Isaac M. Wamatsembe, Godfrey Asea and Stephan M. Haefele

A survey: potential impact of genetically modified maize tolerant to drought or resistant to stem borers in Uganda

Agronomy, 2017; 7(1):24-1-24-16

Published version: http://dx.doi.org/10.3390/agronomy7010024 *agronomy*

MDPI

Article

A Survey: Potential Impact of Genetically Modified Maize Tolerant to Drought or Resistant to Stem Borers in Uganda

Isaac M. Wamatsembe [1], Godfrey Asea [2] and Stephan M. Haefele [3,*]

1. School of Agriculture, Food and Wine, University of Adelaide, Adelaide, SA 5064, South Australia, Australia; wamusoi@yahoo.co.uk
2. National Crops Resources Research Institute, National Agricultural Research Organisation, P.O Box 7084 Kampala, Uganda; grasea9@gmail.com
3. Rothamsted Research, Harpenden AL5 2JQ, UK

* Correspondence: stephan.haefele@rothamsted.ac.uk; Tel.: +44-(0)-1582-938124

Academic Editor: Tristan Coram
Received: 10 November 2016; Accepted: 14 March 2017; Published: 17 March 2017

Abstract: Maize production in Uganda is constrained by various factors, but especially drought and stem borers contribute to significant yield losses. Genetically modified (GM) maize with increased drought tolerance and/or Bt insect resistance (producing the Bacillus thuringiensis Cry protein) is considered as an option. For an ex ante impact analysis of these technologies, a farmer survey was carried out in nine districts of Uganda, representing the major farming systems. The results showed that farmers did rate stem borer and drought as the main constraints for maize farming. Most farmers indicated a positive attitude towards GM maize, and 86% of all farmers said they would grow GM maize. Farmer estimated yield losses to drought and stem borer damage were on average 54.7% and 23.5%, respectively, if stress occurred. Taking the stress frequency into consideration (67% for both), estimated yield losses were 36.5% and 15.6% for drought and stem borer, respectively. According to the ex-ante partial budget analysis, Bt hybrid maize could be profitable, with an average value/cost ratio of 2.1. Drought tolerant hybrid maize had lower returns and a value/cost ratio of 1.5. Negative returns occurred mainly for farmers with non-stressed grain yields below 2 t·ha^{-1}. The regulatory framework in Uganda needs to be finalized with consideration of strengthening key institutions in the maize sector for sustainable introduction of GM maize.

Keywords: Bt insect resistance; drought tolerance; ex ante impact assessment; GM maize; stem borer

1. Introduction

Maize is the most important cereal crop in global cultivation, before wheat and rice, with an annual global production estimated at 1.017 billion tons cultivated on 185 million hectares [1]. In Uganda, the annual production is estimated at 2.75 million tons cultivated on one million hectares [1]. Maize is a staple for many households, contributing about 11% of caloric intake of the country [2]. Its importance is increasing because of the decline in production of other traditional staple crops, particularly cassava and bananas, which have been devastated in the recent past by cassava brown streak virus and banana bacterial wilt, respectively [2]. In addition to being a staple crop, it is a source of income to those engaged in its production, contributing about 60 million US dollars through both formal and informal trade within the country and the East African region [2–4].

Despite the crops' importance to Uganda, maize yields remain low at 2.75 tons per hectare, far below the global average estimated at 5.5 tons per hectare [1]. A number of production constraints contribute to these low yields, which include poor seed quality, low yielding varieties, low input use, stem borer damage and drought stress, all considered as causing substantial yield losses. Average yield losses due to drought alone in Sub-Saharan Africa are estimated at about 33% which translates into substantial income losses for farmers in the region [5]. Vulnerability to drought is of course a result of dependence on rainfed conditions in regions with insufficient and/or uneven spread rains during crop growth [6]. Average yield losses to stem borer damage in maize have been estimated at about 13.5% within the East African region, further reducing farmers' income [7]. To address drought, two main strategies have been proposed: use of irrigation or development of drought tolerant varieties using both conventional and genetic engineering tools [6]. However, due to the heavy investment required to establish and maintain irrigation facilities, irrigation is rarely used in the tropical regions of Sub-Saharan Africa, leaving the majority of farmers reliant on seasonal rainfall [6]. Thus remains the option of drought tolerant varieties as the most feasible alternative to help farmers reducing the drought risk in the region. Both conventional and genetically modified (GM) varieties have been proposed to help reduce yield losses attributed to drought. Some genetically modified drought tolerant maize varieties have been reported to yield about seven percent higher than conventionally bred drought tolerant varieties [8] and may therefore be a good option to address the problem; however, this is not easy because of a widespread negative public perception and limited GM acceptance [8].

To combat the problem of yield loss due to stem borer damage in maize, chemical pesticides and use of GM maize are the available options suggested [9]. However, because of the high costs of chemical pesticides and their hazardous effects on human health and the environment, GM maize varieties are being adopted in a number of countries. Also, chemical pesticides for the control of stem borers are often not as effective as GM maize resistant to stem borers which has been reported to give up to 100% protection in some regions [9]. Additionally, GM maize resistant to stem borers has been demonstrated to have lower levels of mycotoxins as compared to conventional varieties [10]. Mycotoxins in maize grain pose a health hazard to humans and animals because of their toxicity and carcinogenic properties [10]. However, despite all these benefits, negative public perception of GM crops remains a great hindrance to their acceptance and Uganda is no exception in this matter. Nevertheless, confined field trials (CFT) of drought tolerant maize and stem borer resistant maize (Bt maize, producing the Bacillus thuringiensis Cry protein) are on-going in Uganda with a possibility of commercialization after a regulatory framework is established. Like in other countries where GM crops have been commercialized, understanding the issues and having a clear direction on how this can successfully be achieved is critical. As a step towards this goal, the International Food Policy Research Institute conducted a review of the economic impact of GM crops in developing economies and the methods used to evaluate this impact [11]. The study showed that only few studies have addressed the potential or actual impact of GM crops on smallholder farmers in Sub-Saharan Africa. Several studies are available on the actual impact of Bt cotton and Bt maize in South Africa, but the number of ex ante evaluations in other African countries is still limited. De Groote et al. [7] evaluated the potential for Bt maize in East Africa, and the potential impact of a GM banana on smallholder farmers in the Uganda highlands was investigated by Edmeades and Smale [12]. Further on, Horna et al. [13] assessed ex ante GM vegetables in Ghana whereas more recently Vitale at al. [14] have documented the impact of Bt cotton in Burkina Faso.

Therefore, the aim of this study was to assess the potential impact of GM maize tolerant to drought and resistant to stem borers prior to their introduction into Uganda. Specifically, the study sought to assess yield losses caused by drought and stem borers in nine districts in Uganda and predict the economic impact of GM maize tolerant to these stresses. Secondly, the study investigated some necessary institutional and policy interventions for sustainable introduction of GM maize into Uganda.

2. Results

2.1. General Characteristics of Participating Farmers and Their Practices

The study was carried out in the nine farming systems of Uganda, described by Ugandan farming systems classification [15], and one district was selected from each of the nine farming systems (Figure 1). Basic characteristics of the farmers and their households participating in the survey are given in Table 1, where average values for each district are shown. The data shows that in about 90% of all households the head is male, the average age of the household head is between 40 and 48 years, that most of them went between four to eight years to school, and the average household had between six to nine members. On average, household heads had considerable experience with maize farming (between 14 to 22 years) with exception of the farmers in Kotido, where maize seemed to be a newer crop (only five years of average experience). Total average land holdings per household were usually around 1.7 to 2.9 ha with the exception of larger farms in Kotido (4.2 ha) and Masindi (4.1 ha) district. Of these totals, the maize area covered on average between 0.6 to 2.0 ha, with the biggest areas in Masindi (2.0 ha) and Kapchorwa (1.7 ha) district. Access to agricultural extension services was quite varied, ranging from 20% of the farmers in Serere and Pallisa to 60% of the farmers in Lira and Kapchorwa. Asked about their possible acceptance of GM maize, on average 86% of all farmers would grow GM maize, with the lowest percentage in Serere where only 72% of the farmers there were ready to test GM maize.

Figure 1. Map of Uganda, showing the nine districts surveyed (intermediate shading): Lira, Kotido, Serere, Arua, Masindi, Kapchorwa, Kasese, Iganga, and Pallisa.

Some basic information of agricultural practices for maize cultivation are provided in Table 2, again given as averages for each district. Farmers had several different seed sources providing uncertified seed (e.g., home saved seed, neighbouring farmers) or certified seed (e.g., farm input shops, Non-governmental organizations, extension services/National Agricultural Advisory Service (NAADS)). In most districts, more than 80% of the farmers used uncertified seed, whereas 80% and 100% of the farmers from Masindi and Kapchorwa, respectively, used improved/certified seed. The same trend was reported for external input use because only farmers from Masindi and Kapchorwa used regularly inorganic fertilizer and chemical pesticides. In all other seven districts, inorganic fertilizer was used by less than 11% of the farmers and pesticides by less than 13%. The farmers were also asked to name and rank the most important constraints for maize production on their farms. The most common constraints were stem borer (80%) and drought (79%), followed by poor soils (51%) and poor seed quality/availability (50%). Constraints of intermediate importance were striga (18.0%), termites (14.9%), flooding (13.8%), low maize prices on the market (13.1%), grain mould (10.9%), and the maize streak virus diseases (10.4%). Minor constraints mentioned were the maize lethal necrosis disease (5.6%) and northern leaf blight (2.2%). Across all districts, almost half of all farmers (209) had access to credit previously, slightly more than half reported they did not have access to credit.

Table 1. Basic characteristics of the farmers participating in the survey conducted in 2015. Shown are averages for 50 farmers in each district.

Characteristic	District									
	Mean	**Lira**	**Kotido**	**Serere**	**Arua**	**Masindi**	**Kapchorwa**	**Kasese**	**Iganga**	**Pallisa**
Gender of household head (1 = male, 0 = female)	0.90	0.90	0.94	0.94	0.88	0.90	0.94	0.88	0.82	0.86
Age of household head	43.6	44.7	39.7	42.6	42.3	42.9	44.0	47.9	44.3	43.6
Education level of household head (years)	6.4	7.1	4.0	7.2	5.4	6.4	8.3	5.4	5.2	8.3
Household members	7.4	6.6	6.9	7.9	5.9	6.6	7.4	7.7	8.8	8.5
Experience with maize (years)	15.5	14.9	5.1	14.1	15.3	15.7	19.1	17.3	21.7	16.0
Total land holdings (ha)	2.7	2.6	4.2	2.5	2.2	4.1	2.9	2.1	1.9	1.7
Total maize area (ha)	1.2	1.1	1.0	0.9	0.6	2.0	1.7	1.3	1.3	0.7
Access to AES * (1 = yes)	0.4	0.6	0.4	0.2	0.5	0.5	0.6	0.6	0.3	0.2

* AES: Agricultural Extension Services.

Table 2. Details on average input use of farmers and the importance of grain yield losses from drought and stem borer in the nine survey districts of Uganda.

District *	Improved Seed (%)	Inorganic Fertilizer (%)	Pesticides (%)	Drought Yield Loss (%) **	Stem Borer Yield Loss (%) **
Lira	44	10	8	55.7	35.9
Kotido	10	2	0	66.7	36.5
Serere	14	2	12	62.5	17.1
Arua	06	2	0	54.1	30.6
Masindi	80	50	36	48.0	12.7
Kapchorwa	100	84	46	52.6	18.5
Kasese	24	6	2	59.8	14.8
Iganga	16	8	2	57.1	25.6
Pallisa	52	2	8	55.7	26.6

* Results for 50 respondents per district; ** if drought or stem borer damage occurred.

2.2. Estimated Maize Yield Losses due to Drought and Stem Borer Damage

Average maize grain yields reported by farmers for three different stress scenarios in all districts and the average yields across all districts and all farmers interviewed are shown in Figure 2. The average maize yield without drought or stem borer damage reported by the farmers and across all districts was 3.12 t·ha^{-1}. In all nine districts, farmers reported a reduction in maize grain yield in years when they experienced drought or high maize stem borer infestation. Average yield losses as a result of drought and maize stem borer damage were 54.7% and 23.5%, respectively. This corresponded to an average grain yield of 1.41 t·ha^{-1} with drought and 2.39 t·ha^{-1} with stem borer damage if the respective stress would occur at all sites simultaneously. Yield with and without drought stress was significantly different at a 95% confidence interval in all nine districts. If drought occurred, the highest relative yield loss due to drought was recorded in Kotido (66.7%) (Table 2), whereas the lowest loss was reported in Masindi (48.0%), closely followed by Kapchorwa (52.6%). This is not surprising because Kotido is a known drought-prone district, whereas drought is a less common and severe constraint in Kapchorwa and Masindi. Kapchorwa and Masindi were also the districts where most farmers used agricultural inputs in maize production (Table 2). On average, and based on farmers' evaluation of the frequency of drought occurrence in the last ten years, the risk of drought was estimated at two years out of three, or an average risk of 67% across all years. Assuming two years with stress and one year without drought stress would result in an average grain yield of 1.98 t·ha^{-1}.

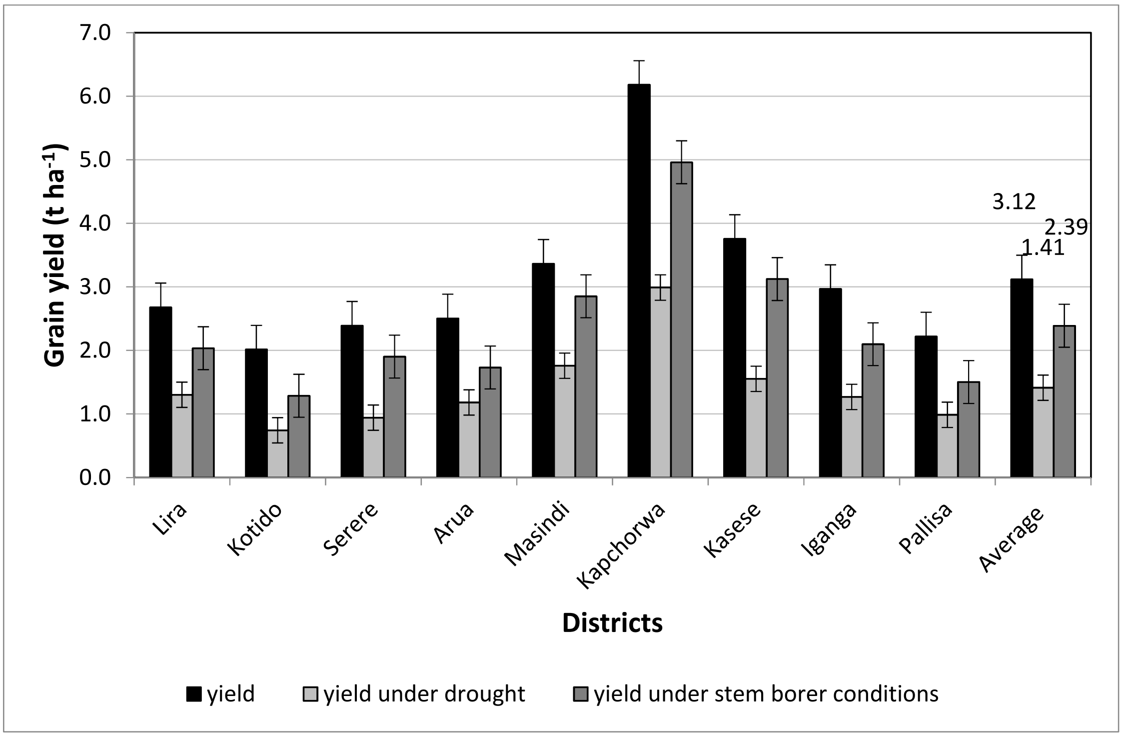

Figure 2. Average maize grain yields without and with drought or stem borer damage in the nine Ugandan districts surveyed, including the average across all districts. The means are based on 50 farmers in each district.

Yield without and with high infestation of maize stem borers was statistically different (95% confidence) in all districts except Serere, Arua and Pallisa. The districts with the highest reported losses were Kotido and Lira at 36.5% and 35.9%, respectively. Those with the least losses were Masindi, Kasese and Serere with 12.7%, 14.8% and 17.1%, respectively (Table 2). Also, relatively low losses to stem borer in Serere, Masindi and Kapchorwa did to some extend correlate with higher pesticide use. Again, farmers estimated the average frequency of significant stem borer damage at two years out of three, or an average risk of 67% across all years. Assuming two years with stress and one year without significant stem borer damage would result in an average grain yield of 2.63 t·ha^{-1}. One year without stress and two years with half drought, half stem borer damage would result in an average grain yield of 2.31 t·ha^{-1}, which is below the reported countrywide average yield of 2.75 t·ha^{-1}.

With farmers' categorisation into low-input and high-input farmers, the trends of yield losses due to drought and stem borer did change considerably (Figure 3). As expected, high input farmers had higher average yields than low input farmers, and this was true with and without stress. Across all farmers as well as in the low-input and high-input farmer groups, the yield loss to drought was significant at the 95% confidence interval. However, the losses due to drought were about five percent higher for low input farmers as compared with high input farmers. In contrast, yield losses due to stem borer infestation were higher for high input farmers (24.0%) than low input farmers (19.2%). A significant grain yield difference without and with stem borer infestation was detected only for the group of high-input farmers. The categorisation into the two different input groups did not consider use of pesticides as a criterion and the average grain yields of the high-input farmers are therefore not related to pesticide use.

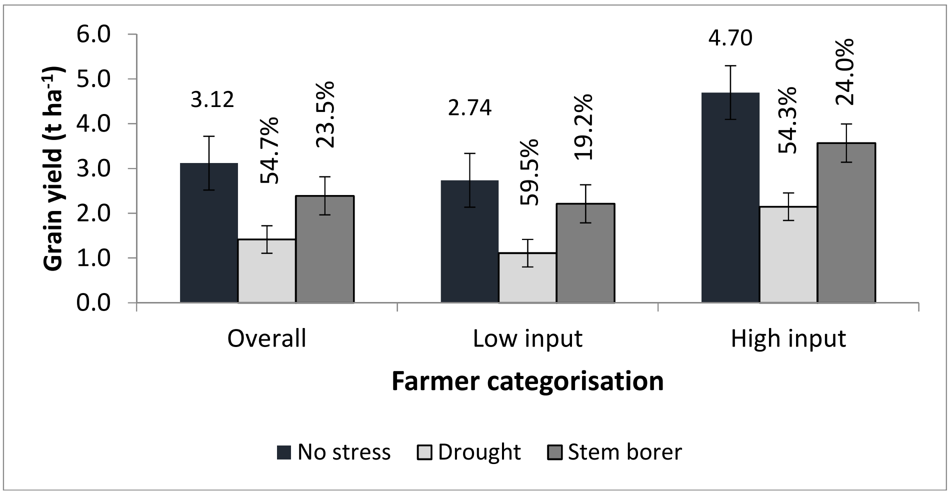

Figure 3. Yield based on farmer categorisation under different conditions for conventional maize varieties. The relative values in % indicate the relative yield loss in comparison with the non-stress yield. Based on their fertilizer use, 83 farmers were categorized as high input farmers and 367 as low input farmers.

2.3. Projected Yield Gains of GM Maize over Conventional Maize Varieties

Based on the assumptions of technical efficiency of the technologies and the survey data on farmers' yields, yield reductions due to drought and stem borer stress, and stress frequency, we estimated yields with and without use of the new GM maize technologies. The projected monetary advantage (expressed in United States dollars; USD) of drought tolerant GM hybrid maize was then calculated using partial budgets for the entire sample and the use of conventional versus drought tolerant GM maize (Table 3). For the two drought scenarios, the only change in costs taken into account was the differing price of seed (19.4 USD·ha^{-1} for home grown seed and 48.2 USD·ha^{-1} for drought tolerant GM hybrid seed). The difference in yields was based on the reduced yield losses when using the GM maize variety in stress years (two out of three years) and a 10% yield increase if no hybrid variety was used before. Table 3 shows that the estimated average yield advantage was 0.48 t·ha^{-1} for the drought tolerant GM hybrid variety, resulting in an average margin of +26 USD·ha^{-1}, and consequently a value/cost ratio of 1.5. Note that this takes into account the one out of three years in which the additional expenses for the drought tolerant GM hybrid variety have to be paid but no stress occurs. Also be aware that the margins do not reflect the total profitability of cultivating maize; only the financial benefit of using drought tolerant GM hybrid maize in comparison with the use of conventional varieties. The assumption in all cases was that the prices of maize grain from conventional and GM maize varieties would be the same.

In the same way as above, the predicted monetary gains from using GM Bt hybrid maize in comparison with conventional maize varieties were calculated (Table 4). The average grain yield advantage for the GM Bt hybrid maize scenario across all farmers was 0.58 t·ha^{-1}, taking into account an average probability of 67% of stem borer attacks in any given year (estimate from farmers' perspective for the past 10 years). Farmers in this scenario also had reduced expenses for pesticides and their application but only the small group of higher input farmer profited from this. However, the larger yield advantage together with slightly reduced costs increased the average margin to 54.2 USD·ha^{-1}, and the value/cost ratio to 2.1.

Table 3. Partial budget analysis for the use of drought tolerant genetically modified maize for all farmers.

Partial Budget Element	Units **	Conventional Seed *	Drought Tolerant Hybrid Seed *
Maize grain yield	t·ha^{-1}	1.98 ***	2.46 ***
Price of maize grain	USD·kg^{-1}	0.11	0.11
Total income	USD·ha^{-1}	224.9	279.7
Probability of drought	%	67	67
Technology fees	%	0	35
Cost of seed (25 kg·ha^{-1})	USD·ha^{-1}	19.4	48.2
Technology efficacy	%	0	25
Total costs that vary	USD·ha^{-1}	19.4	48.2
Net benefits	USD·ha^{-1}	205.5	231.5
Margin	USD·ha^{-1}	26.0	
Value/cost ratio		1.54	

* Small inconsistencies in the data are due to rounding; ** USD = US Dollars, equal to 3500 Ugandan Shilling; *** Note: Maize grain yields for each farmer and both scenarios were calculated considering a 67% chance of drought and a 33% chance of no drought occurring. Similarly, reduced grain yield losses due to drought tolerant GM hybrid maize were also assumed to occur with only a 67% chance, whereas additional costs occurred in 100% of cases.

Table 4. Partial budget analysis for the use of genetically modified Bt maize for all farmers.

Costs/Income	Units **	Conventional Seed *	Bt Hybrid Maize Seed *
Yield	t·ha^{-1}	2.63 ***	3.31 ***
Price of maize grain	USD·kg^{-1}	0.11	0.11
Total income	USD·ha^{-1}	297.4	375.4
Probability of stem borer damage	%	67	67
Technology fees	%	0	35
Cost of seed (25 kg·ha^{-1})	USD·ha^{-1}	19.4	48.2
Cost of pesticides	USD·ha^{-1}	3.4	0
Labour to apply pesticides	USD·ha^{-1}	1.2	0
Technological efficacy	%	0	85
Total costs that vary	USD·ha^{-1}	24.0	48.2
Net benefits	USD·ha^{-1}	273.4	327.2
Margin	USD·ha^{-1}	54.2	
Value/cost ratio		2.13	

* Small inconsistencies in the data are due to rounding; ** USD = US Dollars, equal to 3500 Ugandan Shilling; *** Note: Maize grain yields for each farmer and both scenarios were calculated considering a 67% chance of stem borer damage and a 33% chance of no stem borer damage occurring. Similarly, reduced grain yield losses due to Bt GM hybrid maize were also assumed to occur with only a 67% chance, whereas additional costs occurred in 100% of cases.

However, these average values give only a limited picture of the performance of the technologies evaluated, given the considerable variability of yields and yield losses due to drought stress and stem borer damage. To get a better idea of the variability of technology performance, the yield and profitability calculations were conducted for each individual farmer, and the resulting margins were evaluated in relation to their grain yield without stress.

The respective scatter plot of predicted margins for the GM drought tolerant hybrid maize technology versus grain yields without stress shows a positive linear relation between both factors (Figure 4). Negative margins from the technology resulted for 110 out of 450 farmers (24%) whereas 86 farmers (19%) had good returns and value/cost ratios above 2. Most negative margins were achieved by farmers with unstressed yields below 2 t·ha^{-1}, but even if excluding those the percentage of farmers with good returns (value/cost ≥2) increased only slightly to 26%.

Considerably better results were achieved by the stem borer resistant GM hybrid variety. The scatter plot of margins versus grain yield without stress (Figure 5) shows again a mostly linear and positive relation between both factors. Approximately 13% (58) of the farmers surveyed were predicted to obtain negative margins if they decided to plant Bt maize, whereas 171 of all farmers (38%) had good returns to their investment (value/cost ≥2). Again, the most negative margins were attained by farmers with unstressed yields below 2 t·ha^{-1}, and excluding these increased the percentage of farmers with good returns (value/cost ≥2) to 52%.

Number of all 450 farmers with negative returns	110 = 24%
Number of all 450 farmers with VC ratios ≥2	86 = 19%
Number of all 450 farmers with unstressed yield >2 and negative returns	15 = 3%
Number of all 450 farmers with unstressed yield >2	328 = 73%
Number of all 450 farmers with unstressed yield above 2 t/ha and VC ratios above 2	86 = 26%

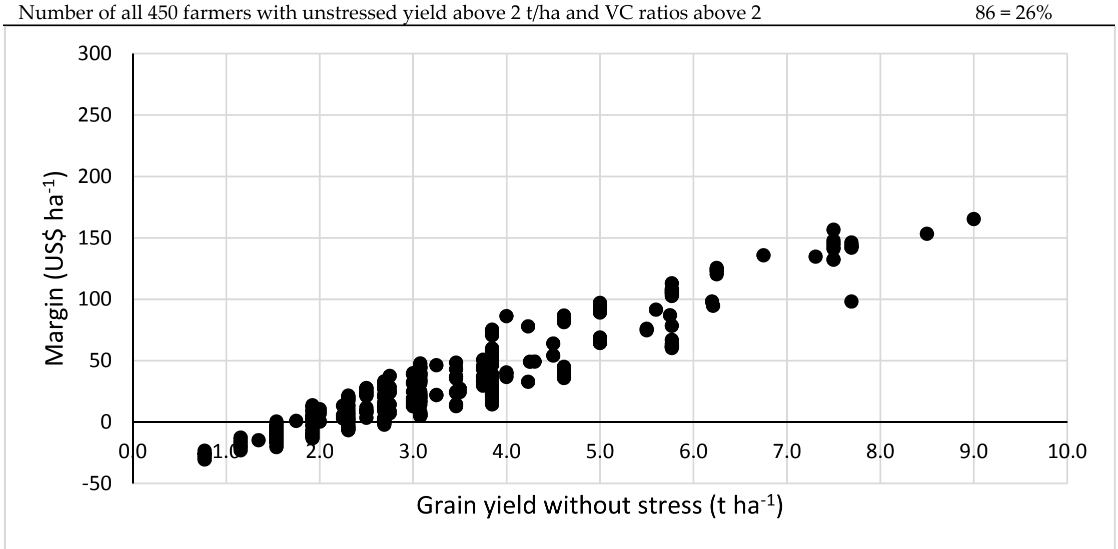

Figure 4. Relation between maize grain yield without stress and the estimated margin of all participating farmers using the drought tolerant genetically modified hybrid maize. Economic performance indicators including the value/cost (VC) ratio are given above the figure.

Number of all 450 farmers with negative returns	58 = 13%
Number of all 450 farmers with VC ratios ≥2	171 = 38%
Number of all 450 farmers with unstressed yield >2 and negative returns	9 = 2%
Number of all 450 farmers with unstressed yield >2	328 = 73%
Number of all 450 farmers with unstressed yield above 2 t/ha and VC ratios above 2	170 = 52%

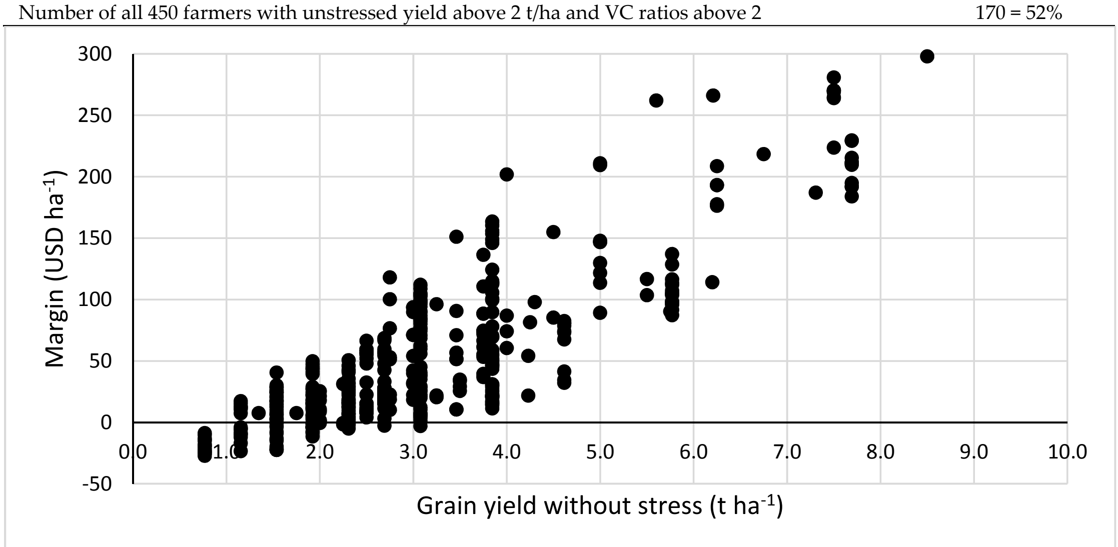

Figure 5. Relation between maize grain yield without stress and the estimated margin of all participating farmers using the insect resistant genetically modified Bt hybrid maize. Economic performance indicators including the value/cost (VC) ratio are given above the figure.

2.4. Regulatory Issues and Seed Sector

To be used by Ugandan farmers, any GM hybrid maize would need to be deregulated. After deregulation, GM hybrid maize would be treated like any other maize variety. The deregulation process of biotechnology products involves a range of stakeholders and, specifically for maize, those that are engaged in the maize seed value chain (i.e., policy makers, research institutions like the National Agricultural Research Organisation (NARO), the National Seed Certification Service (NSCS) of the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF), the Uganda National Council for Science and Technology (UNCST), and seed companies). However, the linkage between these institutions possibly needs further clarification since no specific law stipulates their specific roles. In contrast, various pieces of legislation regulate the seed sector in Uganda. If any new variety is introduced into the Ugandan environment, "The Seed and Plant Act, 2006" [16] regulates variety release procedures, and no difference is made between GM and non-GM varieties. However, import and export of plant materials and their products are regulated by provisions in The Plant Protection and Health Act 2016 [17] which includes specific procedures for GM crops. Intellectual property (IP) on seed is not provided for in existing laws but "The Plant Variety Protection Act 2014" [18] provides for the plant breeders rights (PBR). The National Biotechnology and Biosafety policy [19] is also in place to regulate all matters related to biotechnology and biosafety in Uganda. Finally, the National Biotechnology and Biosafety Bill is under consideration in the Ugandan Parliament which, if enacted into law, will play a central role in Biotechnology regulation.

Ugandan seed companies are relatively small and lack capacity to conduct biotechnology research and development themselves. They also have limited production facilities which could have implications on the simultaneous production of conventional and GM maize varieties. Further, seed companies often depend on farmers, who are not formally trained, for seed multiplication which could jeopardize seed quality if care is not taken. Outcrossing and gene flow into non-GM varieties grown next to GM varieties is possible, and would affect these varieties because the Bt gene is a dominant gene. Separation of GM and non-GM seed production would therefore be necessary. On the other hand, several Ugandan seed companies produce hybrid seed already and have a reasonable track record of quality seed production. Seed distribution is through regional agents who are the direct link to farmers, with limited feedback processes to the seed companies.

3. Discussion

3.1. Survey Results

Participating farmers were mostly in the medium farm size category (mean of 2.39 ha, min 1.5 ha, max 8.6 ha), representing about one quarter or 1.02 million of all holdings in Uganda) according to the "Smallholders data portrait" of the FAO [20]. Their overall positive attitude towards testing of GM maize if it was available was similarly reported by De Groote et al. [21] in neighbouring Kenya. Across all districts, farmers did identify drought as the second most important constraint to production (79%). Average maize yield losses to drought in the Sub-Saharan region have previously been studied and an average of 33% yield loss was reported [5] which is only about half (56%) of what we found in this survey. However, our estimate of 56% was assuming simultaneous drought for all farmers, whereas the farmers estimated the occurrence of drought in only two out of three years. Taking this frequency into consideration increased the average yield in the drought scenario to 1.89 $t{\cdot}ha^{-1}$ (see Table 3), and reduced the average yield loss due to drought to 36.5%, which is close to the report by [5]. An overestimate of drought damage in our study could also be attributed to the targeted sampling technique because we deliberately selected several drought-prone districts for the study due to our objective to evaluate a technology that would address drought. Finally, the regional estimate by [5] may not necessarily be applicable to the specific Ugandan districts we surveyed.

No recent data is available for country or district specific maize losses caused by drought in Uganda. However, as results from this study show, differences in maize yield losses attributed to drought between districts suggest differences in the level of drought severity in the studied districts. Districts traditionally prone to drought (i.e., Kotido) had higher yield losses as compared to those that were less prone (Kapchorwa, Masindi). This is in agreement with a previous study by

Hisali et al. [22] who reported variation in yields due to variation in the length of dry spells. Additionally, the differences in drought damage seemed to be related to farmers' fertilizer use (Figure 3) offering two possible explanations. The more obvious one is that farmers having a higher drought risk and damage don't use much fertilizer [23] but it is also possible that fertilizer use reduces the drought damage [24]. The study could not answer to what extent variations in soil fertility, other agronomic practices or knowledge levels of farmers interviewed across the districts surveyed may have been contributing to the variations in drought yield losses.

Four out of five farmers did identify stem borers as an important constraint to maize production across all districts surveyed. Average maize yield losses to stem borer damage were estimated at 22.6%, based on participating farmers' assessment in the nine survey districts. As for drought, this is almost twice the average loss that has been reported (13.5%) for the East African region [7] and the estimated yield loss of 12.9% for neighbouring Kenya [21]. Considering again the frequency of the stress (two out of three years according to the farmer survey) brings down the average yield loss across years to 15.6%, which is close to the results reported by [7]. Individual district yield losses to stem borer damage reported ranged between 12.7% and 36.5%. Differences in stem borer species for the sampled areas could have contributed to this large variation in stem borer damage between the studied districts. Different stem borer species have previously been reported to cause different yield losses in maize [25]. Another study by De Groote [26] found variation in maize yield losses due to stem borer damage with change in elevation above sea level, which could also have affected the results of this study.

The relationship between the percentage of farmers using pesticides for control of stem borer in the different districts (Table 2) and the severity of stem borer damage remained unclear. Three of the districts using pesticides more frequently had relatively low stem borer damage (Serere, Masindi, Kapchorwa) but little damage in Kasese did not correspond to the low pesticide use there, and some pesticide use in Lira did not seem to have much effect. Limited stem borer losses by farmers using fertilizers even under stem borer attack could suggest a suppression effect of fertilizers on stem borer damage. Such effects were reported by [27] who showed reduced yield losses due to stem borers in maize with increased use of nitrogen fertilizer. However, our data also indicates that high-input users do not only use high amounts of fertilizers, but also other inputs such as pesticides and improved seed. Differences in farmers' other agronomic practices (i.e., timely farm operations) are other possible explanations for the variation in yield losses due to stem borer damage amongst the studied districts.

3.2. Partial Budget Analysis

A basic assumption for the partial budget analysis was that transgenic drought tolerance and stem borer resistance would be combined with hybrid maize technology. We assumed that only this combination would provide enough revenues for a strong seed market and interest of the private sector to invest into these technologies [28]. The downside of this assumption was that the seed became expensive in comparison with home saved seed, and that the investment for buying seed needed to be made even if no stress occurred. Nevertheless, there are examples of hybrid seed spreading even in regions dominated by smallholder farmers (e.g., [29,30]) and additive effects of hybrid vigour and stress tolerance have also been reported [31].

The resulting partial budget analyses for drought tolerant or stem borer resistant GM hybrid maize indicated positive margins across all farmers and all districts. The margin was smaller for drought tolerant hybrid maize as compared with stem borer resistant hybrid maize, and only the latter technology had an average value/cost (VC) ratio above 2, which is considered necessary for technology adoption [32]. This better performance of stem borer resistant GM hybrid maize as compared with drought tolerant hybrid maize was surprising, because drought caused considerably larger yield losses according to the survey. However, the smaller yield loss due to stem borer was compensated by the much higher technological efficacy (85% for stem borer, 25% for drought) and the savings from avoided pesticide use. In the case of drought tolerance, our assumption of 25% technology efficacy is supposed to be on the lower side of possible gains with GM drought tolerance [6]. Similarly, we believe that the estimates of potential gains from the use of stem borer resistant GM maize are conservative. Other studies used between 72% [33] and up to 100% technology efficacy [34] as compared to the 85% used in this study. In addition to the benefits associated to higher margins, GM maize tolerant to stem borers is thought to have lower mycotoxin levels in the grain which are poisonous and carcinogenic [10] as compared with conventional maize varieties. Furthermore, the reduced pesticide usage as a result of growing GM maize besides lowering costs would reduce the hazardous effects to humans and the environment associated with the use of pesticides.

However, the partial budget analyses across all farmers only provided a general evaluation of the technologies tested, and the partial budget analyses analysis for all individual farmers was necessary to evaluate the distribution of technology margins and the risk of negative returns. The predicted margins for both technologies varied between and within districts. Apart from unstressed grain yields, reasons for varying performance were differences in stress levels (drought or stem borer damage) and differences in technology related costs (procurement and application of pesticides). The variation in yield losses to stem borers could also be due to different stem borer species existing in the surveyed districts and causing different levels of crop damage. Stem borer species distribution in Uganda were reported by [35], who found considerable variation across different regions. It was also observed that drought could make crops more susceptible to stem borer infestation. The analysis showed a positive and linear relation between grain yield without stress and the margins achieved (Figures 4 and 5). Thus, negative returns resulted mostly for farmers with yields below 2 t·ha^{-1}, whereas especially farmers with high yields achieved high positive returns. This observation was true for both technologies evaluated but the positive margins were larger and more reliable for stem borer resistant hybrid maize. Recommending the technologies for farmers with unstressed yields above 2 t·ha^{-1} would reduce the risk of negative returns to three percent in the case of drought tolerance and to 2% in the case of stem borer resistance (and still address 73% of all farmers participating in the survey).

This indicates that GM hybrid technologies are more likely to be adopted by farmers with high yields, who often already used hybrid seed and more external inputs. The fact that they used hybrid seed already "reduced" the additional cost of the GM technology. In the case of stem borer resistant hybrids, the higher pesticide use resulted in actual savings when changing to GM maize resistant to stem borers. Further advantages could result from the loss-reducing effect fertilizer can have on stem borer infestations in maize fields as evidenced by earlier studies that reported reduced damage of stem borers with increase in nitrogen fertilizer application [27,36]. Faster adoption of GM technology by advanced farmers was also described by Gouse et al. [29] who reported earlier adoption of Bt maize for farmers who had previously used hybrid seed in South Africa. The same study found a higher maize yield gain for large scale Bt maize growers than small scale farmers in South Africa. However, better profitability and wider adoption of stress tolerant GM maize could possibly be achieved by combining two or more traits in a single GM maize variety through gene stacking. Combining drought and stem borer resistance could possibly also break or weaken the link between drought damage and increased stem borer infestations. The study of Gouse [37] showed that especially stem borer resistant and herbicide tolerant varieties were quickly adopted by smallholder farmers.

3.3. Policy and Seed Sector Issues

Applied biotechnology is a relatively recent development in Uganda, which only commenced informally in 2002 through initial discussions, leading to a National Biotechnology and Biosafety policy in 2008 [19] and eventually commencement of research at confined field trial (CFT) level [38]. This partly explains existing gaps in policy, laws, and institutional capacities. Negative public perception of biotechnology may have contributed to the governments' reluctance to fast track the establishment of a functional regulatory framework that would enable deregulation of biotechnology products. Benchmarking from best practices in countries where commercial release of GM maize has been successful (e.g., South Africa; [37]) is paramount in bringing the government on board for the necessary support. Experiences from such countries could perhaps also help to swing the public perception. With respect to the contribution of seed companies in Uganda, their biggest limitation is their limited size of operations. As a consequence, it is unlikely that any of them could develop a GM (hybrid) maize product and get it deregulated on their own. If, however, a ready-made and deregulated GM hybrid maize product were available to them (e.g., licensed or provided by international research organizations) seed production and distribution could be interesting for them. In a similar situation, several seed producers in Kenya expressed a strong interest to produce and distribute Bt maize seed. Since there is already a substantial percentage of farmers buying hybrid seed in some districts (Table 2) quick adoption could be achieved.

For co-existence of GM and non-GM maize, mechanisms to minimize gene flow and seed mixing should be introduced by the regulator. De Groote et al. [21] reported a very low contamination for maize fields further than 50 m distance apart. However, the risk of gene flow from GM maize varieties does exist and cannot be completely prevented. In order to avoid excessive seed prices, technology fees charged by developers could be negotiated in advance or only genes in the public domain should be used so that the costs would not become prohibitive for technology adoption. Groote et al. [21] found that in neighboring Kenya no (Bt) patents could be filed anymore, and a Freedom to Operate review is needed for Uganda. The last remaining major issue around Bt maize is the development of insect resistance against Bt maize varieties. The current strategy to avoid this is the concept of refugia where enough non-Bt crops are around to ensure that moths emerging from Bt maize intermate in most cases with moths from non-Bt crops. Given that most farms in Uganda practice mixed cropping (see Table 1), often even intercropping, sufficient refugia around Bt maize will in most regions be naturally available. Otherwise a proper refuge management plan [29] could be recommended.

4. Materials and Methods

4.1. Study Area and Sampling Techniques

The study was carried out in the nine farming systems of Uganda, described by Ugandan farming systems classification [15], and one district was selected from each of the nine farming systems. These districts were: Kapchorwa, Kasese, Iganga, Masindi, Lira, Kotido, Serere, Pallisa, and Arua (Figure 1). In the farmer survey, a three stage stratified sampling scheme was used in which the nine farming systems were used as strata. In each stratum, one major maize growing district was selected. Other considerations used in the selection of the district within the farming system were the prevalence of stem borers and proneness to drought which were the main constraints to be addressed. In the selected district within the farming system, the major maize growing sub-county was selected, two to three villages within the sub-county were picked randomly, and in each of these villages maize growing farmers were sampled. The sampling procedure was undertaken with guidance from staff members of the cereals program of the National Agricultural Research Organisation, Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) and the district agricultural extension departments. The NARO staff helped in identifying drought-prone districts in the different farming systems, as well as areas with high incidence of maize stem borers. The district Agricultural Extension staff helped identify sub-counties (administrative units) in which the survey would be conducted, and particular villages within the sub-counties in which maize production was widespread. The MAAIF staff helped in providing information on yield statistics and acreage under maize cultivation per district, and linked the research team to the district agricultural extension staff and seed companies.

4.2. Data Collection

In order to assess the maize crop yield losses attributed to drought and stem borer constraints, 50 farmers were interviewed from each of the nine districts listed above (i.e., a total of 450 participating farmers), picked randomly from two to three villages in one sub-county of the selected district. The survey was conducted between April and August 2015. Questionnaires were administered to farmers through enumerators who had been trained prior to the exercise. The questionnaires captured information on maize production trends in the past ten years and current farmers' practices. In addition to these, reported information on yield losses attributed to drought and stem borers over the last ten years was captured. Farmers provided information on yield obtained under different scenarios: yield under drought conditions, yield under high prevalence of stem borer and yield in the absence of either constraint. In order to better understand variations in farmers' losses from the two constraints and how this would impact on introduction of GM maize, farmers were categorised into "low-input" and "high-input" categories, where fertilizer use was the distinguishing criterion. From the total of 450 farmers, 83 qualified as high-input farmers (using $\geq$100 kg·fertilizer·ha^{-1}) and 367 as low-input farmers (using less than 100 kg fertilizer per ha). Where farmers used intercropping systems (which was the majority), maize grain yield data was converted considering 65% of the intercrop to be maize. All yield data, which were expressed in bags per acre, were converted to tons per hectare.

To assess existing gaps in the Ugandan seed sector in terms of policies, laws and institutional capacities to handle GM maize, informal interviews were conducted with representatives of the seed certification unit, of MAAIF, NARO and three selected seed companies engaged in maize seed multiplication and distribution. Discussed were current seed policies, conventional maize seed certification guidelines, human resource capacity and its knowledge on GM technology, international regulatory requirement and staff numbers involved in certification. For the seed companies, the focus was on their infrastructural capacity, specifically the production lines to separate varieties, contracted farmers engaged in maize seed production, and their distribution network and linkages to farmers. Additionally, we used survey and qualitative secondary data, and literature on various aspects of seed policies in Uganda and in countries where GM maize has been introduced before was reviewed.

4.3. Partial Budgeting in Ex Ante Assessment

Partial budget analysis [32] was used for the economic ex ante assessment of GM maize tolerant to drought and resistant to stem borer before its introduction in the Ugandan environment. The partial budget analysis was selected owing to its simplicity [39], allowing a quick insight into the profitability of any technology without having to conduct a detailed analysis of all production costs and benefits [40]. The two different scenarios evaluated were:

- Use of GM maize tolerant to drought versus conventional maize varieties under drought for all farmers;
- Use of GM maize resistant to stem borers versus conventional maize under high infestation of stem borers for all farmers;

In order to predict the economic benefit of GM maize tolerant to drought or resistant to stem borers, the survey data were used for the calculation of an average budget across all farmers, and for individual partial budgets of each participating farmer. The partial budgets were calculated according to the comprehensive guide by CIMMYT [32]. The quantities of chemical fertilizers and pesticides used were those reported by farmers and converted into values per hectare. Seed prices for GM seed (48.2 USD·ha^{-1}) were estimated by adding a technology fee of 35% on the average price of hybrid seed used by the farmers (35.7 USD·ha^{-1}), based on the cost of GM seed in South Africa and an average seed rate of 25 kg·ha^{-1}. A 10% yield increase was assumed for the GM hybrid scenario and all farmers using farmer produced seed; no such increase was assumed for all farmers using hybrids in their current practice. The estimated percentage of reduction in yield losses (technology efficiency) for the two traits was 25% [6] and 85% for drought and stem borer resistance, respectively, which were used to calculate the reduction in yield losses. Average daily wages for hired labour as reported in the survey were used to calculate the costs of family labour used. In these calculations, male and female labour were valued equally but only at 85% of the value of hired labour [41]. For the calculation of total income, average maize grain farm gate prizes for each district were used based on the survey (varying between 0.09 and 0.15 USD·kg^{-1}, overall mean of 0.11 USD·kg^{-1}). The data were then used for computing expected total income, total costs, expected net income and marginal benefits for all scenarios under consideration. Expected net income and marginal benefits were adjusted taking the probability of experiencing drought or stem borer damage in any given year into consideration. This means that in years without stress (1 in 3 years for both stresses according to the survey results) the GM treatment had increased costs but no benefit from the increased drought tolerance or stem borer resistance.

4.4. Data Analysis

Data collected from the survey were coded and analysed using IBM SPSS version 20 software (IBM, Armonk, New York, USA). Summaries were generated for farmer characteristics, yield data, access to agricultural extension services, maize production constraints, access to credit, access to information, use of agricultural inputs, yield losses due to drought and stem borers and costs involved in maize production. Averages for the different parameters were calculated using Microsoft Excel, with tables and graphs generated for different scenarios. Scatter plots were generated to better understand the distribution of farmers in terms of predicted benefit of the technology. Genstat version 16 (VSN International Ltd, Hemel Hempstead, UK) was used to generate Analysis of Variance (ANOVA) tables to estimate the variation in yield losses attributed to drought and stem borers amongst the different categories of farmers.

5. Conclusions

Results from this study suggest that genetically modified maize varieties could benefit smallholder farmers in Uganda by reducing yield losses attributed to the major production constraints of drought and stem borer damage, and thus increase their profits from farming. Farmers in different districts representative of the major agro-ecological zones would benefit differently from GM maize seed depending on their normal yield without stress and the severity and frequency of the stress. Findings from this study could help in guiding which of the zones would benefit most from the technology if introduced. The study indicates that farmers with yields above 2 $t{\cdot}ha^{-1}$ have almost no risk of negative returns from the investment in GM hybrid maize, and the returns were generally higher for Bt hybrid maize as compared with drought tolerant hybrid maize. The study also suggests that advanced farmers using at least medium agricultural input rates would profit more from drought tolerant or Bt hybrid maize varieties, making them possible early technology adopters. Poorer or less advanced farmers would probably adopt the technology only later when costs can be reduced or the actual benefit of the technology were higher than estimated in our study. Another option to reach that goal would be to combine both traits analysed here separately in one maize variety for the same price. However, any such development needs to be accompanied by enhancing the capacities of key institutions engaged in biotechnology development, dissemination and use. Similarly, existing gaps in regulatory policies, laws and seed related policies need to be addressed to enable the GM maize introduction process.

Acknowledgments: This work was funded by the International Centre for Genetic Engineering and Biotechnology (ICGEB) under the auspices of a capacity building project for African regulators with a grant from the Bill and Melinda Gates Foundation. Special thanks go to the National Agricultural Research Institute, Uganda, for allowing us use their facilities. The views expressed in this article are not necessarily those of ICGEB or the Bill and Melinda Gates foundation but of the authors.

Author Contributions: Isaac M. Wamatsembe, Godfrey Asea and Stephan M. Haefele conceived and designed the experiments; Isaac M. Wamatsembe performed the experiments with local assistance as described in the text; Isaac M. Wamatsembe and Stephan M. Haefele analyzed the data and wrote the manuscript.

Conflicts of Interest: The authors declare no conflict of interest. The founding sponsors had no role in the design of the study, the collection, analyses, or interpretation of data, in the writing of the manuscript, or in the decision to publish the results.

References

1. FAOSTAT. Global Area under Cultivation and Output Of Maize. 2013. Available online: http://faostat3.fao.org/download/Q/QC/E (accessed on 10 October 2016).
2. Haggblade, S.; Dewina, R. Staple food prices in Uganda. Available online: http://purl.umn.edu/58553 (accessed on 10 October 2016).
3. Okoboi, G.; Muwanga, J.; Mwebaze, T. Use of Improved Inputs and Its Effect on Maize Yield and Profit in Uganda. Available online: http://www.ajol.info/index.php/ajfand/article/view/84204 (accessed on 10 October 2016).
4. Uganda Bureau of Statistics. 2012 Statistical Abstract. Available online: http://www.ubos.org/onlinefiles/uploads/ubos/pdf%20documents/2012StatisticalAbstract.pdf (accessed on 10 October 2016).
5. Heisey, P.W.; Edmeades, G.O. World Maize Facts and Trends 1997/98. Available online: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.944.6485&rep=rep1&type=pdf (accessed on 10 October 2016).
6. Edmeades, G.O. *Drought tolerance in maize: An emerging reality*; International Service for the Acquisition of Agri-Biotech Applications (ISAAA): Ithaca, NY, USA, 2008.
7. De Groote, H.; Overholt, B.; Ouma, L.; Mugo, S. Assessing the potential impact of Bt maize in Kenya using a GIS based model. In Proceedings of the 25th International Conference of the International Association of Agricultural Economists, Durban, South Africa, 16–22 August 2003.
8. Edmeades, G. *Progress in achieving and delivering drought tolerance in Maize - an update*; International Service for the Acquisition of Agri-Biotech Applications (ISAAA): Ithaca, NY, USA, 2013.
9. James, C. *Global Review of Commercialized Transgenic Crops*; International Service for the Acquisition of Agri-Biotech Applications (ISAAA): Ithaca, NY, USA, 2003.
10. Wu, F.; Miller, J.D.; Casman, E.A.; Abbas, H.K. Bt corn and mycotoxin reduction: an economic perspective. In *Aflatoxin and food safety*; CRC Press: New York, NY, USA, 2005.
11. Smale, M.; Zambrano, P.; Gruère, G.; Falck-Zepeda, J.; Matuschke, I.; Horna, J.D.; Nagarajan, L. *Measuring the economic impacts of transgenic crops in developing agriculture during the first decade: approaches, findings, and future directions*; International Food Policy Research Institute: Washington, DC, USA, 2009.
12. Edmeades, S.; Smale, M. A Trait-based model of the potential demand for a genetically engineered food crop in a developing economy. *Agric. Econ.* **2006**, *35*, 351–361. [CrossRef]
13. Horna, J.D.; Smale, M.; Al-Hassan, R.; Falck-Zepeda, J.; Timpo, S.E. Insecticide Use on Vegetables in Ghana: Would GM Seed Benefit Farmers? Available online: http://ageconsearch.umn.edu/bitstream/6506/2/462466.pdf (accessed on 10 October 2016).
14. Vitale, J.D.; Vognan, G.; Ouattarra, M.; Traore, O. The commercial application of GMO crops in Africa: Burkina Faso's decade of experience with Bt cotton. Available online: http://soybeaninnovationlab.illinois.edu/sites/soybeaninnovationlab.illinois.edu/files/cotton%20prfotiabilityv13n4a05-vitale.pdf (accessed on 10 October 2016).
15. Mwebaze, S.M. Country pasture/forage resource profiles. *Grasslands and Pasture Crops*. 2002. Available online: http://www.fao.org/ag/AGP/AGPC/doc/Counprof/Uganda.htm (accessed on 10 October 2016).
16. MAAIF. *The Seed and Plant Act, 2006*; Uganda Printing and Publishing Corporation: Entebbe, Uganda, 2006.
17. MAAIF. *The Plant Protection and Health Act, 2014*; Uganda Printing and Publishing Corporation: Entebbe, Uganda, 2015.
18. MAAIF. *Plant Variety Protection Act, 2014*; Uganda Printing and Publishing Corporation: Entebbe, Uganda, 2014.
19. MFPED. *National Biotechnology and Biosafety Policy*; Uganda Printing and Publishing Corporation: Entebbe, Uganda, 2008.
20. FAO. A data portrait of smallholder farmers: An introduction to a dataset on small-scale agriculture. 2016. Available online: http://www.fao.org/economic/esa/esa-activities/esa-smallholders/dataportrait/farm-size/en/ (accessed on 10 October 2016).
21. De Groote, H.; Mugo, S.; Bergvinson, D.; Odhiambo, B. Debunking the myths of GM crops for Africa: The case of Bt maize in Kenya. In Proceedings of the American Agricultural Economics Association Annual Meetings, Denver, Colorado, 1–4 August 2004.
22. Hisali, E.; Birungi, P.; Buyinza, F. Adaptation to climate change in Uganda: evidence from micro level data. *Glob. Environ. Change* **2011**, *21*, 1245–1261. [CrossRef]

23. Pandey, S. Adoption of nutrient management technologies for rice production: economic and institutional constraints and opportunities. *Nutr. Cycl. Agroecosyst.* **1999**, *53*, 103–111. [CrossRef]
24. Haefele, S.M.; Kato, Y.; Singh, S. Climate ready rice: augmenting drought tolerance with best management practices. *Field Crops Res.* **2016**, *190*, 60–69. [CrossRef]
25. Ajala, O.; Saxena, N. Interrelationship among chilo partellus (SWINHOE) damage parameters and their contribution to grain yield reduction in maize (Zea mays L.). *Appl. Entomol. Zool.* **1994**, *29*, 469–476.
26. De Groote, H. Maize yield losses from stemborers in Kenya. *Int. J. Trop. Insect. Sc.* **2002**, *22*, 89–96. [CrossRef]
27. Mgoo, V.H.; Makundi, R.H.; Pallangyo, B.; Schulthess, F.; Jiang, N.; Omwega, C.O. Yield Loss Due to The Stemborer Chilo Partellus (Swinhoe) (Lepidoptera: Crambidae) at Different Nitrogen Application Rates to Maize. Available online: http://www.tandfonline.com/doi/abs/10.1080/00379271.2006.10697483 (accessed on 10 October 2016).
28. Fuglie, K.; Ballenger, N.; Day, K.; Klotz, C.; Ollinger, M.; Reilly, J.; Vasavada, U.; Yee, J. Agricultural research and development: Public and private investments under alternative markets and institutions. Available online: https://www.ers.usda.gov/publications/pub-details/?pubid=40696 (accessed on 10 October 2016).
29. Gouse, M.; Pray, C.E.; Kirsten, J.; Schimmelpfennig, D.A. GM subsistence crop in Africa: the case of Bt white maize in South Africa. *J. Biotechnol.* **2005**, *7*, 84–94.
30. Janaiah, A. Hybrid rice adoption in India: Farm-level impacts and challenges. Available online: https://www.scribd.com/document/50246052/Hybrid-Rice-Adoption-in-India-Farm-Level-Impacts-and-Challenges-TB-14 (accessed on 10 October 2016).
31. Tollenaar, M.; Wu, J. Yield improvement in temperate maize is attributable to greater stress tolerance. *Crop Sci.* **1999**, *39*, 1597–1604. [CrossRef]
32. Perrin, R.K.; Winkelmann, D.L.; Moscardi, E.R.; Anderson, J.R. From Agronomic Data to Farmer Recommendations: An Economics Training Manual. Available online: http://impact.cgiar.org/agronomic-data-farmer-recommendations-manual-economic-evaluation (accessed on 10 October 2016).
33. Labatte, J.-M.; Meusnier, S.; Migeon, A.; Chaufaux, J.; Couteaudier, Y.; Riba, G.; Got, B. Field evaluation of and modeling the impact of three control methods on the larval dynamics of Ostrinia nubilalis (Lepidoptera: Pyralidae). *J. Econ. Entomol.* **1996**, *89*, 852–862. [CrossRef]
34. KocoureK, F.; Stara, J. Efficacy of Bt maize against European corn borer in Central Europe. *Plant Prot. Sci.* **2012**, *48*, 25–35.
35. Ingram, W. The lepidopterous stalk borers associated with Gramineae in Uganda. *Bull. Entomol. Res.* **1958**, *49*, 367–383. [CrossRef]
36. Wale, M.; Schulthess, F.; Kairu, E.; Omwega, C. Cereal yield losses caused by lepidopterous stemborers at different nitrogen fertilizer rates in Ethiopia. *J. Appl. Entomol.* **2006**, *130*, 220–229. [CrossRef]
37. Gouse, M. GM maize as subsistence crop: The South African smallholder experience. *AgBioForum* **2012**, *15*, 163–174.
38. NARO and AATF. *Enhancing Maize Productivity in Uganda through WEMA Project*; National Agricultural Research Organisation and African Agricultural Technology Foundation: Entebbe, Uganda, 2010.
39. Doye, D.G.; Coe, N. *Wheat grazeout versus harvest for grain: Division of Agricultural Sciences and Nanarotural Resources*; Oklahoma State University: Stillwater, Oklahoma, USA, 2001.
40. Lane, D.M.; Rendleman, C.M.; Ott, S.L. Using partial budgets to analyze selected management practices associated with reduced preweaning mortality. *Swine Health Prod.* **1997**, *3*, 95–102.
41. Sharma, B.P. Measuring the price of labour in agricultural economies: the shadow wage rate. *J. Dev. Issues* **2015**, *15*, 24–35. [CrossRef]