicide costs. It is not clear what caused either of these changes.

Ease and Flexibility in Weed Control and “Non-Pecuniary Effects”

Increasing empirical evidence suggests that HT maize and other herbicide-resistant crops can also lead to so called “non-pecuniary” benefits. Non-pecuniary benefits are typically associated with increased simplicity, ease, and flexibility in managing a weed-control system but also with other non-market effects like improved environmental safety (Marra & Piggott, 2006). In developed agricultural sectors, substitution of many selective herbicides for a single broad-spectrum herbicide that provides consistent weed control with a wider application window implies less dependence on weather or weed size and has been taken to provide the producer “convenience” and “peace of mind.” Producers in the United States for instance, have been found to place significant value to such non-pecuniary benefits (*ibid*). Smallholder maize producers in constrained environments have also been found to value simplicity in weed control and it has been shown that such value can drive their potential adoption decisions.

Kalaitzandonakes, Suntornpithug, and Thongrag (unpublished data, 2011) examined the potential adoption of HT maize in Thailand through a national survey of 1,000 maize farmers, and selected data from their survey is presented in Table 8. Thai maize producers, 50% of whom farm six hectares of land or less, were found to place significant economic value on the increased yield potential and cost efficiency of HT maize but also on the potential simplicity and flexibility allowed by the new technology in weed management. Naturally, individual farmers valued the potential impacts differently, but larger individual valuations were associated with higher stated propensity to adopt HT maize (Table 8). On average, likely adopters valued the increased yield potential at $70 per hectare, the potential cost efficiencies from less cultivation at $29/hectare, and the potential savings from lower herbicide costs at $17.50/hectare. Likely adopters also valued “flexibility and ease” in weed management at $17-$19.50/hectare. Finally, they valued human and environmental safety associated with the safety profile of glyphosate at $7-9/hectare. While these economic values overlap and are not additive, they do suggest that all potential impacts of HT maize (both pecuniary and non-pecuniary) can be valued by resource-constrained smallholder maize producers.

Other potential non-pecuniary benefits which have not received significant attention in the literature

Table 8. Valuation of farm-level pecuniary and non-pecuniary benefits of HT maize by Thai producers (in USD).

Incremental value against current weed control practice (in USD/hectare)	Whole sample avg	Not likely to adopt	Likely to adopt	Difference (in $)
Valuation statement (Yield/cost impacts)				
"For lower herbicide costs"	16.1	15.1	17.5	2.4
"For needing less cultivation weeding"	26.6	23.2	29.2	6.0
"For 8% higher average maize yields"	59.0	47.5	70.2	22.7
Valuation statement (Non-pecuniary impacts)				
"For simpler and more effective weed control"	16.1	11.6	19.5	7.8
"For making easier and simpler to manage a maize crop"	15.4	11.4	17.8	6.3
"For making use of conservation tillage in maize production easier"	16.6	12.0	20.0	7.9

Source: Kalaitzandonakes, Suntornpithug, and Thongrag (Unpublished data, 2011)

include the avoidance of drudgery associated with manual weeding or the ability to use family time in alternative activities beyond farming. For instance, in a number of industry surveys in the Philippines evaluating the value of HT maize to smallholders, farmers have indicated that they value the labor savings because they value "spending more time with the family." However, the economic values attached to such potential benefits have not been quantified. It is unclear how much non-pecuniary benefits could affect the adoption of HT maize in Kenya.

Overall, both the current state of weed control in Kenyan maize production and the experience of HT maize from countries where it has been used suggest that there is scope for meaningful agronomic and economic contributions from the use of HT maize technology in the Kenyan maize sector. We quantify the size of such potential economic impacts in the next section.

Economic Impact Analysis

For an effective *ex-ante* economic impact assessment of HT maize, the following must be quantified: a) the potential farm-level impacts of HT maize on input use and yields; b) the intrinsic value of such farm-level impacts to the farmers and, in turn, the farmers' response (e.g., level of HT maize technology adoption, changes in level of adoption over time, etc.); c) the market impacts from the adoption of HT maize (e.g., aggregate change in supply, changes in market prices in response to the new levels of supply, aggregate demand response to these price changes, etc.); and d) the aggregate producer and consumer benefits (usual metrics include producer and consumer "surplus" measures, but also other simpler monetary estimates). We look at each of these issues in this section.

Potential Farm-Level Impacts of HT Maize in Kenyan Maize Production

Both theoretical expectations and empirical evidence from South Africa, the Philippines, and other countries with maize sectors dominated by resource-poor farmers suggest that the most significant agronomic changes caused by the adoption of HT maize involve the substitution of labor and capital inputs used in land preparation and weed control. We therefore use budgets and labor-use data from previous studies in Kenya to calculate the typical range of labor and/capital used for land preparation and associated costs and the typical range of labor used for hand weeding and associated costs. We also use studies from the Philippines and South Africa to approximate the likely practices for pre- and post-emergence use of glyphosate in HT maize systems (e.g., likely glyphosate application rates, required application labor, labor and capital required for additional operations) and calculate their associated costs based on glyphosate prices, labor wages, and other relevant costs in Kenya. Finally, we use estimates of yield gains from studies in the Philippines and South Africa to infer potential yield gains in Kenya and apply them against base yields in Kenyan maize production.

There are inherent difficulties even with these simple approximations. Because of the significant regional and temporal variations in climate, field and farm characteristics, weed infestations, cropping and weed-control practices, maize productivity, labor supply, wage rates, and other relevant factors, "typical" amounts of labor and associated costs for land preparation and hand weeding vary significantly across studies. An additional challenge is the significant heterogeneity that is often inherent in the measurement of certain inputs. For instance, it might take an average of 14-17 man-days of hired specialized males to hoe and weed a hectare of land but 45-50 man-days of less specialized hired or family labor. While these issues suggest that a natural variation might be expected in the estimates used for the analysis, we obtain reasonable ranges of input quantities and costs for all activities of interest.

For our base calculations we use the following ranges: It costs, on average, $49-65 USD/ha (3,800-5,000 KSH/ha) for land preparation and $41-58 USD/ha (3,200-4,500 KSH/ha) for hand weeding in maize production in Kenya. Hence, the total cost of these activities comes to $90-123 USD/ha (7,000-9,500 KSH/ha). Depending on the commercial product used, one application of glyphosate in Kenya costs $26-34 USD/ha (2,000-2,650 KSH/ha). Based on alternative scenarios regarding the glyphosate rate used, potential tankmixes with other supplemental herbicides, and the mix of pre- and post-applications used to replace land preparation and hand weeding activities, we find that a conservative range of possible cost savings from the adoption of HT maize in Kenya would be $15-32 USD/ha. Potential cost efficiencies, however, could be twice this range under fairly reasonable assumptions. If harrowing and more than one tillage/hand weeding operations are normally used, the potential cost efficiencies from the adoption of HT maize could be much larger.

Yield gains from the use of HT maize in Kenya are likely to be larger than those observed in the Philippines and South Africa as the typical weed density and weed seed count in Kenyan fields are higher while land preparation and post-emergence weed-control practices are less mechanized and timely. Nevertheless, 7-15% yield gains have been commonly observed in both the Philippines and South Africa (smallholders), and we use this range of yield gains as a reasonable approximation of the potential benefit from the adoption of HT maize in Kenya as well.

It is likely that HT maize seeds will cost more than conventional maize seeds in Kenya. However, given the lack of clarity on this issue we have not made any specific assumptions about incremental seed prices or technology fees. Hence, the farm-level benefits used in our analysis are "gross" and, as such, the aggregate economic benefits of HT maize estimated below are to be distributed among producers, consumers, technology providers, and seed firms. The exact distribution and the relative benefit shares of the producers, seed firms, and technology suppliers would be determined by the relative difference in prices producers might have to pay for HT maize seeds and the fees seed firms might have to pay to the technology suppliers.

Non-pecuniary benefits may be possible from avoiding the drudgery associated with hand weeding and other manual labor, increasing availability of family and individual time for non-farm activities, saving soil and improving the sustainability of fields, and other factors. While such potential benefits may be valued by Kenyan maize farmers, we do not account for their values in the economic impact analysis.

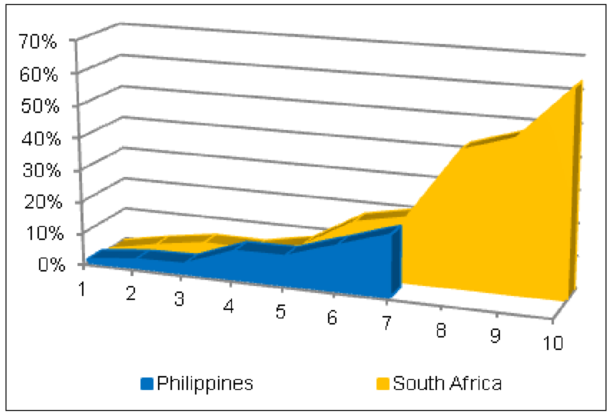

Figure 1. Adoption of HT maize in South Africa and the Philippines.

Potential Adoption Path of HT Maize

Ideally, farm-level data on Kenyan producer valuations of the likely farm-level impacts of HT maize are needed to determine potential adoption. In order to deduce a possible adoption path for HT maize in Kenya, we look to the adoption paths of biotech maize in the Philippines and South Africa. Biotech maize adoption paths in these two countries have been similar and have followed a rather typical pattern of technology diffusion (Figure 1). Biotech maize adoption in South Africa stood at 17% six years after its initial introduction in 1999/2000 and reached 68% of the total maize area in South Africa by 2009/10. In the Philippines, biotech maize was first introduced in 2003/04 and adoption stood at 19% of the total maize area after six years.

In this study, we assume that the rates of adoption of biotech maize in South Africa and the Philippines could be representative of the potential adoption path of HT maize in Kenya due to the similarities in the maize sectors of the three countries. Specifically, the Philippines and South Africa have maize sectors of similar size to that of Kenya—Philippines has harvested 2.3-2.6 million hectares in the last decade, while South Africa has harvested 2.4-3.1 million hectares and Kenya has harvested 1.5-1.7 million hectares in the same period. Furthermore, all three countries have a large number of small, subsistence-level maize farms with similar average sizes. Finally, smallholder maize farms in the three countries have similar weed-control and land-preparation cost structures and use similar amounts of labor for hand weeding. Given these conditions, for the purpose of the economic impact analysis we assume that the adoption in Kenya will follow a path similar to those two countries (their average for the first six years and the path observed in South Africa after that), reaching a maximum level of adoption of 70% within 10 years from the initial commercialization.

The adoption rate is assumed to be driven by producer interest, and no supply constraints on the technology are envisioned. Still, adoption is assumed to be possible only through the use of hybrid seeds and the total share of hybrid seeds in the Kenyan maize sector is currently estimated at 60% of all maize seeds used in Kenya. For our analysis, we assume that the share of hybrid seed in Kenyan maize production increases over the 10-year period of analysis from 60% to 75%.[8] We therefore effectively assume that 10 years after its commercial introduction, HT maize would be used on 52.5% of all maize hectares in Kenya.

Market Effects of HT Maize in Kenya—Model and Estimation Procedures

Because of the opportunity to increase yields from more timely and effective weed control, to reduce labor use and costs, and to gain from other non-pecuniary benefits from HT maize, some Kenyan maize producers would adopt the technology along the lines described above. In fact, some may find it profitable to intensify their production through the use of additional inputs (e.g., fertilizer) or by diverting land from other crops or labor from other activities. In the aggregate, their response could increase the overall amount of maize produced in Kenya and shift the supply in the market. In a "closed" maize economy like that of Kenya, increased supply tends to lead to declining prices, and the typical response of maize buyers is to increase their consumption and demand. At the same time, declining prices also affect producers' decisions for planting and other input use and could lead to a partial pullback in supply. All these movements in the supply, demand and maize prices are collectively referred to as "the market effects" of new technology.

Determining such market effects ultimately allows calculation of the aggregate economic impact of HT maize and its distribution among producers and consumers of maize in Kenya. To effectively estimate the market effects of HT maize, we use a synthetic partial equilibrium model (PEM) that represents the supply and demand conditions of the Kenyan maize sector. The PEM we have developed to represent the economics of the Kenyan maize sector estimates harvested area, yields, production, consumption, stocks, imports, and maize prices. It is calibrated against Kenyan maize data available from the Production, Supply, and Distribution online database; US Department of Agriculture; and Food and Agricultural Organization of the United Nations (FAO; 1990/91 to 2009/10) and published demand and supply elasticities for maize in Kenya. A summary of the studies and the range of demand and supply elasticities found in the literature is presented in Appendix Tables A1 and A2.

In order to evaluate the potential economic impacts of HT maize in Kenya we first develop the counterfactual ("what would Kenya maize supply, demand, prices, and other variables of interest be in the future if HT maize was not introduced"), which will serve as the baseline for all comparisons. Next, we examine the impacts of HT maize under the following four scenarios:

- *Scenario 1 (Sc 7&15)*: HT maize causes a 7% yield gain and a $15 USD/ha cost efficiency—the lower bound of our estimates of the farm-level impacts of HT maize in Kenya;
- *Scenario 2 (Sc 15&32)*: HT maize causes a 15% yield gain and a $32 USD/ha cost efficiency—the upper bound of our estimates of the farm-level impacts of HT maize in Kenya;
- *Scenario 3 (Sc 20&15):* HT maize is introduced stacked with Bt maize and causes a 20% yield gain and $15 USD cost efficiency as it combines the lower-bound farm-level impacts of HT maize with an assumed 13% yield gain of Bt maize;[9] and
- *Scenario 4 (Sc 28&32):* HT maize is introduced stacked with Bt maize and causes a 28% yield gain and $32 USD cost efficiency as it combines the upper-bound farm-level impacts of HT maize with the 13% yield gain of Bt maize.

8. *We evaluate the significance of this assumption through sensitivity analysis and discuss the implications later in this section.*

9. *The assumed yield effect from the potential adoption of Bt maize in Kenya is obtained from the data derived through the Insect-Resistant Maize for Africa (IRMA) project.*

Table 9. Estimated market effects from adoption of HT maize in Kenya.

Scenarios	Change in production (over baseline)	Change in consumption (over baseline)	Change in imports (over baseline)
In 1000 MT over baseline			
Scenario 1: 7% yield gain and $15/hectare cost efficiency	121	39	-95
Scenario 2: 15% yield gain and $32/hectare cost efficiency	258	84	-203
Scenario 3: 20% yield gain and $15/hectare cost efficiency	339	110	-266
Scenario 4: 28% yield gain and $32/hectare cost efficiency	475	155	-373
In % over baseline			
Scenario 1: 7% yield gain and $15/hectare cost efficiency	4%	1%	-14%
Scenario 2: 15% yield gain and $32/hectare cost efficiency	8%	2%	-29%
Scenario 3: 20% yield gain and $15/hectare cost efficiency	10%	3%	-38%
Scenario 4: 28% yield gain and $32/hectare cost efficiency	14%	4%	-53%

Market Effects of HT Maize in Kenya—Empirical Results

The assumptions of the alternative farm-level impacts as described in Scenarios 1 through 4 as well as the assumptions on adoption path of HT maize are imposed on the PEM one set at a time and the results are reported in Table 9. Adoption of HT maize with farm-level impacts as in Scenario 1 would generate almost 121,000 metric tons (MT) of additional maize production (a 4% increase over the baseline), 39,000 MT of additional consumption (1% increase), and a 95,000 MT reduction in imports (14% reduction). These impacts are the combined (net) effects of demand and supply shifts caused by the adoption of HT maize. For instance, while production expands from the use of HT maize, the additional supply induces a price decline in the market, which in turn causes the total maize area to decline somewhat, thereby reducing production.

Adoption of HT maize with farm-level impacts as in Scenario 2 results in almost 260,000 MT of additional maize production, 84,000 MT of additional production, and a bit over 200,000 MT of reductions in maize imports. When HT maize is introduced stacked with the Bt trait, the market effects are larger. For instance, adoption of the HT/Bt maize with a farm-level impact as in Scenario 4 would generate 475,000 MT of additional production (14% increase over baseline), 155,000 MT of additional consumption (4% increase over baseline), and a 373,000 MT reduction in imports (53% decrease over baseline).

An important factor that influences the size and distribution of the aggregate economic impacts of new technologies in any country is trade. Kenya is a deficit maize producer. Its production has been growing somewhat slower than its demand in recent years and domestic consumptions has consistently exceeded production. The main driver for the increased demand of maize is population growth, which has been increasing at almost 3% per year (thereby adding almost 13 million people to the Kenyan population between 1991 and 2010). Land for maize production is limited in Kenya, so gains must come mainly from higher yields. Maize yields, however, have been stagnant in recent years and domestic supply has not been keeping up with domestic demand, even though yields in 2010/11 were high. Per-capita consumption has also not been keeping up and has declined from 115 kg in 1991 to less than 80 kg in recent years, suggesting deteriorating food security. In this context, the growth in domestic maize production that could be achieved through the adoption of HT maize as illustrated above allows a modest increase in consumption and a significant decrease in its trade deficit of maize, thereby increasing the country's self-sufficiency.

Taking into account market effects, Kenyan maize producers benefit from yield gains and cost efficiencies but lose from lower maize prices (which decline from almost 3% to more than 14% relative to baseline prices depending on the scenario). Kenyan maize consumers benefit both from additional consumption and from the lower prices. To aggregate all such effects in a consistent way, we use standard, so called, producer and consumer surplus measures that are frequently employed by economists to evaluate changes in social welfare from shifts in market supply and demand conditions (Alston, Norton, & Pardey, 1998).[10]

The first column of Table 10 presents estimates of the changes in social welfare (the sum of producer and consumer surplus or total surplus) expressed in USD, and these figures suggest that significant aggregate economic impacts would result from the introduction of HT

Table 10. Total changes in social welfare from introduction of HT maize in Kenya 10 years after introduction when maximum adoption occurs.

Scenarios	Current million $ in year that technology achieves maximum adoption	Million $ NPV calculated in year of the technology's commercial introduction
Scenario 1: 7% yield gain and $15/hectare cost efficiency	67.4	41.4
Scenario 2: 15% yield gain and $32/hectare cost efficiency	140.9	86.5
Scenario 3: 20% yield gain and $15/hectare cost efficiency	170.0	104.4
Scenario 4: 28% yield gain and $32/hectare cost efficiency	237.7	146.0

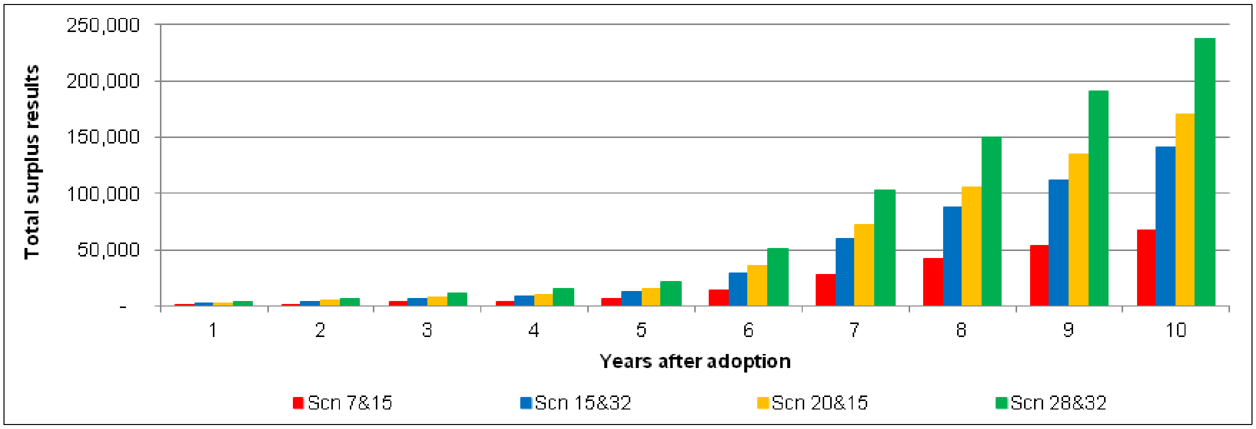

Figure 2. Economic gains from the adoption of HT maize over time (current $1,000).

maize in Kenyan maize production. At the end of the 10-year period when adoption of HT maize has reached its maximum 70%, its aggregate economic impact would be between $67-237 million, depending on the extent of farm-level impacts achieved (as described in Scenarios 1 through 4). To account for the fact that the stream of such economic impacts is spread over a 10-year period, we discount the various annual aggregate economic gains to the year HT maize is first commercialized using a 5% discount rate. The net present value (NPV) of the total economic gains from the adoption of HT maize as a single or stacked trait would then range between $41 and $146 million.

It is interesting to note here that the bulk of the economic gains from the introduction of HT maize in Kenya is achieved after the technology has been adopted on a broader share of hectares. This temporal pattern is illustrated in Figures 2 and 3. It is also worth emphasizing that after the adoption level stabilizes around its "steady state" maximum level these aggregate economic gains continue at the calculated annual levels into the future unless the farm-level yield and efficiency gains from the technology or the level of adoption are reversed (for instance, from the build-up of weed resistance to the technology or other causes).

In all, the results above suggest that the aggregate economic impact of HT maize in Kenya would be significant even under conservative assumptions about the likely farm-level impacts of technology. And as discussed earlier, the aggregate economic impacts are expected to be distributed between producers and con-

10. *It is important to note here that the standard producer and consumer surplus measures are derived under general assumptions of well-separated profit-maximizing producers and utility-maximizing consumers. The Kenyan maize sector is dominated by subsistence households that are both producers and consumers. Under such conditions, supply and demand responses can be different from these assumed in the standard model. For instance, risk-averse households could increase their production in the face of higher price risk to ensure self sufficiency and insulate themselves from price shocks. Pure producers would tend to reduce production under similar circumstances. The implicit assumption in the calculations performed here is that aggregate supply and demand shifts in the Kenyan maize sector are reflected in historical data and hence in the PEM used here. Accordingly, calculated changes in producer and consumer surplus measures should provide reasonable approximations for welfare changes among Kenya's maize-producing and -consuming households. Indeed, since households are both producers and consumers, the more pertinent measure is the aggregate of producer and consumer surplus (total surplus), which we report.*

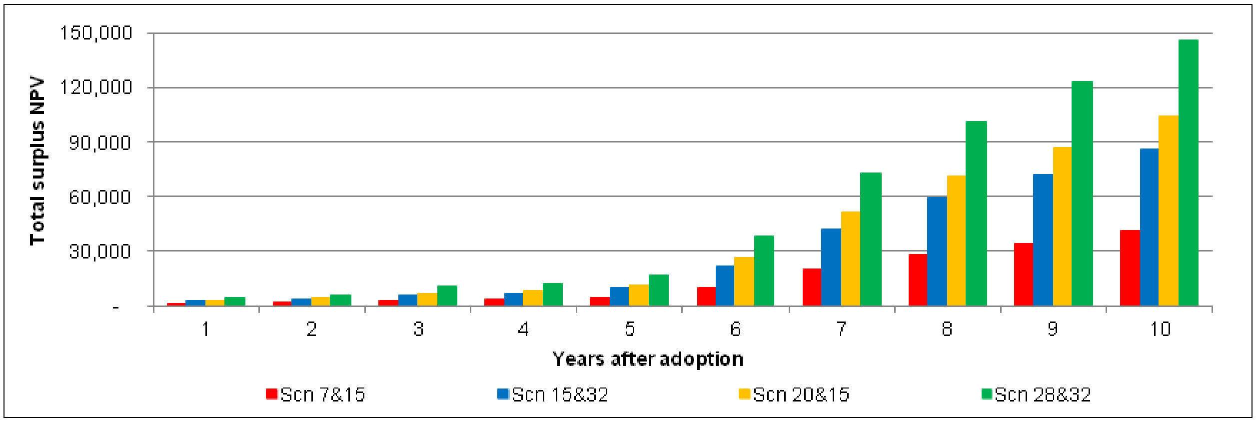

Figure 3. Economic gains from the adoption of HT maize over time (NPV-$1000 base year).

sumers, but a share of the producer benefits is expected to be captured by seed firms and technology providers in the form of higher seed prices. The higher the price premium charged for HT maize, the larger the share that would be appropriated by the seed industry.

Economic Impacts under Lower Levels of Adoption

A number of possible factors identified above could discourage adoption of HT maize in Kenya. These include binding cash constraints that could restrict the household's ability to pay for herbicides early in the production season, lower implied valuation of "unpaid" family labor by households, and high seed prices for HT maize. Furthermore, our assumption about the gradual increase in the use of hybrid seeds from the current 60% to 75% of the seed used within a decade could be optimistic. To evaluate the potential impact of such changes in the underlying assumptions of our analysis, we use sensitivity analysis. Specifically, we re-estimate the aggregate economic impacts of HT maize for all four scenarios of farm-level impacts but with the hybrid seed market left at its current 60% level and the maximum level of HT maize adoption set at 60% after 10 years from commercial introduction. In effect then, we assume that HT maize would be used on 36% of all maize hectares in Kenya within 10 years from its commercial introduction. We report the estimated aggregate economic impacts of HT from this analysis in Table 11.

The results indicate that changes in the underlying adoption path and maximum level of adoption result in a decrease of 29-32% in the estimated aggregate economic impact of HT maize. Hence, the adoption path and, importantly, the maximum possible adoption of HT maize, have important implications for the aggregate economic impact of the technology. Overall, even with this more conservative path of adoption, the aggregate economic impacts of HT maize remain significant.

The Role of Maize Trade Policies on Prices and the Implied Economic Value of HT Maize

For years, the government of Kenya has actively managed the domestic maize market with various policies, including regular restrictions on imports. In the last few years, *ad valorem* import tariffs of 50% have been imposed on imports outside East African countries, and such tariffs have been temporarily suspended only under severe shortages due to drought and other significant production shortfalls. Because of these and other policies, maize prices in Kenya typically exceed international market prices, often by a significant margin. As we illustrate in Figure 4 below, even in the last five years during which international commodity prices have seen steep increases, Kenyan maize prices have remained well above international prices for most of the time.

Given this market structure, at least two points need to be underscored. First, higher maize prices in Kenya mean higher aggregate economic impacts for HT maize. Hence, as long as Kenyan maize prices remain at levels similar to those seen in recent years, yield- and efficiency-enhancing innovations like HT maize will be more highly valued. If international maize prices were to return to lower levels or the Government of Kenya were to adopt policies that opened the domestic maize market to international competition and trade, domestic maize prices would decline and the implied economic value of HT maize would be somewhat lower. Second, there is informal evidence that there can be a wide gap between the local prices received by Kenyan maize

Table 11. Total changes in social welfare from introduction of HT maize in Kenya 10 years after introduction when maximum adoption (60%) occurs and hybrid seed-market growth is limited.

Scenarios	Current million $ in year that technology achieves maximum adoption	Million $ NPV calculated in year of the technology's commercial introduction
Scenario 1: 7% yield gain and $15/hectare cost efficiency	46.4	28.5
Scenario 2: 15% yield gain and $32/hectare cost efficiency	97.8	60.1
Scenario 3: 20% yield gain and $15/hectare cost efficiency	118.8	72.9
Scenario 4: 28% yield gain and $32/hectare cost efficiency	167.5	102.8

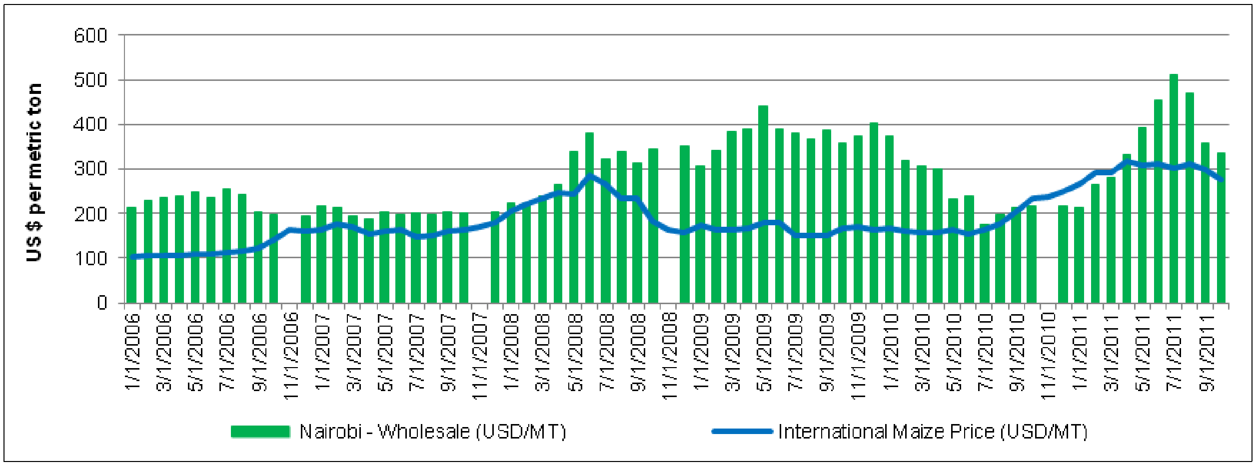

Figure 4. Selected monthly maize prices in Kenya and international markets, 2006-2011.
Sources: FAO, World Bank, personal communication with private commercial vendors, 2011

farmers and those recorded in regional Kenyan maize markets, such as those illustrated in Figure 4. Given the low volumes of maize transacted by individual farmers and the overall poor storage, transport, and marketing infrastructure of Kenya, it is not surprising that marketing margins could be large. If such circumstances generally characterized the Kenyan maize sector, they would imply yet another redistribution of the aggregate economic benefits of HT maize estimated above. While the aggregate economic impacts calculated above would remain largely unchanged, a portion of the total economic benefit would be redistributed from the maize producers to the operators of the marketing chain, more or less proportionally to their marketing margins.

Concluding Comments

Direct empirical evidence on the potential yield losses and costs from ineffective weed control in Kenyan maize production is limited. There is fragmented but significant indirect evidence that suggests that poor weed management might be a source of both high cost inefficiencies and high yield losses in Kenyan maize production. As such, the potential of HT maize might be significant. Experience from the use of HT maize in the Philippines and South America is still emerging, but it is encouraging and suggests that the technology can substitute for large amounts of capital and labor used in land preparation and weeding, it can reduce production costs, and it can increase yields. It should be possible to replicate or exceed such farm-level impacts in Kenya, and based on the analysis presented here the aggregate economic impacts from such farm-level impacts could be large.

Under the farm-level projections presented in this study, the aggregate economic impacts of HT maize appear to exceed those of Bt maize when used alone and the aggregate economic impacts of HT/Bt maize stacks seem even higher. Market evidence from the Philippines and South Africa seems to support such valuations. Data collected in 2009/10 in Hlabisa, South Africa suggests that all farmers in the sample who used biotech maize had shifted to either HT maize or HT/Bt stacks, and none reported using Bt hybrids despite significant adoption in previous years. Similarly, while Bt maize was first introduced in the Philippines in 2003 and its adoption increased gradually over the four following years, after the commercial introduction of HT and HT/Bt stacks in 2006, the adoption of Bt maize has waned. In

2009/10, only 2% of total maize hectares in the Philippines were planted with Bt maize, 4% with HT maize, and 13% with HT/Bt stacks.

Additional empirical evidence from the use of HT maize in the Philippines, South Africa, and other developing countries could help further clarify the farm-level impacts of HT maize. Furthermore, farm and household data from Kenya on the potential value—both pecuniary and non-pecuniary—as well as the incentives and constraints for the adoption of HT maize could help solidify the estimates of its aggregate economic impacts presented here.

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Appendix

Table A12. Elasticities of demand used in the construction and calibration of the Kenya partial equilibrium model.

Study	Estimate	Notes
Bezuneh et al. (1988)	-1.19	
Jayne et al. (1995)	-1.41	Long-run (LR) Marshallian
Mills (1998)	-1.00	
Munyi (2000)	-0.45	Short-run (SR) Marshallian
Seal et al. (2003)	-0.46	SR Marshallian
Waliweta et al. (2003)	-0.90	
Nzuma (2008)	-0.53 to -0.83	SR/LR Marshallian
Nzuma (2008)	0.83 to 0.93	Expenditure elasticity

Table A2. Elasticities of supply used in the construction and calibration of the Kenya partial equilibrium model.

Study	Estimate	Notes
Maitha (1974)	0.93	
Booker (1983)	0.40	Acreage response—SR
Kori and Gitu (1992)	0.68	
Mills (1998)	0.68	
Munyi (2000)	0.32	Acreage response—SR
Renkow et al. (2004)	0.66	Acreage response—SR
Nzuma (2008)	0.34	Acreage response—SR