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GM Maize as Subsistence Crop: The South African Smallholder Experience

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The South African smallholder GM maize experience has been—to date and internationally—the only example where a subsistence crop is produced by smallholder resource poor-farmers using GM seed. Their experience is thus of great interest, especially to African decision makers, international food and agricultural organizations, and the technology innovators. This article sheds light on eight years of research investigating the socio-economic impacts of GM maize adoption by smallholder farmers in South Africa. The main objective of the article is to highlight methodological and practical research challenges faced in this project in order to inform future socio-economic impact assessments and to contextualize research findings. Limited project findings are presented in the form of a discussion on the characteristics of early-adopting farmers and the yield impacts of GM maize adoption over the eight season period, emphasizing the variability between seasons and to show how methodological limitations impact research findings.

Key words: South Africa, genetically modified, maize, GM, Bt, HT, insect resistant, herbicide tolerant, subsistence, smallholder, small-scale.

Introduction

In 1997/98, South Africa became the first country in Africa to have a GM crop produced on a commercial level, with the release of insect-resistant (Bt) cotton. Bt maize was approved for commercial production in 1998/99, and Bt yellow maize was planted in that same season. The first plantings of Bt white maize two years later in 2001/02 established South Africa as the first GM subsistence-crop producer in the world. Commercialization of herbicide-tolerant (HT) maize followed in 2003/04, and "stacked" traits Bt+HT (BR) maize was released for the 2007/08 production season.

Adoption of GM crops by South African commercial farmers has been impressive. In the 2009/10 production season, approximately 69% of the total South African maize area was planted to GM maize, with Bt maize alone covering 43% of total area. GM cotton covered 92% of South Africa's total cotton area in 2007/08, and unofficial estimates report the 2009 area at close to 100%. The area under HT soybeans increased from 5% to more than 80% in only six years.

The investment focus of the pre-democratic South African government has translated into the geographically inequitable establishment of key support services such as roads; railways; agricultural training centers; and research, extension, and financial services. Small-scale and subsistence farmers in certain areas in the former homelands (such as Transkei and Ciskei in the Eastern Cape) and designated tribal areas (such as KwaZulu [Zululand] in northern KwaZulu-Natal [KZN]) have faced—and still face—various production and marketing constraints that are similar to those of other smallholder farmers in Sub-Saharan Africa. Though large-scale commercial growers produce the bulk of the national maize crop (generally more than 95%), the GM maize experience of smallholder farmers in South Africa is of great interest to African decision makers throughout the continent, to international food and agricultural organizations, and to the technology innovators.

This article sheds light on eight years of research investigating the socio-economic impacts of GM maize adoption by smallholder farmers in South Africa. The main objective of the article is to highlight methodological and practical research challenges faced in this project in order to inform future socio-economic impact assessments and, importantly, to contextualize research findings reported in this article and possible future articles.

The next section presents an overview of how GM maize was introduced to smallholders in South Africa, which is important for understanding research challenges. The research area, surveys, and data are summarized, followed by research challenges and how these were addressed. Limited project findings are presented in the form of a discussion on the characteristics of early-adopting farmers and an illustration and discussion of the yield impacts of GM maize adoption over the eight-season period, emphasizing the variability between seasons and to show how methodological limitations impact research findings.

Adoption of GM Maize by Smallholder Farmers

In order to introduce the new seed technology to small-scale farmers, the owner of the Bt events most widely used in South Africa, Monsanto, identified and selected nine areas across the Mpumalanga, KwaZulu-Natal, Eastern Cape, and Limpopo Provinces in South Africa, where subsistence farmers or rural households produce maize under dry-land conditions. With the help of extension officers of the different provincial Department of Agriculture offices, Monsanto invited roughly 3,000 farmers to workshops in their respective areas and informed them about the traits and characteristics of Bt maize in the local language. Farmers received certificates stating that they had attended a Bt maize training day, and if they wished, they also received two small bags of white maize seed each. One of the bags contained 250 grams of Bt maize seed (CRN 4549) while the other bag contained 250 grams of the conventional near-isoline (CRN 3549). As most farmers plant roughly a half hectare in some areas and about a hectare in others, and Monsanto supplied only small quantities of seed (enough for about 750 maize plants), farmers still had to buy and plant their usual seeds or use their own saved maize seeds.

Whereas farmers received small seed samples for free in the first or introduction season, farmers had to purchase their own seed in 2002/03, basing their maize seed purchase decision on their experience of the previous season. However, only a limited number of small-scale farmers were able to buy Bt seed due to a limited seed supply caused by seed multiplication problems on the side of Monsanto and an increased demand for Bt white maize seed by large-scale farmers. The 2002/03 season did see an impressive demand for Bt seed from various areas, but a significant number of subsistence farmers were able to procure and purchase Bt maize seed in only two sites in KZN—Hlabisa and Simdlangentsha.

HT maize was approved for commercial release for the 2003/04 season, and the seed company planted a couple of demonstration plots in some areas where Bt maize was introduced in 2001/02. The characteristics of the HT maize were explained at farmer days, and herbicide application demonstrations were done on the maize plots. Pamphlets explaining (in the local language and in a stepwise fashion) how and when herbicide should be applied were also distributed. The seed company also supplied additional training to government extension officers on the use of herbicides. In 2005/06, there was a growing demand for HT, especially maize in KZN, but in 2006/07 again there was not enough white HT maize seed available and many smallholders who wanted to buy HT seed were unable to do so.

There are no accurate data that enable the identification of GM maize-adopting subsistence, smallholder, and emerging maize farmers in South Africa. Seed companies are not able to maintain accurate records on each farmer who procures conventional or GM seed, as seed is sold by distributors and supplied to municipalities, projects, or agri-development groups, and the end user is in many cases not identified. Some buyers also share seed with neighbors or members of their farmer association. Based on seed company information, seed sales and assumptions regarding seed quantity, bag sizes, and seeding rates, Gouse, Kirsten, and Van Der Walt (2008) estimated that approximately 10,500 smallholder maize farmers—or approximately 23% of the estimated 46,500 smallholder farmers that regularly buy hybrid seed from the three largest maize seed companies—planted GM maize seed in 2007/08. The smallholder GM maize area covered about 33,700 hectares. This area also includes a number of smallholder projects, and it is believed that the area and number of individual adopters are even less. Considering that there are an estimated 240,000 small-scale farmers (small surplus producers) in South Africa and more than 2 million subsistence farmers, it is clear that GM maize adoption by smallholders is still minimal.

Monsanto has had some problems with seed multiplication, resulting in limited seed availability, and it appears as if in some seasons seed distribution to smallholder farmer areas were not planned or managed well. As Monsanto had not been selling much conventional maize seed in smallholder maize production areas (prior to Bt's introduction), it can probably be argued that they were still learning how to service this market. Smallholder GM maize adoption will in all likelihood never reach the high level observed with commercial farmers, as the motivations ofsmallholders differ—not all are profit driven and a surplus production is not always the objective. However, it is likely that GM maize adoption by South African smallholder maize farmers would have been higher—10 years after first introduction—if they had had more constant access to Bt and HT seed.

Research Area, Surveys, and Data

The analysis presented in this article is based on data collected from smallholder maize producers in the Hlabisa district of KZN for eight seasons, 2001/02 to 2007/08 and 2009/10. The Hlabisa municipality is situated in the former KwaZulu homeland area, and commercial agriculture in this region focuses on sugar cane and timber. Infrastructure and services supporting maize production and marketing by smallholder maize farmers are limited.

The Hlabisa area was chosen as the study site, by default, as it is one of few—if not the only—areas in South Africa where smallholder maize farmers have continuously produced genetically modified maize for nine seasons (up to 2009/10). In terms of GM maize adoption, this site is thus not representative of general smallholder maize conditions in South Africa, and the Hlabisa farmers' experience with GM maize should rather be viewed as a case study. However, Hlabisa farmers' production practices, limitations, and motivations are comparable to smallholders in the rest of KZN and South Africa.

In 2001/02 a list with the names of farmers who attended the workshops was obtained from Monsanto; with the help of extension officers and enumerators from six areas and across four provinces, a representative number of these farmers were surveyed. In 2002/03, with the limited seed supply, only farmers in Hlabisa and Simdlangentsha were able to procure and purchase Bt seed. Farmers in Hlabisa who planted Bt maize seed were identified through farmer associations or the seed sales records held by Monsanto and the farmers' cooperative who sold the seed. As only a couple of farmers in Simdlangentsha were able to procure Bt seed, this area was not surveyed again until the 2006/07 season. Future publications will analyze and compare 2006/07, 2007/08, and 2009/10 panel data for Hlabisa and Simdlangentsha, but this article will only focus on the eight years of research in Hlabisa.

In 2002/03, Bt adopters were relatively few; close to the total population of Hlabisa Bt seed adopters were surveyed. As few farmers in the initial samples planted substantial areas of both Bt and a conventional hybrid, the enumerators were asked to find an equal number of conventional hybrid-maize-planting farmers in the same areas as the Bt planting farmers. The study thus employed a purposive sampling approach in selecting the adopters and random selection (within close proximity to adopters) of non-adopters in order to have a comparable stratified sample.

In all the following seasons, close to the total population of GM adopters (Bt and HT) was surveyed, and in the later seasons 2004/05 to 2009/10, care was taken to continue with the farmers surveyed in 2003/04 in order to build a panel data set (while adding new adopters). However, some farmers had to be dropped from the sample due to crop failures caused by adverse weather conditions and animal damage, and some farmers did not plant hybrid maize in the drier seasons. It was possible to build a nearly balanced panel for approximately 90 Hlabisa farmers for the three seasons 2006/07, 2007/08, and 2009/10.

Methodological and Research Challenges

A number of foreseen and unforeseen problems and challenges emerged as the project continued from 2001/02, and it was necessary to adjust and adapt. Some of the main challenges are discussed next.

Small Samples

Limited seed availability resulted in limited adoption and even though, in most seasons, close to the total population of Bt and HT maize adopters were surveyed, the seed-specific farmer subsets remained small. These small samples complicate analysis and seed-specific comparisons. It is largely for this reason that the same farmers were followed for the latter seasons in order to develop a panel data set. Adding a time series element to the data adds credibility to the findings, as it controls for observed and un-observed farmer-specific effects. However, in the partial productivity measures used in this article, the benefit of the panel is not as evident as when the data is analyzed using an econometrically estimated production function or stochastic production frontier; in the partial productivity comparisons, some substantial yield differences are found not to be statistically significant due to the small sample size. Conversely, it should also be kept in mind that some statistically significant findings are based on small samples and individual seasons and should be interpreted in context.

Data Collection

As the study progressed and developed, new GM traits were introduced, and more interesting research questions appeared, the questionnaires used in the farmer surveys became more comprehensive. The 2001/02 survey, focusing mainly on whether the technology works (insecticide use and yield impact), consisted of one twelve-page questionnaire and relied on farmer recall. Analysis of data collected in the first couple of seasons showed that farmer recall (longer period) data has low accuracy and quite often is more indicative of the enumerator's knowledge than the farmers' indications. In order to address this, four questionnaires were used in the latter seasons and farmers were visited at least seven times throughout the season to collect data on input use, production activities, and expenditures as it took place.

Output Measurement

Output measurement presented various problems. Fresh maize cobs (green maize ears) are consumed during the season, decreasing the total output measured at the end of the season. Furthermore, the majority of small-scale subsistence farmers do not deliver their harvest or even a share thereof to a buyer, miller, or cooperative, with the effect that there is no "official" output measurement that a farmer can report. In the first season of research (2001/02) farmers were asked to indicate their harvest output according to the number of bags harvested. Farmers harvest dried maize cobs (ears) in used maize meal bags (50 kg or 80 kg sizes) in order to carry and transport the maize to the homestead.

In 2002/03, yields were measured by means of volume and weight. By using a bucket (25 liters) filled with maize cobs, the weight and quantity per volume was measured. By taking various samples from various farmers, an average volume-weight ratio was calculated. By taking measurements of the storage containers where farmers keep their maize, the volume of the containers could be calculated. Using the volume-weight ratio, the weight of the cobs was calculated, and—using an average cob/grain factor of 50% as derived from publications by Nel and Verwey (1976) and Möhr (1974)—the weight of the harvested grain was calculated. In comparing the "measured" output and farmers' indications in bags, it was found that there was no tendency by farmers to over- or under-estimate, and generally farmers' estimations were reasonably close to the "measured" figure. With this in mind, farmer's output data for the following seasons were based on the number of bags harvested. In order to ensure maximum accuracy, enumerators reminded farmers before harvest time that they needed to keep careful count of the size and number of bags harvested; farmers were visited immediately after harvest time to collect output data. Even though there are more scientifically precise methods of estimating output, most of these are associated with higher research costs and tend to be invasive of the farmer's production system. It is believed that the bags method used resulted in sufficiently accurate data and there was no error bias. Farmers were asked to indicate the number of green maize harvested and the dry weight of these cobs was added to the total harvest.

In order to be able to compare outputs between farmers, it was necessary to adjust the outputs of some Hlabisa farmers for the 2006/07 and 2007/08 seasons. For these seasons a leader farmer bought a couple of large bags of "commercial farmer seed," measured, and sold it to his neighbors and members of his farmer association. The difference between "small-scale farmer seed" and "large-scale farmer seed" is that commercial farmers prefer smaller seeds that can be used in mechanized and precision planters, while smallholder farmers tend to prefer larger sized seeds that can easily be planted by hand. Smaller seeds mean more seeds per kilogram, and this meant that farmers who bought from the lead farmer actually planted more seed than indicated by seed weight. Based on industry indications, outputs for these farmers were adjusted downwards by 20%.

Maize Plot Size

It became apparent in 2002/03 and 2003/04 that maize plot size (area) indications as supplied by farmers were quite far from the actual size. Based on enumerators' estimations, input use, observed plant spacing, and ultimately plot-size measurements by enumerators, it became clear that the majority of farmers tended to over-estimate the size of their maize plots. It is possible that local land preparation contractors (mechanized) contribute to this misconception by charging farmers for a hectare or a half hectare when most of the maize plots have never officially been measured.

From 2005/06, enumerators were asked to measure the maize plot size by walking around the maize plots (not necessarily the plot but the area covered by maize) and to draw a picture on the back of a questionnaire indicating the shape and measurements in steps. Enumerator steps were measured on a number of occasions and over an extended distance in order to attain an enumerator-specific average step size; this was used to calculate the plot sizes. This approach is less than perfect and measurements were influenced by uneven terrain, odd plot shapes, and—on a couple of occasions—snakes, but the seeding rates and yield data made more sense; it was clear that these plot size estimations were substantially closer to the actual size. In order to determine how accurate enumerator measurements were, a couple of distances and areas measured by enumerators were also measured using a hand held GPS instrument with an area calculation application. Enumerators' measurements were found to be surprisingly close to that of the GPS, and though the GPS instrument is also not 100% accurate, the comparison confirmed that enumerators' measurements are quite accurate and a reasonable representation of the actual maize plot size.

However, a number of yield indications, as well as seed, fertilizer, and labor use indications per unit of land, still showed unexplained variability with the land-size indication as the distorting factor. Therefore it was decided to use a seed-quantity-linked land-size indication to "smooth" the measured plot-size indications.

Counterfactual

In order to enter the South African maize seed market and obtain South African maize genetic material, Monsanto acquired a South African seed company, Carnia, in 1999. Though Carnia sold some maize seed to smallholder farmers, another South African seed company, Pannar, held the largest share of the smallholder hybrid seed market, especially in KZN. As a result, finding a substantial (statistically representative) group of farmers planting the near-isoline to serve as the counterfactual was challenging.

In the first season (2001/02), farmers received both the Bt (CRN 4549) and the near-isoline (CRN 3549) seeds for free, and individual farmers were able to compare the two seed types with one another. As it was back to normal in 2002/03 and farmers had to buy their own seed, it was not possible to compare the Bt seed with its non-modified isoline, since CRN 3549 had not been a widely sold or planted variety in KZN prior to 2001. The bulk of the conventional group for the subsequent seasons was made up of farmers planting PAN 6043, sold by Pannar. This hybrid is the most popular non-GM variety in Hlabisa and though following seasons saw increased adoption of Monsanto's non-GM varieties (in 2003/04 the isoline [CRN 3549] made up 31% of the counterfactual group), PAN 6043 remained the main counterfactual conventional hybrid.

There are a number of reasons why PAN 6043 has been the most popular hybrid in some regions in KZN and is also widely sold in Swaziland. Pannar describes PAN 6043 as "an extremely popular white hybrid variety with excellent yield potential" (Pannar, n.d.). It is also said to have "excellent stress tolerance," a high level of adaptability, and "multi/double cobbing." PAN 6043 is well known for its drought tolerance, so much so that it was used by Li and Van Staden (1998) and Batlang (2006) as the "tolerant variety" in water stress experiments. In the seasons when a larger number of farmers planted the non-GM Monsanto varieties, comparisons showed that there was not a substantial or significant difference in the yields of PAN 6043 and the near-isoline non-GM hybrid. PAN 6043 is thus by no means an inferior maize variety and well suited to be used as counterfactual.

In 2004/05, a new Bt variety (DKC 7815) was released along with the HT variety (DKC 7835). Both these varieties are based on the germplasm of CRN 3505 that also saw some adoption, and an effort was made to include farmers planting this variety in the counterfactual group. In later seasons, Bt and HT maize could also to a degree serve as counterfactuals to one another, as they are based on the same germplasm. This is an advantage since in 2009/10 farmers in Hlabisa bought GM seed (HT and stacked) from Pioneer Hi-Bred and not Monsanto, as in all the other seasons. The reason for this was that the Pioneer seed agent was on site when farmers wanted seed and some farmers had trouble obtaining Monsanto seed from local agro-input dealers. Pioneer planted some trials in Hlabisa in the previous year, and according to the leader farmer (mentioned above) and an extension officer, the seed performed well. When farmers were asked why they opted for the Pioneer seed rather than the Monsanto seed, few were actually aware that the seed was from a different seed company. The most important factor seemed to be that it was herbicide tolerant.

In a couple of seasons, data was collected from a number of farmers for more than one maize plot. This data was only used if farmers were able to keep plots completely separate in information on inputs use and harvesting. Even though not being able to compare Bt and HT maize with only the near-isoline as produced by the same farmers is less than ideal experimental design, it does avoid the potential problems of trying to compare GM hybrid maize with traditional seed or saved seed. Establishing quasi-experimental conditions to compare near-isogenic lines with transgenic varieties grown by the same farmers in multiple locations may be the preferred method for estimating yield advantages with precision, but this approach removes farmer decision-making regarding seed types from the context (Smale et al., 2009). It is important to point out that with this smallholder real-world type of study, it is not possible to scientifically assess the yield difference between Bt and HT varieties and their respective near-isolines. A study of that nature should be done under strict controlled conditions and would require that all variables (soil type, land preparation, rainfall, fertilizer, etc.)

remain constant while only the seed types are varied (ceteris paribus). In contrast, this study determines the performance of the new GM technologies by comparing it to the performance of the best-performing alternative within the actual smallholder context, which is the reality on which farmers base their decisions.

Self-selection Bias

Qaim (2009) admonishes that comparisons done with data collected from a stratified or representative random sample of adopting and non-adopting farmers can be associated with selection bias. It is possible that the adopting farmers are more educated or better farmers than their non-adopting counterparts and then the net technology impacts may be overestimated, as the adopters may perform better even without the GM technology. It is also possible that the GM technology is adopted only by farmers under specific conditions (like comparing adopters in high insect-pressure areas with non-adopters in low-pressure areas), and then the net impacts might be underestimated. There are a number of ways of reducing selection bias econometrically but also through observing developments over time and collecting data for a number of seasons, or by using with-in farm comparisons where farmers plant both GM and conventional varieties.

For this study, the possible effect and direction of the effect of the self-selection bias for the first seasons are not entirely clear. The possible selection bias is also complicated by the maize variety used, with the counterfactual being relatively drought-resistant and the Bt and HT varieties being based on new high-yielding but high-input demanding varieties. However, due to the fact that farmers were surveyed for eight years and there was some adoption, "dis-adoption." and re-adoption of Bt, HT, and conventional seed based on preferences but also seed availability, and based on the discussion on the early-adopting farmers (below), it is argued that selection bias for the final couple of seasons is less substantial. Though present in all likelihood, it is reasoned that the impact of self-selection bias has been diluted by the number of years since first adoption, with the GM seed technology becoming more main-stream, if not community wide, at least inside the survey sample group.

Selected Findings

Characteristics of Early Adopters

The farmers who first planted Bt seed were the farmers who attended the Monsanto workshops in 2001 and received free seed samples. These farmers cannot really be considered as the first adopters as they did not make an informed seed purchase decision. In 2002/03, only a limited quantity of seed was available and the adopting farmers were few. To shed light on who the early adopters were, I considered the farmers who adopted in 2003/04.

Table 1. Comparison of Bt adopters and non-adopters (2003/04 season).

	Farmers planting conventional	Farmers planting Bt maize
Households headed by males	69%	77%
Household head older than 60	48%	56%
Household head with no formal education	25%	37%
Average number of people in the household	9.3	10.8
Main income sources:		
Pension	20%	35%
Other government grants	13%	8%
Permanent wage income	34%	18%
Maize production	10%	16%
Households with cattle	59%	68%
Average seed quantity planted in 2003/04	6.5 kg	7.1 kg

Source: Author surveys

A total of 135 farmers were surveyed in 2003/04, and data was collected for 188 maize plots. Out of the total, 20 farmers planted both Bt and conventional maize, and they were excluded from the early adoption comparisons. Of the 77 farmers who planted Bt in 2003/04, 43 planted Bt in 2001/02 and 48 in 2002/03, and 91% indicated that the main reason why they plant Bt maize is higher yield. Of the non-adopters, 52% indicated that Bt maize seed is too expensive, and another 27% indicated that they cannot afford Bt seed—the slight difference being the willingness to buy, but inability to afford, the seed. This means that almost 80% of non-adopters indicated the price of the Bt seed as the main reason for not adopting. Of the conventional-maize-planting farmers, 11% indicated that they did not plant Bt maize as they do not know the seed, i.e., they have not heard about Bt seed.

While keeping in mind that the seed-specific farmers groups are small, it is possible to cautiously deduce from Table 1 that the households who adopted Bt maize earlier than others had slightly older household heads with less formal education and had more household

Table 2. Comparison of conventional, Bt, and HT maize seed adopters (2005/06 data).

	Conventional hybrid	Bt	HT
Households headed by males	39%	54%	55%
Household head older than 60	43%	41%	55%
Household head with no formal education	15%	16%	5%
Household head with primary education	43%	49%	57%
Average number of people in household	8.7	9.6	7.7
Average number of people in household older than 60	0.66	0.59	0.83
Main income source:			
Permanent wage income	12%	14%	27%
Old age pension and other grants	73%	78%	55%
Average maize plot size	0.46 ha	0.48 ha	0.46 ha
Average seed quantity planted	5.12 kg	5.82 kg	5.09 kg

Note: Percentage indicating the share of surveyed households
Source: Author surveys

members. More Bt-planting households had cattle and planted slightly more maize than their conventional-maize-planting counterparts. The main income source indications are more noticeably different. Old-age pension and government grants are the main income sources for 43% of Bt-planting households compared to 33% of conventional-maize-planting farmers; the percentage of conventional-maize-planting households whose main income source is permanent wage income is almost double that of Bt households; and 16% of Bt households, compared to 10% of conventional-maize households, has maize as the main income source. A Chi-squared test showed that the differences between the two groups are statistically significant at the 99% level.

It would thus seem as if the farmers who were the early adopters of Bt maize were more dependent on agriculture and maize production than their conventional-maize planting counterparts due to less off-farm income and more mouths to feed. It could possibly also mean that they were more committed to agricultural production, attended more farmers' days, and thus possibly are slightly better farmers or just more motivated. However, more elderly decision makers and a lower household income might serve as limiting factors to production and the presence or direction of possible self-selection bias is thus not obvious.

HT maize was first adopted by a substantial number of farmers in 2005/06. Table 2 compares conventional hybrid, Bt, and HT producers. In comparing this 2005/06 conventional maize and Bt adopter comparison (Table 2) with the 2003/04 comparison (Table 1), it is clear that some differences still exist, but others are less pronounced (and not statistically significant). For instance, Bt adopters still plant slightly more maize than conventional-maize users, and the Bt-adopter households are still larger and headed by mainly men. However, household head ages for Bt-adopter households and non-adopters are quite similar, as are household-head education levels and main income sources. This might mean that four years after introduction of Bt maize, some early adopters have "dis-adopted" and there are some new adopters. This might also mean that Bt has become a more "normal" agricultural input and not only adopted by the farmers whose households are highly dependent on maize or those hoping to produce a substantial surplus.

The difference between the early HT-maize adopters and the conventional and Bt planters is clear. By also keeping the early Bt-adopters comparison from Table 1 in mind, it is apparent that, like with the early Bt adopters, the first HT-adopting households are headed by comparatively elderly men. However, in contrast these, household heads seem to be slightly better educated and the households smaller (fewer members) and less dependent on government grants. HT-adopting households also had more elderly people in the household on average than conventional or Bt-planting households. Though the average maize plot size for HT- and conventional-maize-planting farmers were identical, it can be argued that due to smaller households, more elderly household members, and more households with a permanent off-farm income, there is a lower level of labor supply in the HT households and probably more means to purchase relatively more expensive HT seed and herbicides to control weeds.

Analysis of 2007/08 and 2009/10 adoption data showed that though more HT- and BR-adopting households have an off-farm income source, a high number of pension-dependant households have also adopted the weed-control technology. The early BR-adopting households are slightly larger than the rest—and this is in line with what was observed for the early Bt adopters. It is likely that the BR adopters previously planted Bt maize but were willing to also pay for the comfort of controlling weeds with a broad-spectrum herbicide. There is very little difference in the average maize plot sizes for the four seed types. These adoption indications among the four seed types in the different seasons, however, require more rigorous and in-depth analysis. The fact that fewer female-headed households have adopted GM varieties especially requires further research attention.

Partial Productivity Measure—Yield

Yield is a partial productivity measure in that it indicates a measure of the quantity produced (output) relative to only one particular input. Conventionally, yield is indicated as weight of output per unit of land, but yield can also be indicated as output per kilogram seed planted, per kilogram fertilizer applied, or per man hour. In the first part of this section, the Hlabisa farmers' outputs for the different seed varieties for the seasons 2001/02 to 2007/08 and 2009/10 are compared according to output per kilogram seed planted; in the second part, the outputs are compared according to output per hectare of land for the more recent seasons.

Maize yield (output per area planted) is influenced by a number of factors, including rainfall, fertilizer use, pest control, seeding rate, and the yield potential of the seed. As it was established that farmers' land-size indications were problematic and more accurate plot size measurements were only recorded for the more recent seasons, yield comparisons for the eight seasons are presented according to grain production per kilogram of seed planted (Figure 1). Farmers' indication of quantity of seed planted is thought to be substantially more accurate than the plot-size indications, and even though this approach complicates yield comparisons with other studies and pest control and fertilizer levels still have an influence, it does control for farmers' different seeding rates.

Analysis of the input data for the different seasons shows that fertilizer use by Bt-adopting farmers is not substantially higher than that of conventional-hybrid-planting farmers. In fact, in a couple of seasons, conventional-hybrid farmers use slightly more fertilizer than both Bt and HT farmers. Econometrically estimated production functions are better suited to incorporate the effects of the "other" inputs, but for this section it should be sufficient to state that though fertilizer usage in all likelihood did influence yields slightly, the effect was not biased in favor of Bt or HT but rather in favor of the conventional-maize-planting farmers. However, the farmers who planted HT maize in the 2006/07 season are the exception. They spent 65% or applied just over 70 kg of fertilizer more per hectare than both Bt- and conventional-hybrid-planting farmers. This partly explains the substantial yield advantage with HT seed in 2006/07.

It is important to stress again that in most seasons the performance of Bt and HT maize are compared to that of a relatively drought-tolerant non-isoline hybrid. Bt and HT maize varieties are based on new high-yielding varieties that perform best under high rainfall and high fertilizer application levels. It is thus possible that in the better seasons (higher rainfall), the Bt or HT "yield advantage" might be over-estimated, and in drier seasons when PAN 6043's drought-tolerant ability plays a role, the "yield advantage" might be under-estimated.

Figure 1 also indicates rainfall in the Hlabisa area, as recorded at the local Department of Agriculture offices. Both the rainfall for the total relevant maize production period September to March and for the early and first half of the production season September to December are indicated. In the KwaZulu-Natal and Mpumalanga Provinces of South Africa, maize is generally planted in October or November, and grain is harvested May or June. The September to December rainfall figure is important as it covers the period of early rain, land preparation, planting, germination, vegetative growth, flowering, and pollination. Generally the January to March period (distance between two rainfall lines in Figure 1) covers the cob/ear-forming stage. and the impact of rainfall on the maize yields is clear.

In interpreting Figure 1 it might be useful to keep in mind that the KZN Department of Agriculture recommendation for smallholder farmer in Hlabisa is that they plant 10 kg seed on a half hectare. Smallholders prefer maize seed that is larger in size for planting by hand and 20 kg of seed on a hectare should render about 54,000 plants. At a 50 kg grain/kg seed ratio, a farmer yields 1 metric ton of maize per hectare.

2001/02. In the introductory season, 35 farmers planting both Bt and the conventional near-isoline indicated a 29% average yield advantage with Bt maize (statistically significant at 99% confidence level). Even though this was the season with the highest rainfall of the eight seasons and (in retrospect) possibly the season with the highest stem-borer pressure, it would be unwise to put too much emphasis on this result. This was the season when farmers received small bags of seed for free and the workshop on the potential benefits of Bt maize was still fresh in their minds; this could have influenced their production practices, perceptions, and answers. However, comparing the yields in 2001/02 with that of seasons with relatively better rainfall conditions (2007/08 and 2009/10), the 2001/02 yield indications do not seem to be all that distorted.

2002/03. As farmers had to buy the Bt seed, it can be argued that farmers were more critical about the performance of Bt maize. Bt farmers indicated an average yield 31% (statistically significant at 90% confidence level) higher than conventional-maize-planting farmers. In 2003/04, farmers indicated that the stem-borer pressure in 2002/03 was higher than that of 2003/04, but chemical control of borers was limited. In an effort to deal with problems associated with small sample sizes (Bt n=22 in Hlabisa) and to get a more general figure for northern KwaZulu-Natal smallholder farmers, data was pooled for Hlabisa and Simdlangentsha (104 farmers in total) and showed a 16% higher yield for Bt maize, statistically significant at 95% confidence level (Gouse, Pray, Schimmelpfennig, & Kirsten, 2006).

2003/04. Adoption of Bt maize increased in 2003/04 and it was possible to collect comprehensive production and livelihood data from 48 farmers who planted Bt maize and 90 conventional-hybrid-planting farmers. It is clear from Figure 1 that rain for the first part of the 2003/04 season was not sufficient, and though the area received 470 mm in the three months of January to March, it seems as if the maize was not able to recover. As PAN 6043 is considered to be a drought-tolerant variety, it possibly performed better than the CRN based varieties (Bt and conventional near-isoline) for this season. An additional issue is that due to the dry season, maize cobs were in some cases not heavy enough to hang (pointing downwards) and rain that fell in the late season penetrated the husk and spoiled the grain (Gouse et al., 2006). This complicated yield reporting and comparisons. Even though 9% of farmers applied a chemical insecticide to control borers (highest of the eight seasons), based on farmers' indications, the yield difference was not substantial or significant.

2004/05. Due to the less-than-ideal rainfall distribution of the previous season and recurring dry conditions at planting time, a number of the farmers in the 2003/04 survey sample either did not plant maize, planted traditional seed only, or planted hybrid maize but without fertilizer. Most farmers planted late to very late with 52% of farmers planting in December and 16% only planting in January. In South Africa, early or late plantings of maize generally suffer more stem-borer damage due to a peaking in stem-borer moth flights, but again farmers did not indicate substantial borer pressure for this season. Based on the yields reported by 76 farmers (Bt n=23), Bt maize outperformed conventional maize by 32%. This yield advantage is statistically significant at 95% confidence level.

2005/06. With 186 mm of rain falling in November and December 2005, it was again possible to survey a large percentage of the 2003/04 stratified sample and additional conventional-seed planters and new Bt and HT adopters. Based on HT maize demonstration plots in 2004/05, a number of farmers adopted HT maize seed (HT n=31) and close to the total population of Bt maize planters (n=38) were surveyed. Based on farmers' yield indications, conventional maize outperformed HT maize by 3% and Bt outperformed conventional maize by 14%. Though this was in all likelihood a reasonable representation of the season, due to a high level of variability in the output data, neither of these two indications was statistically significant. This was the first season that saw substantial HT adoption, and as relatively few farmers in Hlabisa had experience with the use of herbicides, a number of farmers struggled with mixing and application. Some farmers delayed application to wait for government extension officers or other farmers to assist them with applications or to borrow knap-sack sprayers, and nearly one-third of HT adopters did not apply herbicide at all, as they were unable to afford or find the correct herbicide at the local shops.

2006/07. The 2006/07 season presented some really interesting findings. Due to financial mismanagement at the Hlabisa farmers' co-operative, Monsanto maize seed was not available in Hlabisa, and no other seed companies were selling GM maize directly to smallholder farmers in northern KZN. Other maize hybrids were available in local shops, but if a farmer wanted to buy Bt, HT, or conventional Monsanto seed they had to travel to Pongola (about 120 km one way). A farmer in Hlabisa bought a couple of large bags of Bt and HT "commercial farmers seed" and repackaged and sold it to the community in measured 2 kg units. The output for farmers who bought seed from these farmers were adjusted to compensate for the smaller seed-weight ratio.

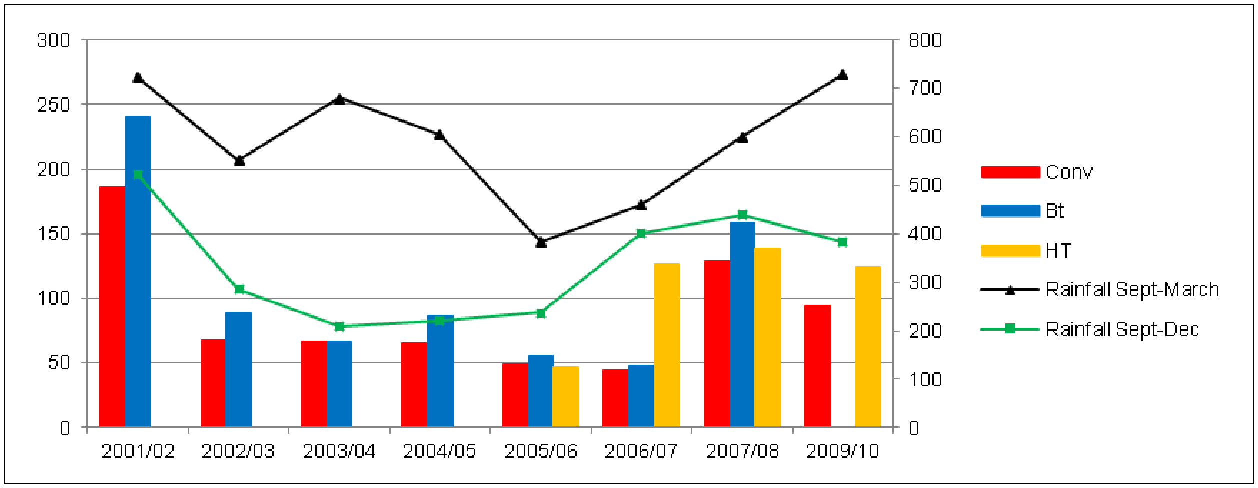

Figure 1. Yield comparison for conventional, Bt, and HT maize for the eight seasons 2001/02 - 2007/08 and 2009/10.

According to farmer indications, Bt maize yielded 8% more grain than conventional maize, but due to the decreasing number of farmers planting Bt seed (small sample), the difference was found not to be statistically significant. In contrast, HT-maize adopting farmers enjoyed a 184% higher yield than conventional maize and 176% more than Bt (both statistically significant at 95% confidence level). This considerable yield difference seems exaggerated but can be explained.

When considering the rainfall for this season, it is clear that the area enjoyed good rain from September to December, but from January to March only 58 mm was received. Due to good rain in the first half of the season, both maize and weeds flourished; however, during the dry later stages of the season, the soil moisture was minimal and weeds had a substantial impact on maize yield. Farmers and extension officers indicated that by using herbicides to control weeds, farmers were able to control weeds more effectively than their manual weeding counterparts. This effect was exacerbated by HT farmers applying approximately 70 kilograms of fertilizer more per hectare than the Bt- and conventional-hybrid-planting farmers. With higher soil moisture due to better weed management, HT farmers' maize was able to utilize the higher fertilizer quantities and substantially outperform Bt and conventional maize produced with less fertilizer and manual weeding practices. It can be argued that without the more effective chemical weed control, the HT maize would not have been able to utilize the higher fertilizer application. Self-selection bias in all likelihood also plays a role in the substantial difference, as it is possible that it was some of the better farmers that were able to procure HT seed. Small plantings also tically significant at the 95% confidence level (small play a role, with some farmers only planting 2 kg of HT seed.

Though 184% and 176% seems extraordinary and slightly unbelievable, it makes more sense when considering it in a near-zero weed damage approach. The HT technology using farmers' average yield was 126 kg grain/kg seed planted (about 2,500 kg/ha for farmers planting 20 kg of seed), and this was the yield level when there was limited weed-related output damage because weeds were controlled more effectively with the use of herbicides. This means that weeds caused 65% damage on conventional maize. If this figure is compared to weed-damage estimations of Gianessi (2009), Mabasa and Nyahunzvi (1995), and Marais (1987), the output differences between HT, conventional, and Bt seem quite sensible.

2007/08. In this season, as many farmers as possible from the 2006/07 sample were surveyed and a couple of extra farmers were added. With higher rainfall in the first and second half of the production season than in the previous five seasons, it was expected that stem-borer pressure would be slightly higher and that weeds and weed management would not have such a pronounced impact on yield. Based on the previous season (and not surprisingly), farmers seemed to have noticed the weed management benefits of HT seed, with a number of farmers dropping Bt maize and opting for either HT seed or the newly released BR (stacked) seed. Bt, HT, and BR outperformed conventional maize by 25%, 8%, and 33%, respectively. Bt yielded 15% more grain on average than HT maize. BR maize yielded 7% more than Bt. These differences are substantial but not statis-seed-specific subgroups).

Table 3. Yield comparison for conventional, Bt, HT, and BR maize (kg grain/hectare).

		Conventional (kg grain/hectare)	Bt (kg grain/hectare)	HT (kg grain/hectare)	BR (kg grain/hectare)
2005/06	n	61	37	21	
	Std dev	275	250	256	
	Mean	440	537	481	
	Mean difference to conv		22%	9%	
	t-Stat		1.79 (0.039)	0.621 (0.269)	
2006/07	n	38	22	35	
	Std dev	335	376	477	
	Mean	451	470	875	
	Mean difference to conv		4%	94%	
	t-Stat		0.192 (0.424)	4.359 (0.000)	
2007/08	n	28	12	38	19
	Std dev	839	1,296	949	1,205
	Mean	1,869	2,261	2,062	2,263
	Mean difference to conv		21%	10%	21%
	t-Stat		0.963 (0.176)	0.869 (0.194)	1.236 (0.113)
2009/10	n	16	0	67	15
	Std dev	612		577	615
	Mean	1,707		1,880	1,910
	Mean difference to conv			10%	12%
	t-Stat			1.025 (0.158)	0.918 (0.183)

Source: Author surveys

2009/10. In 2009/10, none of the farmers in the panel planted Bt seed, and 67 out of 98 opted for HT seed. Even though farmers again had trouble sourcing Monsanto maize seed from suppliers, and the vast majority ended up planting HT and BR seed from Pioneer Hibred, the shift from conventional and Bt to HT is undeniable, with farmers opting for the convenience of controlling weeds with herbicides. The yield for HT maize was—on average—32% higher than that of conventional maize with manual weeding labor, and this difference is statistically significant at the 95% level.

By pooling the data for the six seasons (2002/03 to 2007/08) it was found that Bt maize yielded 12% more grain on average than conventional maize (at the 90% confidence level). The average figure compares well with the 11% yield differences reported for commercial maize farmers by Gouse, Pray, Kirsten, and Schimmelpfennig (2005). However, it is clear from Figure 1 that this average figure hides substantial variation between seasons and that it is probably not a good idea to pool these data.

Table 3 summarizes the output per hectare comparisons for the last four seasons when maize plots sizes were measured more accurately. It is clear that small sample sizes and substantial variability also limits the statistical significance of the yield comparisons. There are some interesting differences between the output per kilogram seed planted and the per-hectare comparisons. For instance, using the per-hectare comparison, Bt maize yielded 22% more than conventional maize in 2005/06 (statistically significant at 90% level) when compared to the 14% (not statistically significant) yield of the kilogram grain per kilogram seed comparison (kg/kg). HT maize also showed a positive yield difference (9%) with kg/ha in 2005/06 compared to the -3% with kg/kg. The kg/ha yield advantage of HT maize in 2006/07 is slightly less extraordinary but still massive.

It is clear that the manner of measure in which yields are expressed for comparison also has an effect on the magnitude and statistical significance of the differences, with the “other” inputs having a larger or smaller impact. By using econometric production functions, it should be possible to determine the actual yield differences based on the effects of all the measurable inputs. Though small sample sizes will also act as a limiting factor in econometric analysis, it is hypothesized that the small sample problem can be overcome by analyzing the data as a panel.

Conclusions

South Africa is the only country in the world where small-scale subsistence farmers have been producing a genetically modified subsistence crop for a relatively long period of time. This research project has followed smallholders' experience with GM seed for eight seasons stretching over nine years. As new GM maize events were released, the project evolved and care was taken to collect detailed and accurate farm-level data. However, limited adoption—due to (amongst others) limited seed availability, low rainfall, and smallholders' different production objectives—resulted in a small population and resulting small samples sizes. It is hypothesized that the small sample problem can, to a certain extent, be overcome through panel analysis and by comparison with surveys in other smallholder areas.

Even though this study has limitations and the findings presented in this article are limited, it is possible to conclude that Hlabisa smallholder farmers highly value Bt and HT maize seed. Though seed availability might have played a role, by the final study season (2009/10), none of the farmers in the panel sample planted Bt, few still planted conventional maize, and the rest all planted HT or BR maize. Farmers seem to be willing to pay for the weed-control convenience; it appears as if farmers value the yield increase and (especially) the labor-saving benefit of HT maize more than the borer-control insurance of Bt maize. This inclination should be seen in the context of the relatively low borer pressure over the research period and the limited able-bodied labor force in rural KZN, caused by out-migration in search of employment, a high HIV/AIDS infection level, and elderly farmers. Future analyses and publications will focus on the labor-saving benefit of HT maize, potential expansion of production due to the decreased need for weeding labor, and gender implications of GM maize adoption and use.

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