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Genetically modified maize impacts in Honduras: production and social issues

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Abstract Maize production is one of the most important activities for the Honduran economy, both in terms of area cultivated and food security provided. This article reports the results of a survey undertaken to gauge knowledge, perceptions, opinions, and attitudes of Honduran farmers towards genetically modified (GM) maize. Data were collected from 32 maize producers in 2018–19, of both conventional and GM, in five different departments (regions) of Honduras. Results show that over 75% of interviewed farmers have significant knowledge of basic biotechnology concepts and GM maize. Overall, producers have a positive opinion about GM maize because yields are higher than conventional maize, and adopting farmers have higher incomes. A significant finding was the reduction in the number of necessary pesticide applications, 84% of interviewees who used GM maize did not apply any pesticides. Farmers indicate the two main reasons for using GM maize are higher incomes (48%) and ease of use of the crop (33%). Overall, GM maize impacts in Honduras could be greater if the federal government took on a more proactive role in knowledge dissemination and facilitation of credit access.

Keywords Adoption benefits · Chemical use · Economic impacts · Farm-level evidence · Yield increases

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Introduction

In 2002, Honduras became the first Latin American country to authorize the commercial cultivation of genetically modified (GM) maize. Production of maize is an important activity for the Honduran economy (Hintze 2003); it is also responsible for providing 26% of the calories consumed by urban dwelling Hondurans, and 48% of the calories consumed by those residing in rural areas (Cruz 2013).

However, Honduran maize productivity is hampered by biotic and abiotic stressors (Diaz-Ambrona et al. 2013; Pitre 1988). Cognizant of the constraints to maize productivity, and of the importance of this crop to domestic food security, the Honduran Secretariat of Agriculture and Livestock (SAL) turned to GM *Bacillus thuringiensis* (Bt) maize technology to bolster domestic productivity. Field trials of these hybrids prior to commercial adoption showed greater tolerance against insects, yielding up to 25% higher than conventional maize hybrids (Pacheco 2002). Currently, Honduras is one of only seven countries in Latin America that allows the commercial cultivation of GM crops (ISAAA 2018). Nonetheless, per the request of certain communities, GM maize cultivation is restricted to three of the 18 federal departments,[1] one municipality and predominantly happens in regions higher than 1,000 m above sea level (GAIN 2019).

Honduran agricultural biotechnology policy and regulation is the responsibility of the National Service of Food Safety, Plant and Animal Health (SENASA). Recently, SENASA has taken proactive steps towards reviewing and revising its long established biotechnology regulatory system, to accommodate novel agricultural biotechnologies. On 10 January 2018, the official Honduran Gazette published SENASA's Guide of Processes and Procedures of the Regulatory System for Genetically Modified Organisms (GAIN 2019). This guide lists the steps that need to be followed when field testing, pre-commercializing, and undertaking commercialization of new events (GM traits). Honduras has also refined its agricultural biotechnology regulatory system in anticipation of new breeding techniques (NBTs) and genome editing technologies (SENASA 2019; Bogdanove et al. 2018).

NBTs can produce novel plant varieties whose genetic make-up is indistinguishable from conventionally bred plants (Bogdanove et al. 2018). Experts opine that NBTs can broaden the crop breeding 'toolkit' and provide significant societal and economic benefits (Lassoued et al. 2019). An overwhelming majority of experts (85%) think that either a product-based model, or dual-product/process system, is the most appropriate way to regulate these novel technologies and their products (Lassoued et al. 2020). In the Honduran case, according to Agreement C.D.-008-2019, SENASA determines if the advice of the National Committee of Biotechnology and Biosafety is necessary in determining whether a product generated by a NBT is a living modified organism. With this new agreement in force, Honduras has taken a concrete step towards regulating NBT products, and not the processes by which they are obtained, such as is the case in the European Union. Thus, it is important to document the impacts and nuances of first generation biotechnology (i.e. GM crop technology), so that this information may guide future agricultural policies pertaining to field applications of NBTs.

Falck-Zepeda et al. (2012) were among the first to comprehensively assess GM insect resistant (Bt) and glyphosate tolerant (RoundUp Ready™) maize impacts in Honduras. That analysis showed that GM maize yields were 856–1781 kg/ha higher than conventional maize (60%–130% increase over 1961–2012 Honduran average), and that adopters achieved higher net incomes than non-adopters, in spite of GM seed being twice as costly as conventional hybrid seed. The research showed that even with the adoption of GM maize, the production system marginally changed, implying that the technology potentially goes underutilized due to limited GM crop management knowledge in field conditions.

More than a decade after that survey, the long-term farm level impacts of GM maize in Honduras remain under-explored. This article discusses the knowledge, perceptions, opinions and attitudes Honduran maize farmers have about GM maize hybrids. A brief background on GM crops is discussed in the following section. A detailed exploration of the impacts of GM maize in Colombia, the Philippines, and South Africa is provided to contextualize Honduras' experience with the technology. Honduran maize production is discussed in "Honduran maize production" section. "Methodology" section details how the survey was structured, and the statistical methodology followed to analyze obtained results. "Results and discussion" section reports survey results, and conclusions are succinctly summarized in "Conclusion" section.

[1] 'Department' is the name of sub-national divisions within Honduras. These are known as states or provinces in other countries.

Background

Encroaching climate change and a growing and more affluent world population demanding greater animal protein in their diets, puts greater demands on the tools farmers have to undertake agricultural production. These realities have weighed on the decision to adopt GM crop technology for important food crops in many developing countries (ISAAA 2018). A decision that experience has proven to be correct, given that GM crop technologies increase crop yields and profits to a greater degree in developing countries, than in developed ones (Brookes and Barfoot 2020; Klümper and Qaim 2014). Moreover, in the specific case of maize, cumulative evidence shows that GM hybrids not only out-yield conventional hybrids, but they also reduce human exposure to mycotoxins (Pellegrino et al. 2018). Nonetheless, despite over two decades of evidence showing an array of positive impacts, GM crops continue to be dismissed and questioned by some (Smyth et al. 2019). At a time when the suite of technological options available to farmers should be as broad as possible and include agricultural biotechnologies (Ruane and Sonnino 2011), it seems unwise to dismiss a technology that has demonstrated capability to deliver economic, environmental, and public health benefits. Thus, it is illustrative to explore the impacts that GM maize has had in other developing countries to contextualize Honduras' experience with the technology.

Colombia

Unrestricted GM maize planting and production in Colombia, has occurred since 2007 (GAIN 2018). In the Valley of Cauca, GM maize that is both insect resistant (IR) and herbicide tolerant (HT), yields 46% higher than conventional maize, and because fewer agri-chemicals are required, less water (240 l/ha per year) is needed to spray the chemicals (Céleres 2015). GM maize production in Colombia has resulted in a decrease in insecticide costs of US$42/ha to US$55/ha, with herbicide costs falling by US$32/ha and US$44/ha (Brookes 2020). Combined, these impacts have increased farmer income (between 2003 and 2008), by an equivalent of US$294/ha per year for stacked maize (GM maize with more than one event) (Brookes 2020). GM maize cultivation has also had another positive externality in the form of a reduced environmental impact in Colombia. Use of insecticides on GM IR maize has decreased by 279,400 kg of active ingredient and the use of herbicides has decreased by 278,000 kg (Brookes 2020). However, despite the benefits and positive impacts provided by GM maize, adoption of the technology remains low. Govaerts et al. (2019) suspect that low adoption is due in part, to the apparent complexity of complying with the Colombian GM crop regulatory system. Moreover, efforts to disseminate the technology are spearheaded almost entirely by the GM maize seed manufacturers.

The Philippines

Bt maize was first commercially available to Philippine farmers in 2003. GM maize adoption in the Philippines offers significant economic impact evidence, given the ex-ante (Cabanilla 2004) and ex-post studies (Afidchao et al. 2014; Mutuc et al. 2012; Yorobe and Quicoy 2006), that have been undertaken to assess the technology. Yorobe and Smale (2012) show that the use of Bt maize has a statistically significant net-income increasing effect of 4,353 pesos per hectare ($\sim$ US$86). This research identifies that the probability of falling below the poverty line declines when Philippine farmers plant Bt maize. Afidchao et al. (2014) document that due to current socio-economic and agronomic conditions in Isabella province, the economic advantages offered by GM maize are not attained there. High seed costs, coupled with a prohibitively expensive credit system and technical inefficiency (farmers manage GM maize as though it were conventional maize), results in no significant difference in net income between GM and conventional maize variety cultivation.

South Africa

In 2001/02, South Africa became the first country to commercialize Bt white maize for subsistence farmers. Gouse (2012) notes the difficulty of studying the impact of this technology in the South African context, as in 2006/07, there was a shortage of HT white maize seed because the seed provider did not know how to appropriately service the South African market. Many smallholder farmers who wanted to purchase GM maize seed were unable to do so, leading to a data gap. Gouse notes that by the final study season (2009/10), most farmers planted GM maize with stacked traits

(HT and IR), and that farmers valued weed control convenience over insect control. In South Africa, conventional maize requires 276 h of hand weeding per hectare per season, Gouse (2013) notes that smallholder farmers who adopted GM HT maize spent, on average, 267 h/ha on manual weeding over three seasons. Weeding is typically done by women and children and is defined as drudgery, with Gouse determining that female household members averaged 10–12 fewer days hand weeding with GM maize. This additional time was spent with their children and tending to their vegetable plots. Gouse et al. (2016) show female farmer preference for labor-saving HT varieties stacked with IR. Thus, in South Africa, GM maize impacts are greater in the social dimension, rather than economic dimension.

After exploring the impacts from GM maize adoption in three developing countries, a pattern can be detected. That is, the technology itself does not appear to fail small subsistence farmers, rather it is the institutional arrangement around the technology that limits the benefits farmers receive from the technology. This institutional failure takes the form of high seed costs, limited or total lack of credit availability, lack of GM crop management information available to farmers, and in the South African case, lack of seed availability. Gouse et al. (2005) previously discussed this phenomenon; whereby, the technology itself is not responsible for its lack of impact, rather the institutional environment into which it is adopted is to blame. From these experiences, it can be inferred that the institutional environment into which GM crop technologies are adopted, need to be appropriately arranged so the technology has a net positive impact. This highlights the importance of innovation, the technology cannot simply be launched into the market without support mechanisms that will enable technology uptake.

Honduran maize production

According to FAOSTAT (2020), between 1961 and 2001, the average maize yield in Honduras was 1.3 tonnes/ha; between 2002 and 2018, this increased to 1.7 tonnes/ha (Fig. 1). The existence of two cropping seasons complicates the estimation of average landholding in Honduras (approximately 1.2 hectares). Early May to June is known as the 'first or rainy' season; the 'second or dry' season runs from August until November. In addition, maize can be produced as a standalone crop or intercropped (typically with red beans). Overall, total maize production has tended to increase, but the path production has followed is clearly erratic.

In 2002, the first year of GM maize approval, 500 ha of land were planted with GM maize; in 2017, this increased to 32,000 (ISAAA 2018). This latter number represents less than 10% of total average land planted with maize in Honduras since 2002. Hintze et al. (2003) have noted the slow adoption of improved maize varieties in Honduras is due mainly to farmer lack of awareness and information about them. Falck-Zepeda et al. (2015) posit that lack of information, is one of the factors directly responsible for the limited adoption of GM maize in Honduras. Thus, if effective policies and institutional arrangements that foster the adoption of agricultural biotechnology are to be devised, more information on the impact and barriers to adoption of the technology are needed.

Methodology

The survey was administered in the departments of Olancho, Comayagua, Copán, Yoro and Santa Barbara in 2018–2019. These regions were selected because it is where most maize production is concentrated and producers there have used, or continue to use, conventional maize landraces (Zamorano 2019). The survey was administered by a Zamorano University agronomist in the form of face-to-face interview.[2] A total of 32 farmers that produce both conventional and GM maize, and have participated in past research activities with the university were surveyed. This could be considered a limitation of the survey, however Falck-Zepeda et al. (2012) note the difficulty of locating and reaching producers to survey them in a random sampling framework. Producers who agreed to participate were assured that their responses would be treated with strict anonymity.

The survey focused on gauging knowledge, perceptions, opinions and attitudes of Honduran maize producers towards GM maize in contrast to

[2] Interviews were conducted in Spanish. Questions and answers have been translated to be as accurate to the Spanish questions and answers as possible.

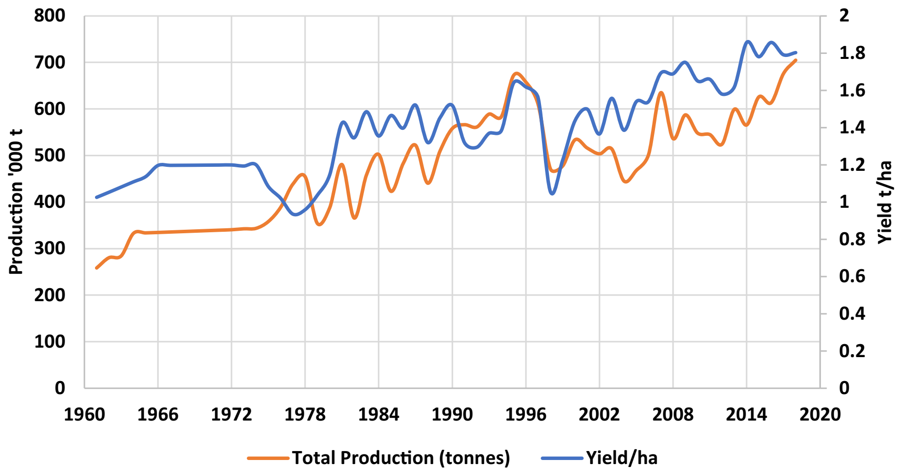

Fig. 1 Honduran maize production and yields, 1961–2018 *Source*: FAOSTAT (2020)

conventional maize hybrids. To obtain this information a total of 124 questions were asked. The survey was divided into the sections: general producer information, biotechnology knowledge, opinions about health and environmental impacts, pest abatement and revenue obtained from GM maize hybrid use. Data were analyzed using IBM SPSS (Statistical Package for the Social Sciences) version 23. Descriptive statistics were obtained by determining response averages, frequencies and percentages.

Results and discussion

All surveyed producers were men with considerable experience in GM maize production (Table 1). Of surveyed producers, 41% have a university degree, 34% have secondary schooling, 22% have primary schooling and only 3% reported not having any formal schooling. Producers planting GM maize (32) have, on average, 8 years of experience with the technology. Forty-seven percent of producers own their land, and an additional 41% both rent and own land. Interestingly, 97% of those surveyed cultivate 6 ha of land or more, which might be indicative of the minimum amount of land to be cultivated if GM maize production is to be profitable in Honduras.

Producer knowledge and understanding of biotechnology and GM maize

Eighty-four percent of respondents reported knowing that GM maize is a product of molecular biology (Table 2). Sixty-two percent had not heard of any biotech crop other than GM maize. This is not a surprise, as most producers reported that their main source of knowledge about GM crops is the firm selling them the GM maize seed. This indicates that producer knowledge and understanding can be attributed to experience gained from cultivating the hybrid. It also shows that producers know about GM maize hybrids because of the information provided to them by seed providers (private firms), and technical agronomic support provided to them at some point.

Producer comprehension about the use of GM maize technology was gauged through three questions (Table 3). In discussions following these questions, a minority of producers commented that they did not implement refuge areas because of lack of knowledge about them, and lack of technical assistance on how to implement them. Others indicated that they did not implement a refuge area because of the production practices in neighboring maize plots. This result indicates that some farmers are taking advantage of the spillover effects from the refuge area their neighbors are planting (i.e. 'halo effect') (Dively et al. 2018). A majority of farmers (65%) implement some sort of refuge area, with nearly all reporting familiarity for refuge areas.

GM maize impacts

Ten affirmations contrasting GM and conventional maize were used to gauge GM maize productivity (Table 4). The affirmations revolved around two key

Table 1 Farmer demographic information

Parameter	Number of producers	Percentage (%)
Schooling level		
No School	1	3
Primary school	7	22
Secondary school (high school)	11	34
University	13	41
Department		
Yoro	7	22
Comayagua	4	13
Olancho	12	38
Copán	8	25
Santa Bárbara	1	3
Type of land tenure		
Own land	15	47
Rent land	4	13
Own and rent land	13	41
Type of producer		
Small (1–5 ha)	1	3
Medium (6–30 ha)	16	50
Big ($\geq$ 31 ha)	15	47

Gender: 100% of producers are men (N = 32)

Table 2 Producer knowledge of biotechnology and basic concept of GM maize

Question	Yes	
	%	SD
Q1. Do you know that genetically modified maize is a product of molecular biology with a foundation in genetic modification and that can be applied in agriculture?	84	0.4
Q2. Do you know that GM maize is a genetically modified hybrid?	97	0.2
Q3. Have you heard of another biotech crop that is not GM maize?	38	0.5

SD standard deviation

themes, management practices and pest abatement capacities of GM maize.

Ninety-four percent of producers indicated that GM maize provides enough pest abatement so as to not warrant any pesticide applications; due to this benefit provided by GM maize, 97% of producers reported obtaining higher yields. Only 38% of producers reported to have changed their conventional maize management practices. This may indicate that even after 8 years managing GM maize, farmers have not fully adjusted to the new technology package, which may be limiting the overall benefits the technology is capable of providing.

Economic aspects of planting GM maize

All 32 respondents indicated that their income has risen and their quality of life had improved due to GM maize adoption. Eighty-eight percent indicated that their quality of life had improved very much or somewhat from the adoption of GM maize (Table 5).

Producers were asked whether GM maize allowed them to increase the area they cultivated with maize, with 95% of those interviewed very much or somewhat agreeing. Though producers are aware that using GM maize technology increases their income, most cultivate other crops in addition to maize. That is, they plant GM maize only for one season and it is not their

Table 3 Producer comprehension of GM maize technology (refuge areas)

Question	Yes	
	%	SD
Q5. Are you familiar with refuge areas?	88	0.3
Q6. Do you or the firm that provides your GM maize seed plant a refuge area on your plot?	66	0.5

	Number	%
Q7. Of total maize area, how much of a refuge area do you plant?		
0% of area planted	11	34
5% of area planted	10	31
10% of area planted	10	31
Other	1	3

SD standard deviation

Table 4 Producer perception of GM maize pest abatement and productivity

Affirmation	True	
	%	SD
Q8. Regarding pesticides, I have noticed a reduction in the need to apply them since I plant GM maize	94	0.2
Q9. With respect to weed control, I have noticed savings in weed management costs because I use less herbicides since I use GM maize	97	0.2
Q10. GM maize requires the same amounts of fertilizer as conventional maize	75	0.4
Q11. Since I plant GM maize, occasionally I use more than two pesticide applications due to lepidopteran attacks	6	0.3
Q12. I agree that the GM maize hybrid I use has an adequate resistance to lepidopteran attacks	94	0.3
Q13. Producing GM maize increases my manual labor productivity in comparison to conventional maize	63	0.5
Q14. To produce GM maize, I must change my traditional maize management practices (weed management, pruning)	38	0.5
Q15. Producing GM maize, I save a lot of manual labor because of the reduction in the number of applications (pesticides and herbicides)	84	0.4
Q16. Since I produce GM maize, I have a better yield in terms of maize ears thanks to the absence of lepidopterans	97	0.2
Q17. The production cycle for GM maize is longer than the conventional maize cycle	9	0.3

SD standard deviation

Table 5 Farmer opinions on the economic aspects of GM maize cultivation

Affirmation	Very much		Somewhat		A little	
	No.	%	No.	%	No.	%
Q19.Since I produce GM maize, my income has been higher	25	78	7	22	–	–
Q20.Since I produce GM maize, my quality of life has increased due to a better income	14	44	14	44	4	13
Q21.Producing GM maize allows me to improve my quality of life	21	66	11	34	–	–
Q22.The income obtained from cultivating GM maize allows me to gradually expand my landholdings	12	38	15	47	5	16

aim to increase the area of maize they sow. Furthermore, those who do rent land, usually do not have the option to rent more land in the immediate vicinity of their landholdings. Thus, should they choose to rent more land, production and crop management would be complicated because of the distance they would have to travel to a new plot.

GM maize environmental and human health impacts

Six questions were asked to capture producer opinion on environmental and human health risk management related to pesticide applications (Table 6). The vast majority, 88% of those surveyed believe that pesticides negatively affect the health of those exposed to these chemicals. Ninety-four percent believe that GM maize poses no risk to livestock, given that on occasion, producers use these plants to produce silage or send their livestock to feed on GM maize fields, with no adverse consequences reported.

Due to the length and structure of the survey instrument, after these initial questions were asked, responses to the remaining questions were compiled and discussed in broad sections. The entire survey instrument has been added (Online Appendix 1).

Producer attitudes on pest management and control

By using GM maize, the number of insecticide applications has been reduced considerably (Table 7). Results indicate that 84% of producers did not need to apply insecticides at all, in contrast to 44% of conventional maize producers who had to make between three and four applications. Moreover, there was virtually no difference in the number of applications, or amount of fertilizer required in either modality of production (conventional or GM).

When asked about pest pressure, 59% of GM maize producers reported no insect attacks, compared to 59% of conventional maize producers who reported severe pest pressure (Table 8). An equal percentage (66%) of producers in either production modality reported severe weed pressure. However, GM producers further detailed that weeds on their plots of maize were easily controlled with glyphosate. On disease incidence, a greater percentage of GM maize producers reported to having no pressure compared to conventional maize producers, but less conventional maize producers reported severe disease pressure compared to GM maize producers.

GM versus conventional maize yield

GM and conventional maize yields were converted to tonnes/ha and averaged (Table 9). GM maize producers reported an average yield of seven and half tonnes/ha, whereas conventional maize producers reported an average yield of 5 tonnes/ha. When planting GM maize, Honduran maize farmers have greater certainty about the yield they will obtain in contrast to conventional maize. Farmers were asked to comment on why they thought GM and conventional maize productivity has been, or will be, impacted. A clear majority of producers (both conventional and GM) think climate has had, or will have, a negative impact

Table 6 Producer opinions on GM maize cultivation effects on human health and the environment

Question and affirmations	True	
	%	SD
Q25.Do you believe that insecticides used against pests have a negative effect on the health of the person who applies them?	88	0.3
Q26.The reduction in number of applications has had some effect on health	34	0.5
Q27.Producing GM maize, there are fewer empty bottles of pesticides thrown into the environment	78	0.4
Q28.GM maize represents a threat to livestock	6	0.3
Q29.Since I cultivate GM maize, I observe in my plot, bees, termites, and ants	81	0.4
Q30.Have you or anyone that applies pesticides against pests experienced health problems during or after applying them in your maize plots?	25	0.4

SD standard deviation

Table 7 Number of pesticide and fertilizer applications done by producers on GM and conventional maize

Treatment	Maíze hybrid	Number of applications									
		0		1–2		3–4		5–6		7–8	
		No.	%	No.	%	No.	%	No.	%	No.	%
Insecticides	Conventional (32)	1	3	17	53	14	44				
	GM (32)	27	84	5	16						
Herbicides	Conventional (32)	17	53	15	47						
	GM (32)			32	100						
Fertilizers	Conventional (32)			24	75	7	22	1	3		
	GM (32)			25	78	5	16	1	3	1	3

Table 8 Producer opinion on pest pressure (GM and conventional maize)

Question	Maize hybrid	No pressure		Little pressure		Somewhat pressure		Severe pressure	
		No.	%	No.	%	No.	%	No.	%
How intense was the pest pressure in your field?	Conventional	–	–	4	126	9	28	19	59
	GM	19	59	9	28	2	6	2	6
How intense was the weed pressure in your field?	Conventional	–	–	4	13	7	22	21	66
	GM	–	–	4	13	7	22	21	66
How intense was the disease pressure in your field?	Conventional	8	25	12	38	9	28	3	9
	GM	11	34	9	28	7	22	5	15

Table 9 Producer opinions on maize yield

	Conventional maize (tonnes/ha)		GM maize (tonnes/ha)	
Harvest average	5.0		7.5	
Quantity expressed in maize ears or grain	Grain		Grain	
Compared to maize expected to be obtained	No.	%	No.	%
A lot less than I expected	–	–	–	–
Less than I expected	7	22	1	3
More or less what I expected	20	63	13	41
Exactly what I expected	5	16	18	56
*For what reasons do you think maize productivity was or will be impacted? **1st and 2nd most important motive*				
Seed Variety	20	63	5	16
Pests	11	34	12	39
Climate	26	81	31	100
Other	18	22	14	45

on maize productivity. Figure 1 shows that this belief is not unfounded, as total maize production and yield have tended to increase, the paths followed have been erratic and declines coincide with adverse weather events.

Despite GM maize seed being more than twice as expensive as conventional maize seed, GM maize out yields conventional maize by an average of 50%, which more than justifies the expense of GM seed (Table 10). Producers reported there was virtually no difference in the amount of fertilizer used, with conventional producers spending US$15.45 more on fertilizers than GM maize producers. Moreover, GM maize production costs per hectare are US$48.87 higher than conventional maize varieties, but revenue per hectare was US$719 higher than conventional maize varieties. The marginal rate of return of GM maize when compared to conventional maize is US$14.70. That is, for every additional dollar that is invested in the production costs of GM maize, US$14.70 dollars of benefits are received.

Credit access and technical assistance

Sixty percent of producers received financial support during the 2018–19 maize production season. A majority (53%), reported having an open line of credit at the time the survey was administered. Obtaining this financial support was relatively easy for most producers (63%), and 60% reported that the conditions of the financial support were favorable for them. Producers reported an array of sources for their loans or financial support: maize buyers (3%); banks (25%); cooperatives (6%); other sources (25%); and 41% of producers declined to name the source of their loan. Of those who receive financial support, the average amount is US$400, which must be repaid within 6 months.

When asked about technical assistance, 47% of producers reported not receiving any type of technical

Table 10 Production cost and revenue per hectare of maize comparison

Component (US Dollars/ha)	Conventional maize	GM maize
Land rental (per year)	353.16	353.16
Machinery and equipment	189.20	189.20
Seed costs	75.34	180.34
Plant protection costs		
Insecticides	95.45	9.59
Herbicides	46.11	68.50
Fertilizers	171.72	156.27
Sub total	313.28	234.36
Labor costs		
Fertilization	43.38	39.48
Herbicide applications	13.11	13.11
Insecticide applications	30.16	6.56
Harvest	166.27	216.56
Drying of grain	87.82	87.82
Sub total	340.75	363.53
Total costs	1271.72	1320.59
Net benefit estimation		
Expected production (ton/ha)	5	7.5
Expected price ($/ton)	307.11	307.11
Price of production (a) * (b) in $/ha	1536	2304
Production costs ($/ha)	1272	1320
Revenue/ha (c)–(d) in $	264	983
Revenue/ha (landowner)	617	1336
Marginal rate of return	–	14.7

*Input prices reported in this survey are prices given as credit to producers, which is why they are higher than the Honduran average assistance for this production season. Of those who did receive assistance, 19% reported receiving it on three occasions from seed provider technicians or agrichemical providers. Most received individual visits (20%) and two other groups (14% each) participated in group chats or went on field trips to fields planted with GM maize.

Conclusion

After over a decade, GM maize technology continues to outperform conventional maize hybrids, providing significant farm-level benefits in Honduras. Producers are knowledgeable about GM maize management, though 62% of those interviewed report managing GM maize hybrids the same way they would manage a conventional hybrid. According to producer responses, the technology continues to be economically beneficial and labor saving. Moreover, farmers that plant GM maize significantly reduce the amount of pesticides they need to spray. This has a positive environmental impact, as well as positive human health benefits because it reduces the possibility of pesticide mismanagement. This is of particular importance because 88% of interviewed farmers believe pesticides have a negative effect on human health, with 25% of them reporting adverse health effects as a direct consequence of spraying them. Though not explored here, the fact that fewer pesticide applications need to be made, results in less water per hectare being used to produce GM maize in Honduras.

Producing GM maize in Honduras requires a higher investment per hectare than conventional maize. However, the return on investment for GM maize is considerably higher than for conventional maize. In contrast to Colombia, complying with the Honduran GM maize regulatory system does not seem to constrain farmers. A considerable number of producers (41%), not as high as in the Philippines, do not receive any form of financial support. This may be a factor limiting the adoption of GM maize technology and may be weighing down the overall Honduran agricultural economy. While Honduran farmers receive both economic and social benefits from planting GM maize, in contrast with the South African experience, GM maize benefits in Honduras are mostly in the economic dimension.

It is noteworthy, that after over a decade of cultivation, the principle source of information and technical assistance on GM maize management continues to be GM maize seed providers. The technology's benefits could be more widespread throughout Honduras, if the government established an extension service capable of instructing maize farmers throughout the country and offered affordable credit to producers. While the Honduran experience with GM maize is overall good when compared to other developing countries that have adopted GM maize, there is room for the Honduran government to fill a knowledge and credit void that private GM seed providers are unlikely to fill.

References

Afidchao MM, Musters C, Wossink A, Balderama OF, de Snoo GR (2014) Analysing the farm level economic impact of GM corn in the Philippines. NJAS-Wageningen J Life Sci 70:113–121

Bogdanove A, Donovan D, Elorriaga E, Kuzma J, Pauwels K, Strauus S, Voytas D (2018) Genome editing in agriculture: Methods, applications and governance. CAST Issue Paper 60:25–42

Brookes G (2020) Genetically modified (GM) crop use in Colombia: farm level economic and environmental contributions. GM Crops Food 11(3):140–153

Brookes G, Barfoot P (2020) GM crop technology use 1996–2018: farm income and production impacts. GM Crops Food 11:242–261

Cabanilla L (2004) Bt corn in the Philippines: How much will farmers expect to gain. In PAEDA Convention, Quezon City, Philippines, Los Banos, October vol 12

Céleres (2015) Los Beneficios Agronómicos, Económicos Y Socio Ambientales De La Biotecnología Agrícola En Colombia: El caso del algodón, del maíz y de la soya genéticamente modificados. Uberlândia: Céleres®

Cruz O (2013) Manual para el cultivo del maíz en Honduras. DICTA, Tegucigalpa

Diaz-Ambrona CG, Gigena R, Mendoza CO (2013) Climate change impacts on maize and dry bean yields of smallholder farmers in Honduras. Rev Iberoam De Estudios De Desarro Iberoam J Dev Stud. https://doi.org/10.26754/ojs_ried/ijds.43

Dively GP, Venugopal PD, Bean D, Whalen J, Holmstrom K, Kuhar TP, Doughty HB, Patton T, Cissel W, Hutchison WD (2018) Regional pest suppression associated with widespread Bt maize adoption benefits vegetable growers. Proc Natl Acad Sci 115:3320

Falck-Zepeda JB, Sanders A, Trabanino CR, Batallas-Huacon R (2012) Caught between Scylla and Charybdis: impact estimation issues from the early adoption of GM maize in Honduras. AgBioForum 15(2):138–151

Falck-Zepeda J, Zambrano P, McLean D, Sanders A, Roca MM, Chi-Ham C, Benett A (2015) Honduras and Bt/HT maize—a small country model for GM crop adoption? In: Mitton, Bennett D (eds.), *Analyses: Africa's future can biosciences contribute?*, vol 106

FAOSTAT (2020) Food and Agriculture Organization of the United Nations, Statistics Division.tr. https://www.fao.org/home/en/

GAIN (2018) Agricultural biotechnology annual Colombia continues to work through regulatory challenges. USDA FAS, Colombia

GAIN (2019) Agricultural biotechnology annual. USDA, Honduras

Gouse M (2012) GM maize as subsistence crop: the South African smallholder experience. AgBioForum 15(2):163–174

Gouse M (2013) An evaluation of the gender differentiated impact of genetically modified crop adoption: a pilot study in South Africa-GM maize and gender: evidence from smallholder farmers in KwaZulu-Natal, South Africa. In: Project report to the Program for Biosafety Systems. International Food Policy Research Institute

Gouse M, Kirsten J, Shankar B, Thirtle C (2005) Bt cotton in KwaZulu Natal: technological triumph but institutional failure. AgBiotechNet 7:1–7

Gouse M, Sengupta D, Zambrano P, Zepeda JF (2016) Genetically modified maize: less drudgery for her, more maize for him? Evidence from smallholder maize farmers in South Africa. World Dev 83:27–38

Govaerts B, Vega D, Chávez X, Narro L, San Vicente F, Palacios N, Pérez M, González G, Ortega P, Carvajal A (2019) Maíz para Colombia Visión 2030. CIMMYT, Mexico

Hintze LH (2003) Characteristics, transaction costs, and adoption of modern varieties in Honduras (Draft). http://www.lib.ncsu.edu/resolver/1840.16/3761

Hintze RM, Sain G (2003) Variety characteristics and maize adoption in Honduras. Agric Econ 29:307–317

ISAAA (2018) Biotech Crops Continue to Help Meet the Challenges of Increased Population and Climate Change. Accessed June 09. https://www.isaaa.org/resources/publications/briefs/54/executivesummary/default.asp

Klümper W, Qaim M (2014) A meta-analysis of the impacts of genetically modified crops. PLoS ONE 9:e111629–e111729

Lassoued R, Macall DM, Hesseln H, Phillips PW, Smyth SJ (2019) Benefits of genome-edited crops: expert opinion. Transgenic Res 28:247–256

Lassoued R, Macall DM, Smyth SJ, Phillips PW, Hesseln H (2020) How should we regulate products of new breeding techniques? Opinion of surveyed experts in plant biotechnology. Biotechnol Rep. https://doi.org/10.1016/j.btre.2020.e00460

Mutuc MEM, Rejesus RM, Pan S, Yorobe JM (2012) Impact Assessment of Bt corn adoption in the Philippines. J Agric Appl Econ 44:117–135

Pacheco VHT (2002) Evaluación agronómica de 20 híbridos de maíz (Zea mays) transgénicos con el gen Bt (*Bacillus thuringiensis*) y sus contrapartes sin

Pellegrino E, Bedini S, Nuti M, Ercoli L (2018) Impact of genetically engineered maize on agronomic, environmental and toxicological traits: a meta-analysis of 21 years of field data. Sci Rep 8:1–12

Pitre HN (1988) A complex of lepidopterous defoliators on sorghum and maize in southern Honduras. Ceiba 29(2):353–361

Ruane J, Sonnino A (2011) Agricultural biotechnologies in developing countries and their possible contribution to food security. J Biotechnol 156:356–363

SENASA (2019) AGREEMENT C.D.-008–2019.tr. https://tzibalnaah.unah.edu.hn/bitstream/handle/123456789/11491/20190912.pdf?sequence=2&isAllowed=y

Smyth SJ, Kerr WA, Phillips PW (2019) GM agriculture and food security: Fears and facts. CABI, Wallingford

Yorobe JM, Quicoy CB (2006) Economic impact of Bt corn in the Philippines. Philipp Agric Sci 89:258

Yorobe JM Jr, Smale M (2012) Impacts of Bt maize on smallholder income in the Philippines. AgBioForum 15(2):152–162

Zamorano (2019) Encuesta a productores sobre el impaco que ha tenido la biotecnología en especia el uso de maíz genéticamente modificado en la producción y temas sociales relacionados. In. Escuela Agrícola Panamericana, Zamorano Honduras