

**Farm-level and socio-economic impacts of a genetically modified
subsistence crop: The case of smallholder farmers in KwaZulu-Natal,
South Africa**

by

Marthinus Gouse

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I, Marthinus Gouse declare that the dissertation, which I hereby submit for the degree PhD in Agricultural Economics at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

SIGNATURE:

DATE:

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Marnus Gouse

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ABSTRACT

Farm-level and socio-economic impacts of a genetically modified subsistence crop: The case of smallholder farmers in KwaZulu-Natal, South Africa

By

Marthinus Gouse

Degree: PhD

Department: Agricultural Economics, Extension, and Rural Development

Promotor: Prof. J.F. Kirsten

Co-promotor: Prof. C. Thirtle

Internationally, genetically modified (GM) crops have been the fastest adopted agricultural technology in recent history with a 67-fold increase in global area planted between 1996 and 2007. The first plantings of insect resistant (Bt) white maize in 2001/02 established South Africa as the first GM subsistence crop producer in the world. South African commercial farmers' adoption of GM seed technologies has been impressive and in 2009/10 approximately 69 percent of the total South African maize area was planted to GM maize. The interesting question is however whether South African resource poor smallholders were able to benefit from the introduction of GM crops. The South African smallholder GM maize experience has to date and internationally been the only example of where a subsistence crop is produced by subsistence farmers using GM seed. Their experience with GM crops is thus of great interest to African decision makers and other role players.

The international literature on the socio-economic impacts of subsistence GM maize production in Africa is limited to publications by the author of this thesis and research collaborators but reported findings are based on one or at most three seasons of data and inconclusive. This study is the first of its kind to comprehensively assess the farm-level and socio-economic impacts of GM maize adoption by smallholder maize producers over an extended period of time. This study analyses data collected from farmers in the Hlabisa

district of KwaZulu-Natal for eight seasons 2001/02-2007/8 and 2009/10. This thesis comprehensively answers the general research question: Taking into consideration the immense variability in production conditions between seasons and in production practises between farmers, have smallholders benefited from the adoption of insect resistant (Bt) and / or herbicide tolerant (HT) maize seed?

The thesis supplies background information on the project's research methodology and challenges in order to inform possible future socio-economic impact assessments and importantly to contextualise the project findings. The empirical assessment part of the thesis is presented in the form of two chapters. First the socio-economic and farm-level impacts of GM maize adoption are assessed using partial productivity and profitability methods. This approach can be misleading as it does not present the aggregate effect of the total impact of all production factors on output. To deal with this shortcoming, econometrically estimated production functions are then employed to include variation in applicable inputs in the assessment. This approach is however also not ideal as it tacitly assumes that all farms are efficient. In order to address this issue and to calculate comparable efficiency measures for individual farmers and different seed technology adopting groups, a stochastic production frontier approach is employed.

The partial productivity and production function and frontier analysis show that smallholder Bt adopters enjoyed higher yields than their conventional maize planting counterparts and in most seasons were better off despite paying more for their maize seed and not saving on insecticides. The analyses also showed that HT maize seed adopting smallholder farmers benefitted through higher yields brought about by more effective chemical weed control, compared to the manual weed control practices of conventional maize planting farmers. The total labour saving benefit of HT maize however depends on farmers' production system with farmers making use of "planting-without-ploughing" using significantly less labour than farmers doing land preparation with tractors or oxen and only then planting.

HT maize rendered the highest net farm income in three of the four latter study seasons and HT maize planting farmers were more efficient than both conventional maize planting farmers and Bt farmers. Farmers seem to be willing to pay for the weed control convenience of HT maize and based on adoption figures, farmers value the yield increasing and labour saving benefit of HT maize higher than the borer control insurance of Bt maize.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Internationally, genetically modified (GM) crops, also called transgenic crops, have been the fastest adopted agricultural technology in recent history with a 67-fold increase in area planted globally between 1996 and 2007 (James, 2007). In 2009 the total global area covered by GM crops reached 134 million hectares, increasing from 1.7 million hectares in 1996, just over 50 million in 2001, 100 million in 2006 and 125 million hectares in 2008 (James, 2007, 2008, 2009). In 2007 South Africa was still the only country in Africa to cultivate GM crops but was joined by Burkina Faso and Egypt in 2008.

The year 2011 was the fourteenth year since the first commercial release of a GM crop in South Africa. In 1997/98 insect resistant (IR) cotton also known as Bt cotton was released for production and South Africa became the first country in Africa where a GM crop is produced on a commercial level. Insect resistant (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 in 2001/02 established South Africa as the first GM subsistence crop producer in the world. Herbicide tolerant (HT) cotton was made available for commercial production in the 2001/02 season along with HT soybeans. Commercialisation of HT maize seed followed in 2003/04. Genetically modified cotton containing the combined or “stacked” traits (Bt + HT) was released for the 2005/06 season and Bt + HT (commercially known as BR) maize was released for the 2007/08 production season.

As can be seen in Figure 1.1, adoption of GM technologies by South African farmers has been impressive. In the 2009/10 production season approximately 69% of the total South African maize area was planted to GM maize. In only 6 years the area under Bt white maize increased from zero to over half a million hectares. GM cotton covered 92% of South Africa’s total cotton

area in 2007/08 and the 2009 area was estimated at close to 100%. The area under HT soybeans increased from 5 to over 80 percent in only 6 years.

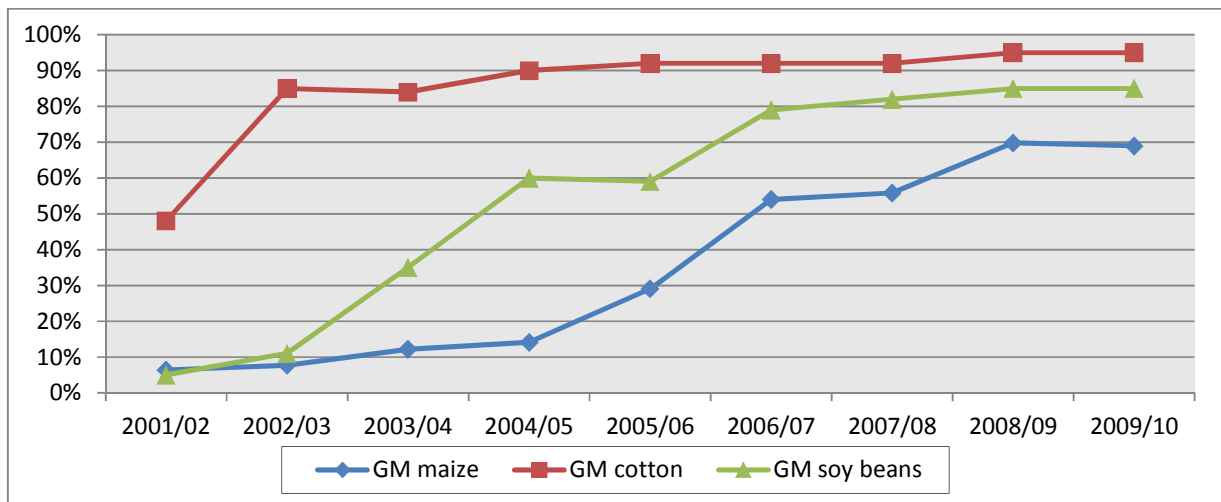


Figure 1.1: Percentage of maize, cotton and soybeans area covered by GM varieties

Source: Own research and South Africa's official GM adoption figures as collected and reported by Van Der Walt (personal communication, 2008, 2009, 2010).

These insect resistant (Bt) and herbicide tolerant (HT) agricultural biotechnology applications were all developed in the United States with the high-tech large-scale commercial farmers in the States as the original target market. South African commercial farmers also compete in a well-developed agricultural sector with functioning upstream credit and input markets whilst having access to efficient domestic and international output markets. Solely based on the remarkable adoption shown in Figure 1.1 it is possible to conclude that South African farmers were able to benefit from the adoption of GM cotton, maize and soybeans. However, as smallholder maize farmers in South Africa mainly produce on a subsistence level and smallholders' contribution to domestic production are minimal (less than 6% between 1996 and 2005 for cotton and usually less than 5% for maize), the adoption indication in Figure 1.1 presents primarily the large-scale commercial farmer adoption picture and not that of the smallholders. The fact that South African commercial farmers have benefited from this technology is not surprising as they compare relatively well with their US counterparts and are plagued by largely the same or rather similar pests. The more interesting question is whether South African resource poor smallholders were

able to benefit from the introduction of GM crops. This is a current and contentious issue as a number of African countries are currently at a crossroads on the decision of adopting and investing in policies and legislation to facilitate and regulate adoption and importation of GM crops.

1.2 JUSTIFICATION OF RESEARCH AND RESEARCH QUESTIONS

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, communication links, agricultural training centres, dams and irrigation facilities, input distribution outlets, and research, extension and financial services. Between 1985 and 1993, budgetary allocations to commercial agriculture were double that earmarked for allocation to the homeland areas (DBSA, 1993). Small-scale and subsistence farmers in certain areas in the former homelands like Transkei and Ciskei in the Eastern Cape and designated tribal areas like Zululand in northern KwaZulu-Natal have faced and still face various production and marketing constraints that are similar to those of other smallholder farmers in Sub-Saharan Africa. Their experience with GM crops are thus of great interest to African decision makers, to international food and agricultural organisations and to the technology innovators.

The introduction, adoption, performance and socio-economic impacts of insect resistant (Bt) cotton in South Africa with specific focus on smallholders have been well documented by a number of authors as well as the author of this thesis; see amongst others Ismael et al. (2002a, 2002b), Gouse et al. (2003), Thirtle et al. (2003), Kirsten & Gouse (2003), Gouse et al. (2005), Shankar & Thirtle, (2005), Hofs et al. (2006), Fok et al. (2007), Gouse et al. (2008) and Gouse (2009). The Bt cotton experience in other developing countries, especially China and India as well as in developed countries has been studied extensively (see Smale et al., 2009). However, compared to the large number of publications on Bt cotton, few peer reviewed publications have reported on the performance of GM maize as produced by smallholder farmers. As a matter of fact, even though relatively small-scale farmers in the Philippines have also adopted GM maize (Yorobe & Quicoy, 2006) for production for the commercial market, the South African

smallholder GM maize adoption example has to date and internationally been the only case where a subsistence crop is produced by subsistence farmers using GM seed.

The international literature on the socio-economic impacts of subsistence GM maize production is limited to publications by the author of this thesis, in collaboration with a number of local and international researchers. Gouse, Pray, Kirsten, & Schimmelpfennig (2005) described the South African maize seed sector and reported large-scale farmer Bt maize impact findings and some preliminary smallholder findings. Gouse, Pray, Schimmelpfennig & Kirsten (2006) presented three years of Bt maize smallholder findings but the study focussed mainly on yield impacts and presented rather inconclusive findings. In another 2006 publication Gouse, Piesse & Thirtle used a stochastic frontier model to make efficiency comparisons between Bt and conventional seed types for one season and also made some ex ante predictions on the labour impact of HT maize.

In the most recent publication Gouse, Piesse, Thirtle & Poulton (2009) analysed smallholder data for three areas in KwaZulu-Natal for one season and showed that the assessment methodology used influences the extent of the difference in performance between the GM varieties and the conventional counterfactual. This means different seed technologies (Bt, HT or conventional) might seem more or less superior depending on the analysis method or approach used as different approaches emphasise or include / exclude the impact of different parameters. Gouse et al. (2009) also came to the conclusion that it is dangerous to make any conclusions regarding the performance and resulting impacts of GM maize seed based on only one season, due to the considerable number of factors that influence smallholder maize production and production conditions as well as the pest specificity of the GM technology.

This thesis aims to add to and complement the existing yet severely limited literature on the use of GM maize seed by smallholder subsistence farmers in Africa. This study is the first of its kind to comprehensively assess the farm-level and socio-economic impacts of GM maize adoption by African smallholder maize producers over an extended period of time. Where the above mentioned journal papers reported on one or at most three seasons of smallholder data, this thesis utilises eight seasons of data collected over a nine year period, focussing on the Hlabisa area in KwaZulu-Natal.

The general research question this thesis intends to answer is: Taking into consideration the immense variability in production conditions between seasons and in production practises between farmers, have smallholders benefited from the adoption of Bt and / or HT maize seed? It is not the objective of this thesis to try and address all researchable issues surrounding smallholder adoption of GM crops but to “tell the story” of South African smallholder maize farmers’ experience with GM maize in a general and responsible manner. This thesis reports on findings for eight seasons and is considerably more comprehensive than previous publications, but in a sense also serves as a general overview and departure point for future research. Through analysis of the substantial and rich data set collected over the nine year study period, a number of other research questions can also be addressed. This study’s contribution to the discipline of agricultural economics and the international debate surrounding genetically modified crops and smallholder farmers is thus substantially greater than that of this thesis document only.

1.3 STATEMENT OF HYPOTHESES

There are two main seed technology specific generalised hypotheses emanating from the above mentioned main comprehensive research question.

Background to Hypothesis 1 - Bt maize:

In 2001 South Africa became the first country in the world to permit the commercial production of a GM subsistence and staple food crop i.e. insect resistant (Bt) white maize. In South Africa and other Southern African countries, the losses sustained in maize crops due to damage caused by the African maize stem (stalk) borer (*Busseola fusca*) are estimated to be between 5 and 75 percent and it was generally accepted that (pre-Bt) *Busseola* annually reduced the South African maize crop by an average of 10% (Annecke & Moran, 1982). *Busseola fusca* and *Chilo partellus* are the most harmful pests of maize and sorghum in South Africa (Kfir, 1997). Gouse et al. (2005) showed that in 2005, with a seemingly conservative estimation of 10% for damage caused by both *Busseola* and *Chilo*, the average annual loss adds up to just under a million tons of maize with an approximate value of R810 million. At a 2008 maize price level the potential damage caused by borers (in the absence of the Bt technology) was estimated to be closer to R1,6 billion. Both *Busseola* and *Chilo* can be controlled to a satisfactory level with the use of the Bt gene

currently used in South African Bt varieties (Cry1Ab). Commercial farmers have been producing Bt yellow and white maize with much success, generally enjoying higher yields as a result of more effective stalk borer control (Gouse et al., 2006a).

As Bt technology is an insect control technology and thus an insect damage limiting technology and not a yield increase technology, it is important to stress that Bt maize will only outperform a conventional isoline (same variety but without the Bt gene and marker genes so in actual fact a near-isoline) if there exists significant insect pressure in that particular season. If the specific pest is not present, there will be no direct benefit in using the insect resistant product and as Bt seed is more expensive, the farmer will in all likelihood be worse-off. It is however difficult to make pre-planting predictions on seasonal stalk borer infestation levels due to the complicated relationship between rainfall, variability in the season, growth of maize, effect of stalk borer on the maize plant and the effect of natural enemies on the host (Annecke & Moran, 1982). Because a dry early season does not necessarily portend a dry season throughout and late maize plantings historically suffer more borer damage, many large-scale commercial farmers consider Bt to be an affordable insurance against unforeseeable stalk borer outbreaks (Gouse et al., 2006a). However, due to the higher variability in production conditions and relatively low input production systems of small-scale and subsistence farmers, increased expenditure on seed due to the additional technology fee could outstrip the “insurance value” for smallholders in seasons with low borer pressure.

Hypothesis 1 - Bt maize:

Smallholder maize farmers in South Africa benefit from adoption of Bt maize varieties in seasons with significant stalk borer pressure, due to higher yields (less borer related damage), and despite paying more for the Bt seed and not saving substantially on insecticide application.

Background to Hypothesis 2 - HT maize:

It has been argued that part of the reason why the Green Revolution has missed most of Africa but has been a success in Asia is because Asia is relatively labour abundant but land scarce, whereas Africa is land abundant but labour scarce. It has been suggested that in Africa the use of fertiliser just means more weeding with limited (family) labour (Benson, 1982). The idea behind

herbicide tolerant (HT) crops is that herbicide can be applied post emergent i.e. after the maize and weeds have germinated and reached a certain growth stage. Herbicide can be applied indiscriminately over the whole field and herbicide tolerant crops survive while the weeds do not. For commercial farmers this weed control approach reduces the need for mechanised weeding and forms the back bone of a minimum tillage production system. For smallholders where weed control is generally done by hand, this technology could result in a decrease in the demand for weeding labour. For rural households this could mean a decrease in the need for family labour, releasing family members to take part in other activities. According to Kent, Johnson & Becker (2001) the principal limiting factor to farm sizes in Africa is the number of necessary weedings during the period following planting. So it is also possible that adoption of this production approach might enable households with limited labour to expand their maize area. It might however also result in a decrease in the demand for hired labour which might be positive for producers but negative for the rural unemployed whose only employment opportunity is seasonal weeding.

Weeds compete with crops for nutrients, space, light and water and where no weeding is done it can decrease maize yields by 55 to 90 percent (Gianessi, 2009). Chikoye, Udensi, Fontem Lum & Ekeleme (2007) found that herbicide use in maize production in Nigeria was more cost effective than manual weed control and also resulted in higher yields. Chivinge (1990) found that herbicide use increased maize yield by 55% in Zimbabwe.

Hypothesis 2 - HT maize:

Smallholder maize farmers in South Africa benefit from the adoption of HT maize through higher yields (due to more effective weed control), a decreased need for weeding labour and despite spending more on chemical herbicides and HT seed. The labour saving benefit of HT maize however depends on the farmer's production system.

1.4 OBJECTIVES

The general objective of this study is to ascertain whether smallholder subsistence farmers in South Africa benefited from the introduction of insect resistant (Bt) and/or herbicide tolerant (HT) maize.

This general objective will be reached, and the hypotheses tested, through a number of specific objectives. These specific objectives focus on a number of GM maize adoption impact levels.

These include:

- Determining the impact on yield
- Determining the impact on insecticide use
- Determining the impact on herbicide use
- Determining the impact on seed cost
- Determining the impact on labour use
- Determining the impact on net / gross farm income
- Determining the impact on production efficiency

1.5 DATA

This thesis will make use of data collected from smallholder maize producers in the Hlabisa district of KwaZulu-Natal for the eight seasons 2001/02 to 2007/8 and 2009/10. Data was collected from Bt, HT and conventional hybrid maize producing farmers with the assistance of a number of enumerators living in the Hlabisa district. Whereas the 2001/02 and 2002/03 seasons' surveys mainly focussed on household demographics and yield assessment, the later seasons' surveys were developed to also capture detailed labour impacts of Bt and HT maize adoption.

Over the eight production years, 745 farmer surveys were conducted with 271 farmers in the Hlabisa area. Of the total, 121 farmers were surveyed only once and 67.5% of the surveys were conducted with farmers that were part of the survey sample for four or more years. Almost 20% of the eight season survey sample was surveyed seven years or more. Chapter 3 supplies a comprehensive discussion on the seasons, samples and data.

1.6 METHODOLOGIES

This thesis departs slightly from the standard thesis format as the empirical assessment part of the thesis is presented in the form of two chapters, each assessing the performance and socio-economic impacts of GM maize under smallholder conditions, using different analytical methodologies. The empirical chapters are thus separated based on different analytical approaches. Predominately new analyses and findings are presented, but the chapters also draw to a lesser extent on the before-mentioned articles co-published in peer reviewed journals by the author.

In Chapter 4 the socio-economic impacts of GM maize adoption are assessed using partial productivity and profitability methods with respect to different seed technologies and across eight seasons. The focus falls on the indicated specific objective impact levels, namely yield, insecticide use, herbicide use, seed cost, labour use and net and gross farm income calculations.

However, the partial productivity approach used in Chapter 4 can be misleading as it does not present the aggregate effect of all the input factors' impact on output. To deal with this shortcoming Chapter 5 employs production functions to include variation in all applicable inputs in the assessment. This approach is however also not ideal as simple regressions take the average line of best fit through the observations and tacitly assumes that all farms are efficient. In order to address this issue and to calculate comparable efficiency measures for individual farmers and different seed technology adopting groups, a stochastic production frontier approach is employed.

1.7 OUTLINE OF THE STUDY

This thesis is organised in to 6 chapters. Following this introduction chapter, Chapter 2 briefly presents some background information on biotechnology and GM crops. International adoption of these transgenic crops is described and adoption and production of GM cotton, maize and soybeans in South Africa are discussed in detail. The economic and socio-economic impacts that motivate these adoption rates are also discussed.

Chapter 3 sheds light on how this research project evolved and discusses the survey area, sample selection, surveys, questionnaires, data, counterfactual and the technology introduction and adoption process. This chapter highlights some research challenges and how these were addressed and also contextualises subsistence farmers in South Africa through analysis and presentation of household demographics and livelihoods information.

In Chapter 4 the socio-economic impacts of Bt and HT maize adoption are compared to that of conventional maize, using partial productivity and profitability methods. This chapter focuses on the impacts on yield, insecticide use, seed cost, herbicide use and labour use and the effect these impacts have on the profitability of the different seed technologies.

Chapter 5 assesses the performance of Bt and HT maize compared to conventional maize, making use of econometrically estimated production functions and then a stochastic production frontier approach is used to determine and compare the technical efficiency levels of farmers using the different seed technologies.

Chapter 6 summarises the study findings in the context of the South African smallholder sector and in reference to smallholder farmers in the rest of Sub-Saharan Africa and concludes with recommendations emanating from the research, to GM crop impact assessment practitioners, agricultural biotechnology and seed companies and the South African Government.

CHAPTER 2

GENETICALLY MODIFIED CROPS: ADOPTION AND PERFORMANCE

2.1 INTRODUCTION

The objective of this chapter is to introduce the concepts of biotechnology and genetically modified crops and to shed light on international, but especially domestic adoption of these transgenic crops. The economic and socio-economic impacts that motivate adoption are discussed on an international and national aggregated level as well as on farm level. The chapter concludes with a brief look at the research methodologies used in farm-level impact assessment to set the scene for the methodologies, analyses and findings that will follow in the next chapters.

2.2 BIOTECHNOLOGY AND GENETICALLY MODIFIED CROPS

It is believed that the term biotechnology was first used in 1917 by a Hungarian engineer Karl Ereky to describe the commercial production of pigs with sugar beets as main food source. Ereky defined biotechnology as “all lines of work by which products are produced from raw materials with the aid of living things” (Glick & Pasternak, 2003). A period followed during which the term biotechnology was used to refer to fermentation processes (in line with Ereky’s definition) but strangely and rather appropriately also to what is today known as ergonomics - the applied science of equipment design to minimise operator fatigue and discomfort. This confusion ended in 1961 when Swedish microbiologist Carl Göran Hedén recommended that the title of a scientific journal be changed from *Journal of Microbiological and Biochemical Engineering and Technology* to *Biotechnology and Bioengineering* (Glick & Pasternak, 2003). Though different disciplines, institutions and entities tend to supply slightly different definitions, it is generally accepted that the term biotechnology describes “..any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use” (Secretariat of the Convention on Biological Diversity, 1992).

Although the terms biotechnology and genetic modification tend to be used interchangeably in the general media, biotechnology is a broader term (as described above) while genetic modification is a biotechnology application by which the genetic makeup of living organisms is altered in order to impart a novel characteristic to the organism. These organisms are then known to be genetically modified, genetically engineered or transgenic.

It is possible to identify three distinct coexisting historical phases or generations in biotechnological undertakings (Nef, 1998):

- The “first generation”, traditional biotechnology (7000 BC to 1940s), was characterised by minimal input of science and engineering. It includes the conventional use of yeasts and fermentation for the production of food, beverages and energy.
- The “second generation” or intermediate biotechnology (1940s to 1980s) was characterised by significant scientific and engineering inputs on an industrial scale, including industrial microbiology, biochemistry and industrial engineering. It utilised fermentation, bio-conversion and bio-catalysis to manufacture pharmaceuticals, produce chemicals and fuels, and to process residues.
- The “third generation” or modern biotechnology (from the 1980s) is characterised by new genetic combinations. It is based on molecular biology and the utilisation of genetic engineering techniques (such as recombinant DNA). Potentially the applications of modern biotechnology encompass all biological processes, leading to new products and applications.

There are numerous current and potential applications of biotechnology in agriculture to produce genetically modified crops for food, feed and fibre. The first wave of modern agricultural biotechnology has generally benefited farmers and producers by providing input or agronomic traits that make production easier and more effective. Most of the food in the market today that is referred to as genetically modified, is food that is produced through field crops that are either herbicide tolerant or has a genetically engineered resistance against certain insects, viruses or fungi. The second wave of agricultural biotechnology will also focus on output or quality traits and will benefit consumers through food with enhanced nutritional components, novel characteristics or healthier oils. It is envisaged that the agricultural biotechnology industry will

evolve into a third generation in which even more bio-industrial applications will emerge in industry, manufacturing and in the pharmaceutical sector.

This thesis focuses on the performance and socio-economic impacts of insect resistant (Bt) and herbicide tolerant (HT) white maize in South Africa. The performance of stacked maize (BR) with both the Bt and HT genes are also presented for the last two seasons but not discussed in detail as findings are based on small samples and only a couple of seasons.

Commercially available Bt maize was created by inserting a gene from the Lepidoptera pathogen soil bacterium, *Bacillus thuringiensis*, into the maize genome. This gene codes for the production of the Bt toxin that, when ingested by a Lepidoptera like the maize stalk borer, causes the formation of pores in the larval digestive tract resulting in sepsis, caused by naturally occurring enteric bacteria, and ultimately death of the specific maize stalk borer. This means that Bt maize is insect resistant as it has an inherent Lepidoptera controlling (killing) ability. Humans, mammals and most other insect groups are not susceptible to these Bt toxins as the receptors necessary for the toxin to bind to, do not exist in these species' intestines. That is also the reason why other insects like the black maize beetle on maize or sucking insects on Bt cotton (that controls for the bollworm complex) still has to be controlled with chemical applications (Ostlie & Helgeson, 1998, Gouse, 2009). In order to prevent resistance development against the Bt toxin, it is compulsory (under the biosafety Bt permit conditions) for, for example, Bt maize adopters to plant a section of their maize field to non-Bt maize. This area is known as refugia and in South Africa farmers have two refugia options: either planting 5% (with no stalk borer control in the refugia section of the field) or 20% (with chemical stalk borer control in the refugia section).

Herbicide tolerant maize or in this case more specifically glyphosate tolerant maize, has the ability to survive or be tolerant to an application of the broad-spectrum systemic herbicide, glyphosate. In practise this means that a broad spectrum herbicide can be applied post emergent over the whole maize field without concern for crop damage. Glyphosate was originally patented in the United States by Monsanto in the 1970s under the name Roundup, but this patent expired in 2000 and currently there are a number of other herbicides on the market with glyphosate as active ingredient. Glyphosate herbicide kills plants by blocking the 5-enolpyruvylshikimate- 3-

phosphate synthase (EPSPS) enzyme. This enzyme is crucial in the biosynthesis of aromatic amino acids, vitamins and secondary plant metabolites. A plant treated with glyphosate will in a couple of days wilt and die because it is not able to produce food through its photosynthesis processes. There are a number of ways by which crops can be modified to be glyphosate tolerant. One strategy is to incorporate a soil bacterium gene that produces a glyphosate-tolerant form of EPSPS or it is possible to incorporate a soil bacterium gene that produces a glyphosate degrading enzyme (ISAAA, 2006). Herbicide tolerant maize is known and sold as Roundup-Ready (RR) maize in South Africa.

2.3 INTERNATIONAL ADOPTION OF GM CROPS

The global area under GM crops has increased every year since its first commercialisation in 1996. For the first 12 years it grew at double digit growth rates and slowed to 9.4% in 2008, and 7% in 2009. In 2009 the total global area covered by GM crops reached 134 million hectares, increasing from 1.7 million hectares in 1996, just over 50 million in 2001, 100 million in 2006 and 125 million hectares in 2008 (James, 2007, 2008, 2009). In 2009 for the first time, more than three-quarters (77%) of the 90 million hectares of soybean grown globally were GM. Almost half (49%) of the 33 million hectares of cotton were GM while more than a quarter (26%) of the 158 million hectares of maize grown globally were GM. GM canola covered 31 million hectares or 21% of total global canola plantings (James, 2009). These four crops remain the largest GM crops with minimal production of other commercialised GM crops like papaya, sugar beets, poplar trees, tomatoes and squash in mainly the United States and China.

Of the 25 countries planting GM crops in 2009, 11 planted stacked traits, i.e. crop varieties with more than one trait like BR maize with both insect resistance and herbicide tolerance. This recent adoption trend is more visible in the countries that first adopted GM crops. For example in 2009, 85% of the 35.2 million hectares of maize in the USA was GM, and 75% of it was hybrids with either double or triple stacked traits (James, 2009).

The well published GM crop adoption map (Figure 2.1) of James (2010) indicates the 29 countries that planted GM crops in 2010. The number of countries growing biotech crops has

increased steadily from 6 in 1996 to 18 in 2003 and 25 in 2008 and 2009. In 2010 GM crops were produced by 10 countries in Latin America and in 2009 Brazil displaced Argentina as the second largest grower of GM crops, following the United States in first place. Brazil's GM area increased by 35% in 2009, mainly due to a 3.7 million hectare increase in Bt maize plantings (James, 2010).

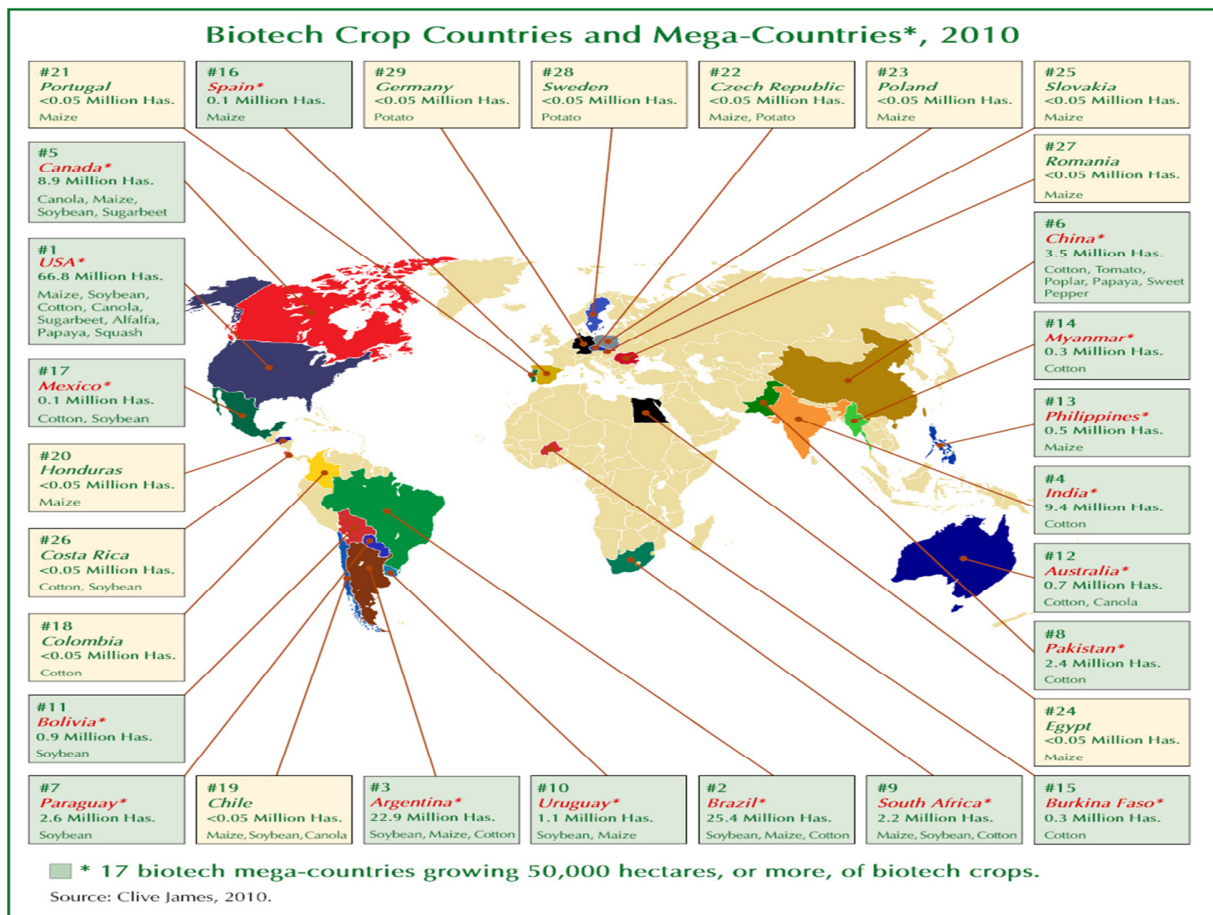


Figure 2.1: International adoption of GM crops

Source: James (2010)

Concurring with the increase in international GM crop area, the number of farmers planting GM crops also increased in 2009 by approximately 0.7 million to 14 million farmers. Over 90% of these farmers are smallholder farmers from developing countries with approximately 7 million and 5.6 million smallholders from China and India respectively, planting Bt cotton. In India alone

0.6 million more smallholders planted Bt cotton in 2009 and the national adoption was estimated at 87% of the total cotton crop (James, 2009).

2.4 ADOPTION OF GM CROPS IN SOUTH AFRICA

In 2007 South Africa was still the only country in Africa to cultivate GM crops but was joined by Burkina Faso (Bt cotton) and Egypt (Bt maize) in 2008 (James, 2008). The year 2009 saw the twelfth year since the first commercial release of a GM crop in South Africa in 1997/98, a year after the first commercial plantings of Bt cotton in the US in 1996. Table 2.1 summarises the GM crops approved for commercial production in South Africa according to year of release, crop and GM event.

Table 2.1: GM crops approved for commercial production in South Africa

Year	Crop	GM Event
1997/98	Cotton	Insect resistant (marketed as Bt or Bollgard cotton)
1998/99	Maize	Insect resistant (marketed as Bt or Yieldgard maize)
2001/02	Cotton	Herbicide tolerant (marketed as Roundup Ready cotton)
2001/02	Soybeans	Herbicide tolerant (marketed as Roundup Ready soybeans)
2003/04	Maize	Herbicide tolerant (marketed as Roundup Ready maize)
2005/06	Cotton	Stacked gene (Bt + RR marketed as BR cotton)
2007/08	Maize	Stacked gene (Bt + RR marketed as BR maize)

Even though Bt maize (as a genus) was approved for commercial production in 1998, only yellow Bt maize was planted in that year and it was only in 2001 when South Africa became the first country in the world to produce a GM subsistence crop and staple food, i.e. insect-resistant white maize. This was mainly because the Bt gene first had to be crossed into the better performing South African white maize hybrids.

As can be seen in Tables 2.2, 2.3 and 2.4 below it is clear that South African farmers' adoption of GM technologies has not been less impressive than what has been observed internationally. In the 2007/08 production season approximately 55% of the yellow maize area in South Africa was planted to GM yellow maize and 56% of white maize was GM. Indications for the 2009/10 season estimate the GM yellow and white maize areas at higher than 70% of total maize plantings. GM cotton covered 92% of South Africa's total cotton area in 2007/08 despite the total

cotton plantings decreasing significantly. The area under HT soybeans increased from zero to close to 80% within 5 years and soybean plantings have increased significantly. The adoption trends for cotton, maize and soybeans are discussed in detail below.

2.4.1 Adoption of GM cotton in South Africa

In 1989 the US seed company, Delta and Pine Land (D&PL), applied to perform contained field trials with GM insect-resistant cotton in South Africa. This set in motion the South African biosafety process and initiated the first trials with GM crops on the African continent. After approval of D&PL's application for field trials with Bt cotton in 1989/99 the company's involvement in South Africa increased. D&PL used South Africa as a location for winter field trials in the development of new varieties for the US, and in 1995 approval was granted to produce Bt cotton seed in South Africa for sale in the US. In 1997 South Africa became the first country in Africa to approve commercially production of a transgenic crop, i.e. Bt cotton (Gouse, 2009).

Table 2.2 indicates GM cotton adoption according to hectares and percentage of total South African cotton crop. Official figures for more recent seasons are not available, but it is estimated that by 2010/11 GM cotton made up close to 100% of the total cotton area (personal communication Van Der Walt, 2010). The initial uptake of the first Bt cotton varieties was less than spectacular reaching 28% adoption (according to area) after three years since introduction (1999/00) and dropping to 22% in 2000/01. The main reason for this was the fact that the conventional varieties the Bt event was introduced into was not the best performing or most popular varieties at the time. The GM varieties of the US cotton seed company Delta and Pineland (D&PL), NuCotn 35B and 37B had to compete with the more popular conventional varieties of the South African ginning companies. Before D&PL became more involved in the South African cotton seed market, Clark Cotton (the largest ginning company in South Africa at the time) also marketed the D&PL variety DP 90. NuCotn 37B was based on this DP 90 variety which had been popular previously but was losing market share to other better performing varieties. NuCotn 35B was not well suited for most of the cotton areas in South Africa and very little seed was ever sold. Some commercial farmers were also cautious during the first seasons

and wanted to test the new technology and see how ginners and the rest of the industry reacted. However, when the Bt gene was introduced into D&PL's popular OPAL variety (originally from Australia) adoption increased dramatically. NuOPAL (Bt), DeltaOPAL RR and NuOPAL RR (Stacked) that are currently planted in SA are all based on the Delta OPAL germplasm (Gouse, 2009).

Table 2.2: GM cotton adoption in South Africa: Percentage of total crop and area in hectares

Event	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08
Bt Cotton %	22%	38%	70%	58%	60%	39%	22%	6%
Bt Cotton Area	12 470	14 700	15 800	20 700	12 719	7 060	2 500	780
HT Cotton %	0	10%	15%	26%	30%	13%	10%	4%
HT Cotton Area	0	3 868	3 386	9 280	6 360	2 350	113	520
Stacked (Bt/HT) Cotton %	0	0	0	0	0	40%	60%	82%
Stacked Cotton Area	0	0	0	0	0	7 240	6 820	10 660
Total Cotton Area	56 682	38 680	22 570	35 690	21 200	18 100	11 365	13 000

Source: Adapted from Gouse, Kirsten & Van Der Walt (2008)

From Table 2.2 it is clear that Bt cotton has been very popular, reaching 70% of total cotton area in 2003. The share decreased somewhat with the introduction of HT cotton but remained the more popular of the two. With the introduction of Stacked cotton (with both the Bt and HT event), Bt's share dropped considerably as farmers opted for cotton with both traits. In the 2006/07 season 92% of the cotton plantings in South Africa were GM. A large share of the conventional cotton was planted as mandatory refugia that are planted alongside Bt and Stacked fields in order to prevent insect resistance development. In more recent seasons farmers used HT maize as refugia alongside Bt and Stacked gene plantings, explaining the close to 100% GM adoption rate.

As large-scale farmers produce the bulk of the South African cotton crop, it would not be totally correct to suggest that the adoption figures in Table 2.2 apply to smallholders as well. In the eleven production seasons 1996/97 to 2006/07, smallholder cotton farmers contributed 8.3% to the total national cotton crop (cotton fibre) and in the period the contribution varied between 1.2 (2002/03) and 20.9 percent in 2005/06 when a substantial number of commercial farmers substituted cotton with maize due to better comparative price indications at planting time.

Adoption of Bt cotton by smallholders has however been as impressive as that of the large-scale commercial farmers. The Makhathini Flats area in northern KwaZulu-Natal is one of only two areas in South Africa where smallholder cotton farmers have been producing cotton on a relatively sustainable level for the last twenty years or so. In the first Bt cotton commercialisation season of 1997, only 4 farmers planted demonstration Bt plots under guidance of Monsanto (the technology innovator). In 1998, 75 farmers or 3.4% of the cotton farmers on Makhathini planted Bt cotton and in 1999, 411 farmers or 13.7% planted Bt. In 2000, 1184 or 39.5% of cotton farmers on the Makhathini Flats planted Bt cotton. In 2001 it was estimated that close to 3000 of the 3229 farmers on the Flats planted Bt, reaching close to 90% adoption in 5 years (Gouse, 2009).

This remarkable adoption rate was explained partly by the impressive performance of Bt cotton as planted by the first adopting Makhathini farmers. However the other major factor that enabled this remarkable adoption rate was that the sole credit and input supplier and cotton buyer on the Flats, Vunisa, also noticed the performance of Bt cotton and started to recommend the seed to their clients / smallholders. As the main objective of a cotton gin is to gin as much cotton as possible, Vunisa wanted to increase the cotton crop on the Flats but not at the expense of their credit book (which they managed in partnership and on behalf of the Land Bank). After monitoring the performance of Bt cotton for the first couple of seasons, Vunisa decided that they can increase the ginable cotton crop, and decrease the risk of crop failure (due to bollworm damage) and thus their credit risk, by recommending Bt cotton to farmers. It can be argued that even though Vunisa was making inputs available to farmers under credit long before Bt came onto the scene, the availability of credit and the role Vunisa's extension officers had in

recommending Bt seed, played a large role in smallholders' ability and decision to adopt the new technology (Gouse, 2009).

It is clear from the last row in Table 2.2 that South Africa's cotton production has decreased substantially over the last number of years, despite the introduction of new seed technologies. Due to the comparatively low world cotton price (partly due to increased production by China and India) commercial farmers have substituted cotton for maize, soybean and sunflower seed production. See Gouse (2009) for a more comprehensive discussion on the South African Bt cotton experience.

2.4.2 Adoption of GM maize in South Africa

Maize is the most important field crop in South Africa and annually covers around 18 to 25 percent of the total arable land (SAGIS historic data seen at www.sagis.org.za). Maize serves as staple food for the majority of the South African population and also as the main feed grain for livestock. Between 60 and 70 percent of the South African yellow maize production is consumed in the booming chicken production sector (Gouse, et al., 2008). Over the last nine years since 2000, South Africa produced an average of 9,3 million tons of maize on 2.75 million hectares. Of the total maize crop white maize made up 60% and was produced on 63% of the land under maize. Even though maize is grown in most parts of the country the main production areas are situated in the Free State, North West and Mpumalanga Province. Historically the Free State and North West province produce between 65 and 75 percent of the total maize crop. In the period 2004 to 2007 domestic use of white maize averaged 4.65 million tons of which more than 80% went for human consumption. In the same period domestic use of yellow maize averaged 3.82 million tons of which only around 7% went towards human consumption (Gouse, et al., 2008).

The initial spread of Bt maize was quite slow (Table 2.3) reaching only 5% after three years of availability. Seed companies and farmers suggested that three main factors were responsible for the slow spread of Bt maize. First, the Bt hybrids that were on the market were not well-adapted to the local South African consumer markets, or for local agricultural conditions. A second reason for slow adoption was that many farmers did not see a big productivity advantage from the

Table 2.3: GM maize adoption in South Africa: GM percentage of total maize crop and GM area in hectares

Event	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10
Bt Yellow Maize %	5%	14.5%	19.5%	19.7%	22.6%	17.8%	35.5%	38.2%	40.1%	26.1%
Bt Yellow Maize Area	59 000	160 000	176 000	197 000	249 000	107 000	391 000	406 000	376 000	267 000
Bt White Maize %	0	0.4%	2.8%	8%	7.9%	22.8%	43.8%	40.1%	44.3%	60.3%
Bt White Maize Area	0	6 000	60 000	144 000	142 000	221 000	712 000	696 000	660 000	1 038 000
RR Yellow Maize %	0	0	0	0	1.3%	11.3%	12.5%	15.0%	16.9%	15.1%
RR Yellow Maize Area	0	0	0	0	14 000	68 000	137 000	159 000	159 000	154 000
RR White Maize %	0	0	0	0	0.3%	6.0%	8.5%	13.0%	10.7%	5.3%
RR White Maize Area	0	0	0	0	5 000	60 000	139 000	218 000	160 000	91 000
Stacked (Bt/HT) Yellow Maize %	0	0	0	0	0	0	0	2%	11.4%	19.6%
Stacked (Bt/HT) Yellow Maize Area	0	0	0	0	0	0	0	23 000	107 000	201 000
Stacked (Bt/HT) White Maize %	0	0	0	0	0	0	0	3%	15.2%	8.1%
Stacked (Bt/HT) White Maize Area	0	0	0	0	0	0	0	60 000	226 000	139 000

Source: Revised Gouse, Kirsten & Van Der Walt (2008) table with updated figures from Van Der Walt (2010)

Bt gene. Many farmers found that if they manage to plant at the recommended time, they will miss the first moth flight and have limited damage whether they plant Bt varieties or not. In addition, many large farmers felt that the increased yield from Bt maize was not enough to pay for the seed's additional technology fee. Thus, at first Bt was adopted only in those areas where stalk borers were a particularly difficult problem. The third reason for the slow spread of Bt maize was farmers' concerns that they would not be able to sell their crop because of consumer concerns about GM food (Gouse et al., 2005).

More appropriate Bt maize hybrids became available in 2000 and 2001 with seed companies starting to sell Bt yellow maize hybrids that were specifically developed for South Africa's drier windy conditions. In 2001, the first Bt white maize hybrids were released. The second constraint – farmers' perception of low profitability – changed in the 2001/02 season as that season was affected by a particularly severe attack of stalk borers and farmers suffered substantial yield losses. As a result more commercial farmers opted to use Bt maize in the 2002/03 planting season. The final constraint, farmers' concern about demand and consumer acceptance, has to date not proved to be a major problem.

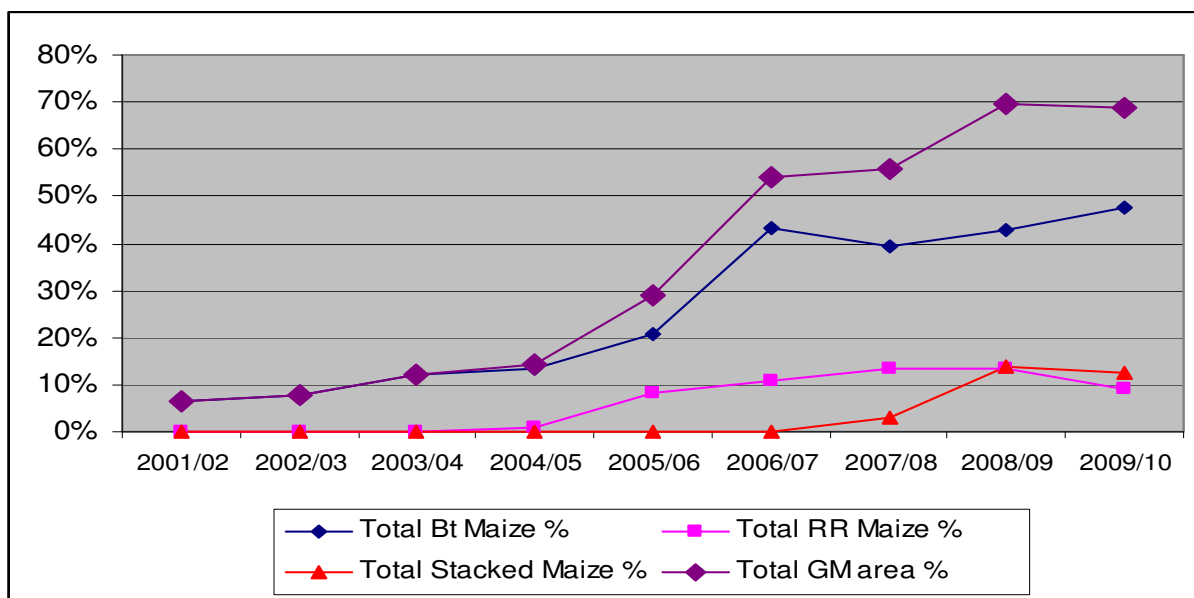


Figure 2.2: Percentage of total South African maize area covered by GM maize

Compared to cotton, the decrease in use of Bt and RR maize since the introduction of Stacked (BR) maize was less pronounced but still substantial. Bt remains the most popular trait partly due to the fact that especially white BR maize adoption has been hindered by inadequate seed availability. In the 2008/09 production season GM maize covered 70% of the total South African maize area with Bt maize as single trait covering 43%. In 2009/10 the Bt maize area increased by a further 269 000 hectares up to 48%, mainly due to a drop in the white BR maize area. This was a result of Monsanto's decision in 2009 to pull the bulk of their best performing BR and RR seed varieties (DKC 78-45 BR and DKC 78-35 RR) from the market following pollination problems caused by seed multiplication irregularities.

Similar to the GM cotton adoption situation discussed above, Table 2.3 and Figure 2.2 in reality describes GM maize adoption by large-scale commercial farmers in South Africa as they produce the bulk of the national maize crop. According to the September 2009 Crop Estimates Committee report subsistence farmers planted an estimated 468 683 hectares of predominately white maize in the 2008/09 season and produced approximately 516 633 tons of maize at an average yield of 1.1 ton / hectare. This is more or less in line with subsistence production in recent years. This means that though subsistence maize covered 16.2% of the national maize area, subsistence farmers produced only 4.2% of national maize output.

To estimate the number of smallholders that adopted GM maize is no simple task. There is no accurate data on or clear separation between subsistence, smallholder and emerging maize farmers and seed companies do not maintain accurate records on each farmer who procure conventional or GM seed. Some seed is sold by distributors, some seed is supplied to municipalities, projects, or agri-development groups and the end user is not identified. Some buyers also share seed with neighbours or members of their farmer association. A guesstimate by Gouse, Kirsten and Van Der Walt (2008), based on seed company information, seed sales and assumptions regarding seed quantity, bag sizes and seeding rates found 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. According to estimations the smallholder GM maize area covered about 33 700 hectares in 2007/08. It is clear that a number of larger smallholder farmers and emerging

farmers were also included as subsistence farmers rarely plant more than a hectare (Gouse et al., 2008). Whether emerging farmers should be included as smallholders based on their “previously disadvantaged” background and whether every rural household with two or three rows of maize in the garden for green maize (fresh) consumption should be considered to be subsistence farmers are points of contention. For many smallholder farmers the success of the season (in most cases rainfall) determines whether they are small-scale surplus producers or subsistence farmers. However, considering that there are an estimated 240 000 small-scale farmers in South Africa and close to 2 million subsistence farmers, it is clear that GM maize adoption by smallholders is still minimal. Whether the current GM technologies available and the hybrid maize varieties they have been introduced into are applicable to the “garden scale producers” are also debatable.

2.4.3 Adoption of GM soybeans in South Africa

Herbicide tolerant soybean adoption by commercial farmers in South Africa has been impressive, increasing from 5 to almost 80 percent within five years. There are no official HT soybean adoption figures but according to James (2009) HT soybeans covered 85% of the total SA soybean area in 2009. The figures presented in Table 2.4 are based on own estimations and personal communication with Van Der Walt (2009).

Table 2.4: Herbicide tolerant soybean adoption in South Africa: Percentage of total crop and area in hectares

Event	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09
HT Soy-beans %	5%	10.9%	35%	60%	59%	79%	82%	85%
Area	6 000	15 000	35 000	91 200	135 000	214 000	135 630	202 300

There are currently no peer reviewed studies on the farm-level impacts of HT soybeans in SA, but based on the remarkable adoption rate, farmers seem to benefit from adoption of the HT technology. A number of international studies have found that HT adopting soybean farmers benefit through saving on weed control activities and expenditures (herbicide, labour, machinery and fuel) but that “ease of crop management” is also indicated as a major benefit (Carpenter &

Gianessi, 1999, 2000, 2001, Fernandez-Cornejo, Klotz-Ingram & Jans, 2002, Marra, Piggott & Carlson, 2004, Qaim & Traxler, 2005).

2.5 ECONOMIC AND SOCIO-ECONOMIC IMPACTS OF GM CROPS

A substantial number of studies and a resulting increasing body of literature assess and discuss the socio-economic impacts of genetically modified crops in developed and developing countries. Though it is difficult to separate the economic issues from the social issues, especially in developing country settings, the bulk of field research conducted in the first ten years since introduction of the first GM crop, have focussed on whether it pays for farmers to purchase GM seed in various farming contexts and to document farmers' use of the technology (Smale et al., 2009). The majority of studies and publications have thus studied the impact of adoption on farmers (economic farm-level impacts) or producers but a number of studies have also assessed the impacts on consumers, the crop industry or sector supplying inputs and buying outputs and regional and international trade.

As this thesis presents a study on the experience of South African smallholder farmers with GM maize, the literature review on the social and economic impacts of transgenic crop adoption will be limited to producer or farm-level impacts of insect resistant and herbicide tolerant maize as produced in other countries and by commercial farmers in South Africa. As the number of publications on HT maize is limited, HT crops are discussed as a group. The different methodologies for assessing the impacts of GM crops are briefly touched on but specific and applicable analytical methodologies will be discussed in detail in Chapters 4 and 5. The next section sheds light on the aggregated pecuniary impact of international GM crop adoption and production.

2.5.1 International and national aggregated impact of GM crops

Solely based on the adoption rates and levels mentioned in section 2.3, in the presence of comparative conventional technologies, it is possible to deduce that adoption of transgenic crops

have been beneficial to the adopters in some way. In a follow-up of their 2005, 2006, 2008 and 2009 publications, Brookes & Barfoot (2010) estimated the cumulative impact of GM crop introduction in adopting countries based on the thirteen years since first release. They base their estimations on journal papers, reports and other study findings as well as industry information. Their estimations for South African GM cotton and maize are to a large degree based on the journal papers co-published by the author of this thesis, indicated in Chapter 1. Brookes & Barfoot (2010) report:

- In 2008 HT soybeans made up 44% of the total international area covered by GM crops, covering more than 62 million hectares in ten countries. In 2008 HT soybeans covered 92% of the total US soybean area and the cumulative farm income benefit, mainly due to saving on herbicide, machinery and labour, is estimated at \$11 billion for the period 1996 to 2008. Globally the farm level savings add up to \$17.9 billion in nominal terms for the thirteen years. The farm income gain due to adoption of HT soybeans in South Africa for the period 2001 to 2008 is estimated at \$4.13 million.
- Globally the farm level economic benefit of using HT maize was \$433.5 million in 2008 (of which 82% was in the US). Cumulatively since 1997, the farm income benefit has been \$1.9 billion in nominal terms and 92% of this benefit was due to cost savings and 8% due to yield gains caused by improved weed control practises. The net cumulative income gain up to 2008 for South Africa is estimated at \$3.77 million.
- Similar to HT soybeans and maize, HT cotton's major benefit was a saving in production costs with an increase in yield due to better weed control only contributing 4% of the \$855.8 million increase in farm income during the period 1997 to 2008.
- Adoption of Bt maize between 1996 and 2008 increased farm level income by \$6.34 billion in adopting countries. This income gain is the result of mainly improved yields due to more effective pest management though farmers in some countries also experiences net cost saving through a decrease in expenditure on insecticides. It is estimated that the aggregate farm

income of Bt maize adopters in South Africa increased by \$476 million between 2000 and 2008.

- The farm income increase for Bt cotton in adopting countries up to 2008 is estimated at \$15.6 billion. Around 65% of this income gain is derived from a yield increase due to more effective insect control and the balance from reduced expenditure on insecticides. In South Africa the yield increase was substantial but saving on insecticides in most seasons not enough to offset the increased expenditure on the improved seed. In the eleven years since 1998 the cumulative farm income gain is estimated at \$21 million.

From the above aggregated figures it is clear that farm level income effects of the selected GM crops have been positive and substantial in adopting countries. The next section discusses some country studies in more detail in order to highlight the different farm level impacts of specifically insect resistant and herbicide tolerant maize.

2.5.2 Farm level effects of insect resistant and herbicide tolerant maize

Compared to the number of peer reviewed papers on GM cotton and specifically Bt cotton, the number of publications on maize is minimal. In a 2009 literature review of accredited and peer reviewed publications on GM crops in developing countries, Smale et al. (2009) listed 63 publications on Bt cotton of which 46 focussed on farm level impacts. Only 14 peer reviewed papers were published on Bt maize and only 5 focussed on farm level impacts. There were no publications on HT maize in developing countries during the same period. The next two sections supply a literature review to shed light on the actual and possible farm level effects / impacts of Bt and HT maize.

2.5.2.1 *Farm level effects of insect resistant maize (Bt)*

Research on Bt cotton and maize has shown that due to the nature, focus and efficacy of the Bt event, farm level income is directly impacted in mainly three ways:

- Increase in yield due to more effective pest management

- Decrease in expenditure on inputs through savings on insecticide chemicals and application costs.
- Increase in input cost through a higher seed price and an additional technology fee.

Studies show that the use of insect resistant crops reduces the number of sprays and thus pesticide volumes needed to control problem insects. If the reduced spraying need outweighs the additional cost of seed, then production cost decreases and farmers gain. Substantial evidence has accumulated that farmers in many different locations and conditions can benefit from planting Bt maize in years with a significant stalk borer infestation level. Table 2.5 summarises some studies and their findings. Most of the authors admonish that findings vary between season, regions and even farmers within regions.

Table 2.5: Bt maize studies and their main findings

Country	Yield	Insecticide use	Production cost	Farm income	Publications
US	Increase 3-9%	Decrease 15-16 \$/ha	Small increase 1-9 \$/ha	Increase	Carpenter & Gianessi (2002) Marra, Pardey & Alston (2002) James (2003) Sankala & Blumenthal (2003 & 2006)
Argentina	Increase 5-9%	No effect	Increase 20-22 \$/ha	Increase	James (2003) Trigo (2002) Trigo & Cap (2006)
Philippines	Increase 14-34%	Small decrease	Increase	Increase	Gonsalves (2005) Yorobe (2004) Ramon (2005)
South Africa	Increase 5-32%	Decrease	Small effect	Increase	Gouse, Pray, Kirsten, & Schimmelpfennig (2005) Gouse, Pray, Schimmelpfennig & Kirsten (2006) Gouse, Piesse & Thirtle (2006)
Spain	Increase 3-15%	Decrease	Decrease 37-61\$/ha	Increase	Brookes (2003) Gomez, Barbero & Rodriguez-Corejo (2006)
Other EU countries (mainly field trials)	Increase	Decrease	Variation between countries	Increase	Brookes (2008)
Uruguay	Increase 5-9%	Similar to Argentina	Similar to Argentina	Similar to Argentina	Brookes (2010)
Brazil	Increase 3-6%	Decrease	Decrease	Increase	Galveo (2009)
Honduras (field trials)	Increase 10-30%	No effect	Probable increase	Increase	James (2003) Falck-Zepeda et al. (2009)

Source: Compiled by author based on Brookes and Barfoot (2010)

Marra, Pardey & Alston (2002) found that there were major benefits to planting Bt maize in the United States through increased yields even when borer infestation levels were not great enough to control with insecticides. Marra, Carlson & Hubbell (1998) reported that the use of Bt maize boosted yields by 4-8 percent depending on location and year. Marra et al. (2002) indicated a range of yield increases in different US states from 444 kg/ha in Iowa to 1,138 kg/ha in Minnesota. Results from outside the United States show a similar pattern. In the Huesca region in Spain, Brookes (2002) reported a yield increase of 10% over conventional maize protected with pesticides and an increase of 15% when insecticides were not used. Other regions in Spain enjoyed an average Bt maize yield advantage of 6.3% within a range of 2.9–12.9 percent. Gonzales (2002) recorded a yield advantage of 41% for Bt maize on field trails in the Philippines, while Philippine farmers indicated an even higher 60% yield improvement. Another recent Philippines study by Mutuc, Rejesus & Yerope (2011) reports yield increases of 33% in 2003 and 45% in 2007, based on farmer surveys.

Bt yellow maize has been produced in South Africa since the 1998/99 season, and large-scale commercial farmers appear to have benefited from its adoption. Despite paying more for seeds, adopters enjoyed increased income over conventional varieties through savings on pesticides and increased yield due to better pest control. Irrigated and dryland commercial farms surveyed in Mpumalanga, Northern Cape, and the North West province enjoyed statistically significant yield increases of 11 and 10.6 percent respectively (at a 95% confidence level) on average during the 1999/2000 and 2000/01 seasons (Gouse, et al., 2005).

In most countries (not including Spain and Brazil) the additional cost of the technology (technology fee levied on the seed) has exceeded the saving on insecticides and thus has resulted in an increase in production cost. In some countries (Argentina, Philippines, Honduras) farmers do not apply insecticides on conventional maize and therefore there is no saving on insecticide expenditure. In all the countries and for most seasons however, adoption of Bt maize resulted in an increase in farm level income.

2.5.2.2 *Farm level effects of herbicide tolerant maize (HT)*

The vast majority of studies on the farm level impacts of GM crops have focussed on Bt cotton and studies on HT crops have focussed predominantly on the fastest adopted HT crop – RR soybeans. Even in the US where HT maize has been planted since 1996, studies on HT maize are limited. Studies seem to focus more on the HT technology with HT soybeans as main study crop and HT maize, cotton and canola did not receive much attention. There are a number of possible reasons why HT maize has not enjoyed much research focus; some of these are:

- HT maize was initially not well adopted in the US due to the fact that the event was originally not available in the most popular hybrids and because HT maize was not approved for import into Europe – storage and marketing complications (Gianessi, 2005).
- Adoption of HT soybeans in especially Latin America has been nothing less than remarkable – drawing substantial research focus and funds.
- Adoption of HT maize was in 2008 still limited to the US, Canada, Argentina, South Africa and the Philippines.
- Contrary to the complicated link between insect pressure, insect control and the performance and profitability of IR crops, weed pressure are more constant over seasons and over crops and the impact levels are thus relatively similar over different crops.

Based on the findings of a number of HT technology studies it is clear that farmers, who adopt HT crops benefit due to lower expenditure on herbicides, labour, machinery and fuel (Carpenter & Gianessi, 1999; 2000; 2001; Fernandez-Cornejo, Klotz-Ingram & Jans, 2002; Marra, Piggott & Carlson, 2004; Qaim & Traxler, 2005). In most cases HT crops did not show a significant yield difference compared to conventional varieties but in a couple of cases where weed control was ineffective with selective herbicides or where weeds were only mechanically controlled a yield advantage was reported - HT soybeans in Romania and HT maize in Argentina (Qaim, 2009). Though most studies found that HT crops did provide substantial benefits through saving on weed control activities, a number of these studies have also shown that in some cases, due to the increased HT seed price (compared to conventional) the impact on gross margin has been marginal or even negative. Efforts to understand why farmers continue to adopt HT technology, even without clear direct profit advantages found that weed control with HT technology is easier

and there is a substantial saving in management time. Fernandez-Cornejo, Hendricks & Mishra (2005) found that while adoption of HT soybeans was not associated with higher farm income in the US, it was associated with higher off-farm income and overall household farm income as HT crops free up labour and management for off-farm employment, leisure or the expansion of the farm. Gardner, Nehring & Nelson (2009) also found savings in management labour and Hurley, Mitchell & Frisvold (2009) concludes that these non-pecuniary benefits were the main reason for the remarkable adoption rate in especially the US. In South America the positive average gross margin effects of HT crops are higher than in North America and this along with the non-pecuniary benefits explain the extraordinary adoption rate of especially HT soybeans (Qaim, 2009). In Argentina, increased profitability and ease of management with HT soybeans has resulted in a substantial expansion in the soybean area planted (Trigo, 2011).

2.5.3 Impact assessment methodologies

In 2009, IFPRI researchers published a report reviewing the peer reviewed literature on the ex post socio-economic impacts of genetically modified crops in developing countries (Smale et al., 2009). In a review of 67 journal papers and peer reviewed reports on farm level impacts of GM crops in developing countries, published between 1996 and 2007, the report found that researchers used mainly two approaches to assess impacts. The first is farm accounting or partial budgets. By compiling comparative partial budgets for the GM crop and the counterfactual (for surveyed adopters and non-adopters) it is possible to consider changes in costs and benefits. Changes in yields, amounts and costs of inputs (for the GM technologies mainly insecticides, herbicides and labour) as well as partial productivity measures can be compared. Even though this partial budget approach is useful to identify impacts and to get some kind of measure of the magnitude of the different impacts, the indications are complicated by inconsistency in other causative variables. The second approach to farm level impact assessment utilises these variables and variation to estimate a statistical model that is grounded on a theoretical economic framework such as a production or a cost function.

This thesis also makes use of the two approaches. The partial approaches will be utilised in Chapter 4 of this thesis while more inclusive econometric production functions and frontiers will

be employed in Chapter 5. Both approaches and the advantages and disadvantages thereof will be discussed in each specific chapter.

2.6 SUMMARY

This Chapter supplied background information on agricultural biotechnology, genetically modified crops and international and national adoption of these transgenic crops. Farm-level impact results show that farmers who have adopted these new GM seeds have benefitted and the aggregated financial impacts on farm income have been positive and quite substantial. The farm-level impacts of insect resistant (Bt) and herbicide tolerant (HT) maize were discussed in detail by considering impacts in other countries, South African commercial farmers' experience and based on the experience with similar traits in other crops.

The Chapter concluded with a brief look at the research methodologies used in farm-level impact assessment. Chapters 4 and 5 will discuss these methodologies in more detail but first Chapter 3 will discuss the study areas, the data collection methodology, tools and challenges, farmers and production systems and efforts taken to insure that the data collected and ultimately used in the analyses are consistent and a reliable reflection of farm-level reality.

CHAPTER 3

EIGHT YEARS OF SURVEYS AMONGST SMALLHOLDER ADOPTERS OF GM MAIZE IN SOUTH AFRICA: CONTEXT, METHODS AND DATA

3.1 INTRODUCTION

The main objective of this Chapter is to set the scene for Chapters 4 and 5. This is important so that the analyses and findings that will follow can be seen and interpreted in context. First the South African smallholder maize farmer milieu is sketched on the hand of the agricultural and political history of South Africa. Then the evolution of the research project, the research approach, data, challenges and assumptions and issues of sample selection and the counterfactual are presented. The Chapter then concludes with a discussion of the household demographics of the survey samples, the role of maize in the livelihood of South African small-scale farmers, a discussion on the first GM maize adopters and the problem of self-selection bias.

3.2 SMALLHOLDER SUBSISTENCE FARMERS IN SOUTH AFRICA

More than three decades before the Cape, Natal, Transvaal and Orange Free State Colonies were merged into the Union of South Africa (1910), a dominion of the British Empire, the authorities of the time had established “reserves” or “locations” with the intention to separate white and black South Africans (Giliomee, 2003). Through the history of South Africa these segregations took various forms and were driven by different governments and motivated by various ideologies and objectives. After the National Party came to power in 1948 there was a renewed push for the forming of Bantustans or Homelands. As a result ten separate Bantustans were established in South Africa with the objective of concentrating the members of designated ethnic groups (Xhosa, Zulu, Pedi, Ndebele, Venda, Shangaan, Tsonga, Tswana and Sotho), thus forming ethnically homogeneous territories and creating independent states for South Africa's different black ethnic groups. In 1951 the Homelands made up 13% of South Africa's land but were intended to house 80% of the population (Giliomee & Mbenga, 2007). Between 1963 and 1971

Transkei, Ciskei, Venda and Bophuthatswana received independence while KwaZulu, Lebowa and QwaQwa received only partial autonomy.

While Transkei had the advantage of geographically consisting out of one piece of land, resources and infrastructure were limited. Bophuthatswana contained rich platinum deposits but was made up out of 19 separate areas and in the late 1950s less than a third of the Tswana people lived there. KwaZulu in the east consisted out of 29 larger and 41 smaller enclaves with no mineral resources and a relatively mountainous landscape. Approximately 50% of the Zulu people lived in KwaZulu in the 1960s (Giliomee & Mbenga, 2007). Even though designated areas received independence and ventured into mining and manufacturing, all the areas remained dependant on the rest of South Africa and the major income source were remittances. Despite the importance of the Homelands concept to the Apartheid regime, investment driven development in these areas were minimal, with less than 45 000 job opportunities created between 1956 and 1966. In 1966 the total production of the Homelands was only 1.9% that of the Republic (Giliomee & Mbenga, 2007). Between 1990 and 1991 the Homeland areas accounted for 45% of the population but received less than 25% of the national health budget. Between 1985 and 1993, budgetary allocations to commercial agriculture were double that earmarked for allocation to the homeland areas (DBSA, 1993).

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, communication links, agricultural training centres, dams and irrigation facilities, input distribution outlets, and research, extension and financial services. Despite various efforts by the post-apartheid government to support development of the former homeland areas, these limiting conditions still prevail in especially the former Transkei and Ciskei in the Eastern Cape and former designated tribal areas like Zululand in northern KwaZulu-Natal. According to analysis of data from the National Income Dynamics Study (NIDS) by May and Carter (2009) 42% of subsistence producers in South Africa are currently situated in KwaZulu-Natal, 19% in the Limpopo Province and 15% in the Eastern Cape. According to the General Household Survey (2006), 1.3 million households in the non-metro areas of South Africa has access to land for farming purposed, of which 82.8% has access to a hectare or less. Vink & Van Rooyen (2009)

found that South African small-scale farmer production and productivity are limited by agronomic factors like disease and adverse climatic conditions coupled with a lack of adequate information on how to manage these events, institutional factors such as insecure land tenure arrangements and limited access to production credit to purchase inputs, as well as failing agricultural support services such as applicable research and the provision of extension services. As this less than ideal agricultural production enabling environment is quite comparable to that faced by smallholder maize producers in the rest of Africa, KwaZulu-Natal smallholder farmers' experience with GM crops is of interest as it might be possible to extrapolate findings to especially other Southern African countries. To what extent it is possible to directly compare South African smallholder maize farmers with smallholders in the rest of Africa will become clearer through this Chapter and the rest of the dissertation as household demographics and production practises are discussed.

3.3 INTRODUCTION OF GM MAIZE TO SMALLHOLDER FARMERS

As was indicated in Chapters 1 and 2, Bt maize was approved for commercial production for the 1998/1999 season. Maize as a genus was approved meaning that both yellow and white maize with the Bt event received approval for general release for production. Bt yellow maize was planted in 1998/1999 but the Bt gene first had to be crossed into the better performing South African white maize varieties with the effect that substantial Bt white maize plantings only realised in 2001/02. As yellow maize is mainly used for animal feed in South Africa (SA) and yellow maize production by smallholder farmers are minimal, the SA smallholder GM subsistence crop experience only started in 2001/2002.

In order to introduce the new technology to small-scale farmers the multinational agro-input producer and owner of the Bt events most widely used in South Africa, Monsanto, identified and selected nine areas across the Mpumalanga, KwaZulu-Natal (KZN), Eastern Cape and Limpopo Provinces in South Africa where subsistence farmers or rural households produce maize under dry-land conditions. With the assistance of extension officers of the different provincial Departments of Agriculture offices, Monsanto invited about 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 CRN 4549 seed, also known as Yieldgard, insect-resistant or Bt maize seed, while the other bag contained 250 grams of the conventional near-isoline, CRN 3549, which is genetically nearly identical to CRN 4549 with the main difference that it does not contain the Bt gene. As most farmers plant around half a 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. Farmers were asked to plant and harvest these free samples separately but in all other practices to treat them the same way as they would treat their other maize.

Herbicide tolerant maize was approved for commercial release for the 2003/04 season and a couple of demonstration plots were planted in areas where farmers have adopted Bt maize. 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 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.

The research this dissertation is based on commenced following the Monsanto workshops in 2001 and continued until 2010. Data collection from the farmers who attended Monsanto's initial workshops and approaches and surveys to collect data from farmers who adopted Bt maize and HT maize in the subsequent seasons, are discussed next.

3.4 SURVEY SITE SELECTION

Following Monsanto's 2001 workshops, surveys were conducted in six selected sites. Sites were selected based on the number of farmers that attended workshops and in order to be representative of the Provinces. Potential enumerators from the specific areas were identified with assistance from provincial Department of Agriculture extension officers and trained to collect the necessary data from small-scale farmers.

For 2001/02 a total of 368 farmers were surveyed in six areas (Table 3.1). The farmer sample size in each site was calculated so as to be significant and representative of the population that received free maize seed samples from Monsanto.

Table 3.1: Province, area and number of farmers surveyed.

Province	Area	Number of farmers surveyed
Mpumalanga	Northern Highveld (Moutse)	60
	Southern Highveld (Mlondozi & Nhlazatshe)	90
KwaZulu-Natal	Hlabisa	58
Limpopo	Venda	60
Eastern Cape	Mqanduli	40
	Flagstaff	60

Monsanto did not supply any free seed in following seasons and 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 small number of small-scale farmers were able to buy Bt seed due to a limited seed supply caused by seed multiplications problems on the side of Monsanto and an increased demand for Bt seed by large-scale farmers. The 2002/03 season did see an impressive demand for Bt seed from various sites (smallholders in the Eastern Cape for instance ordered 4,5 tons of Bt seed), but in only two sites in KZN, Hlabisa and Simdlangentsha, were a significant number of subsistence farmers able to purchase Bt maize seed. As Hlabisa was part of the first season's study it was possible to build on the enumerator research capacity created in the first season but Simdlangentsha was not part of the first seasons' research so new enumerators had to be trained.

With adoption of Bt maize by smallholder farmers in other areas of KZN, Mpumalanga and the Eastern Cape remaining limited in 2003/04, Hlabisa and Simdlangentsha became the main study areas. Data was collected from Hlabisa farmers for eight seasons 2001/02 to 2007/8 and again 2009/10. Limited data was collected in Simdlangentsha for the 2002/03 and 2003/04 seasons when relatively few farmers planted Bt maize but a larger sample was surveyed for the 2006/07, 2007/08 and 2009/2010 seasons. This thesis reports on the eight season GM maize experience of the smallholder farmers in Hlabisa.

It is important to stress that this study do not focus on Hlabisa because the smallholder farmers in this areas are particularly innovative or poor, because stem borer pressure is extraordinarily high or because this site was selected as focus area before the study commenced. The Hlabisa area was chosen as study site, by default, as it is one of few, if not the only area 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 producers in South Africa and the Hlabisa farmers' experience with GM maize should rather be viewed as a case study. Hlabisa farmers' production practices, limitations and motivations are however comparable to smallholders in the rest of KZN and South Africa and the findings thus applicable.

3.5 SAMPLE SELECTION

In 2001/02 a list with the names of farmers who attended the workshops was obtained from Monsanto and a representative number of the farmers were found and surveyed with the help of extension officers and enumerators from the areas. In 2002/03 farmers in Hlabisa who planted Bt maize seed were identified through the seed sales records held by Monsanto and the farmers cooperatives who sold the seed or through farmer associations. Bt adopters were few and close to the total population if Bt seed adopters were surveyed. The study thus employed a purposive sampling approach in selecting the adopters (Bryman, 2004). 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 2003/04 Bt planting farmers were again identified from seed sales lists held by the farmer cooperative in Hlabisa. As new research focus fell on the labour use impact of Bt maize, a larger number of farmers were randomly selected from farmer association lists to make up the conventional maize planting group.

In 2004/05 the sampling objective was to continue with the farmers of the 2003/04 stratified sample in order to develop a panel data set for a number of seasons. 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, due to severely dry conditions during the October, November, December period (planting time and early season in KZN) a number of farmers in the sample did not produce maize or reverted back to relatively inexpensive and drought tolerant conventional hybrids or planted traditional (saved) maize seed. In 2005/06 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 were added from the seed sales lists. Table 3.2 indicates the number of farmers surveyed in Hlabisa for the eight seasons with respect to the different seed types used. No surveys were done in 2008/09 due to a “between projects” situation leading to no financial research support to continue the research.

Table 3.2: Number of surveys in Hlabisa and maize plots used in analysis

Season	Number of farmer surveys	Number of useable plots	Bt plots	HT plots	BR plots	Conventional plots
2001/02	59	58	58	0	0	58
2002/03	67	78	31	0	0	47
2003/04	135	188	64	2	0	122
2004/05	78	68	17	3	0	48
2005/06	121	125	39	22	0	64
2006/07	87	95	21	35	0	39
2007/08	102	97	12	38	19	28
2009/10	96	95	0	65	14	16

The 2007/08 and 2009/10 data sets built on the 2005/06 farmers and additional farmers added in 2006/07 resulting in a strong panel data set. With increased interest in the HT maize seed and the introduction of the BR (stacked) seed in 2005/06 it became more difficult to find a significant number of Bt planting farmers in the Hlabisa area and very close to the total Bt population was surveyed in 2006/07 and 2007/08 while no farmers in the sample planted Bt maize in 2009/10. The reasons for this will become clear in the following Chapters. Of the total number of farmers surveyed, 67.5% of the surveys were conducted with farmers that were part of the survey sample for four or more years. Almost 20% of the total number of farmers was surveyed for seven seasons or more.

3.6 SURVEYS

Enumerators were identified with the help of government extension officers. Enumerators had to be able to speak and write English and isiZulu and have a basic understanding of maize production. It was also important to select enumerators living in the area where they had to collect data. This made identification and tracking of farmers easier and generally ensured a relationship of trust.

As the study progressed and developed, farmers adopted new GM traits and more interesting research questions appeared, the questionnaires used in the farmer surveys became more comprehensive. The 2007/08 questionnaires are attached as Annex A. The 2001/02 survey, focussing mainly on whether the technology works (insecticide use and yield impact), consisted out of one twelve page questionnaire and relied on farmer recall regarding especially production practises and input use. In contrast the 2006/07, 2007/08 and 2009/10 surveys used four questionnaires (29 pages in total in 2009/10) and farmers were visited at least seven times through the season to collect data on input use and production activities (labour) and expenditures as it took place. Analysis of data collected in the first couple of seasons showed that farmer recall data has low accuracy and quite often is more indicative of the enumerator's knowledge than the farmers' indications (Gouse et al., 2006b).

Table 3.3: Farmer visits and survey schedule

Month	Maize production activities focussed on	Questionnaire	Visits
October	Start-up meeting, identify farmers, train enumerators		1
November	Land preparation and planting - record all inputs used (land preparation and planting service hired or labour, seed, fertiliser, herbicide)	Q 1	1
December	Weeding, top dressing, insect control	Q1	1
January	Weeding, insect control	Q2	1
February	Weeding, green maize harvesting	Q2	1
March	Green maize harvesting	Q3	1
April	Quiet period while maize dries in field		
May	Harvest	Q4	1
June	Harvest	Q4	1

Table 3.3 above indicates a generalised schedule of visits to farmers as was followed for the final three seasons. It was often necessary for enumerators to visit farmers more than once with the same questionnaire after contradicting information or missing answers were identified by the researcher. The timing of the visits as indicated in Table 3.3 depended on pre-season rainfall as farmers only start planting following the first substantial summer rain. During the study period and depending on the season, planting started as early as late September or as late as the end of December.

The initial visits to each household in November/December entailed the collection of a significant amount of household information, in addition to the labour data and input use for the land preparation and planting activities. During the January/February visits, information was collected on pest incidence and on quantities of green maize (fresh mealies) harvested, in addition to the on-going collection of data on labour and input use. Previous seasons' surveys showed that the March/April period is rather quiet, with few maize production activities. The major labour-using periods are during land preparation and planting and the first six to eight weeks after planting for weeding and pesticide application. In May and June, data was collected on the quantities of maize harvested and the associated labour used.

3.7 DATA

Though analysis in Chapters 4 and 5 focuses on only Hlabisa farmer data, some of the sections below also present household demographic data for Simdlangentsha farmers to serve as comparison to Hlabisa farmers' demographic indications. Chapter 4 analyses eight seasons of production data, 2001/02 to 2007/08 and 2009/10, to shed light on Hlabisa farmers' experience with GM maize. More comprehensive and disaggregated data was collected in the final four seasons (2005/06, 2006/07, 2007/08 and 2009/10) and this data will be used in Chapter 5 to estimate production functions and stochastic production frontiers to assess and compare the performance of the different maize seed technologies.

The different seasons' data was captured in Excel spread sheets and underwent thorough cleaning and standardising conversions to remove survey as well as capturing errors and to ensure that the

data is interpretable and comparable between farmers and seasons. Output (yield), land size and labour indications required special attention and consideration and are discussed next.

3.7.1 Output

Output measurement presented various problems. Fresh maize cobs (green maize) 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 miller or cooperative, with the effect that there is no “official” output measurement that a farmer can report. In the first season of research (2001/2002) 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 litres) 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 (Table 3.4). By taking measurements of the storage containers (room, maize cage, “*inqolobane*”) 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 & Verwey (1976) and Mohr (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 estimated 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 need to keep careful count of the number of bags harvested and farmers were visited immediately after harvest time to collect output data. Even though there are scientifically more precise methods of estimating output, most of these are associated with higher research costs and tend to be invasive on 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 were added to the total harvest.

Table 3.4: Maize weight assumptions based on measurements

A 0.025 m ³ bucket filled with dried maize cobs weighs approximately 10 kg on average
A 0.025 m ³ bucket filled with grain weighs approximately 18 kg on average
A 50 kg maize meal bag filled with dried maize cobs weighs approximately 35 kg
A 80 kg maize meal bag filled with dried cobs weighs approximately 52.5 kg
A 50 kg maize meal bag filled with grain weighs approximately 54 kg
A 80 kg maize meal bag filled with grain weighs approximately 81 kg

When considering Table 3.4 above it is important to think of the 50 kg and 80 kg maize meal bags as bag sizes and not as weights. These bags contained 50 kg or 80 kg of maize flour when the farmer purchased it at a shop, but now the bags are used for harvesting and can contain a different weight of cobs (ears) or grain. A different conversion is used for 50 kg and 80 kg bags as farmers do not fill 80 kg bags to the top as it becomes too heavy to carry. According to farmers and swap millers an 80 kg maize meal bag of grain delivered to a swap miller can weigh up to 95 kg and a 50 kg bag up to 60 kg.

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” and measured and sold it to his neighbours 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 mechanised and precision planters while smallholder farmers tend to prefer larger seeds that can easily be planted by hand. Smaller seeds mean more seeds per kilogram and this meant that farmers who bought from the leader farmer actually planted more seed than what their seed weight indication suggests. Based on industry indications that 80 000 commercial farmer seeds weigh between 22.5 and 25 kilograms and that there are approximately 2 700 larger smallholder seeds in a kilogram, outputs for these farmers were adjusted downwards by 20%.

3.7.2 Land size

It became apparent in 2002/03 and 2003/04 that maize plot size (area) indications as supplied by farmers were quite far off 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 mechanised land preparation contractors contribute to this misconception by charging farmers for a hectare or half a hectare and 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 and 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 and 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 hundred percent 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, fertiliser and labour use indications per unit of land still showed unexplained variability with the land size indication the distorting factor. There for it was decided to use a seed quantity linked land size indication to "smooth" the measured plot size indications. Extension officers in KZN recommend that 18 to 20 kilograms of seed be planted per hectare (communication with Hlabisa extension officer P. Thabete, 2001 to 2010). As it was clear that the vast majority of farmers surveyed planted less than a hectare and input use on a smaller plot tend to be higher, the higher seeding rate of 20 kg per hectare was

used. Though spacing of seed planting stations between and in rows vary quite dramatically between farmers but also within a single maize plot (due to manual planting), a farmer applying 10 kg of seed was assumed to plant half a hectare of maize. This assumption was applied to the maize plot estimations and a new maize plot estimation variable was calculated by taking the average of the farmers' indication of the maize plot size, the enumerators' measurement and twice the seed quantity related plot size.

3.7.3 Labour

Detailed labour data was collected for especially the final three seasons. Hourly data for children, females and males were collected for all the maize production activities. Hourly hired labour and working group labour data were also collected but are presented as an expenditure in monetary terms as separating a tractor driver's labour from his tractor or a hired oxen team from their owner's hourly input becomes problematic.

In order to be able to compare labour use between farmers and seed types, family labour data was aggregated into seven hour man-days with males and females contributing at the same level but children (younger than 16) at a 50% equivalent (C. Poulton, personal communication, 2007 and P. Thabete, 2001 to 2010). Enumerators were sent back to farmers to correct or confirm outliers and care was taken to remove double counting and obvious capturing errors.

Though it is possible to compare labour use between farmers using different seed types, labour use comparisons between different seasons present a problem as slightly more detailed labour was collected for the later seasons; for example supervisory labour for hired services was only added for 2006/07 and 2007/08. It is possible to correct this, but it is not an objective of this study to compare labour use between seasons.

3.8 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 isoline (CRN 3549) 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 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. In 2002/03 only a small number of farmers reported on both their Bt and conventional hybrid plantings and for the second season the data set thus compares the yield of Bt maize seed produced by a group of small-scale farmers with that of conventional seed mostly produced by a different group of farmers in the same area. The isoline variety was still not available from the closest sales points and the conventional seed group for this season contained only three isoline planters. The bulk of the conventional group was made up of farmers planning 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. The Bt seed sold to farmers in two, five or ten kilogram packaging contained an additional small bag of seed for the required refugia area. In the first three to four seasons this refugia seed was CG 4141 and in later seasons a conventional isoline, CRN 3505. Conventional refugia maize in Bt fields was harvest as Bt maize.

There are a number of reasons why PAN 6043 has been the most popular hybrid in some regions in KZN and are also widely sold in Swaziland. Pannar describes PAN 6043 as “An extremely popular white hybrid variety with excellent yield potential”. 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 & 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 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 also to a degree served as counterfactuals to one another as they are based on the same germplasm. This is an advantage as 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 the agro-input dealer in Pongola, apparently mainly due to outstanding payments. 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 as is clear from Table 3.3 when the number of usable plots are more than farmers surveyed. 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 stress that it was not the objective of this study 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, fertiliser 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 farmers base their decisions on.

3.9 THE SURVEY AREA

The Hlabisa Local Municipality is one of five municipalities within the Umkhanyakude District in northern KZN. The Umkhanyakude District is one of nine municipal districts forming the KwaZulu-Natal Province (Hlabisa Municipality, 2008). The Hlabisa municipality area has a rugged topography and stretches from the Umfolozi River in the south to the Lebombo Mountains in the north. The average rainfall is 760 mm per annum but varies quite significantly within the area due to steep slopes, high and low altitudes (600 meters above sea level in the mountains and down to 50 meters to the coast) as well as the effect of the warm Indian Ocean in the east (Masuku, 2005). Due to climatic and soil quality variation in the area, farmers within a relative close proximity to the town of Hlabisa and with relative homogenous production conditions were selected for the surveys. The majority of Hlabisa farmers in the sample are situated in Mgovuso, Madondo, Nhlanhleni and Siwohlo districts situated around the town of Hlabisa.

Hlabisa has seen significant development in the last ten years. In 2001 the only tar road was the couple of hundred meters of main road through the town but the roads between Hlabisa and Mtubatuba to the south and Nongoma to the north has since been reconstructed and tarred. Basic general stores have been joined by a new supermarket, a couple of building supply stores as well as a franchised takeaway and commercial bank branches. New municipality offices were also erected to join the Hlabisa hospital as the main focus points of the town. However, commercial agricultural in the area is limited to timber and sugarcane production and there are no formal maize buyers or storage facilities to support or stimulate maize production.

3.10 HOUSEHOLD DEMOGRAPHICS AND LIVELIHOOD ROLE OF MAIZE

The next couple of sections shed light on the households in Hlabisa with respect to demographics, endowments, income sources and expenditures and the role maize plays in their livelihoods. The aim of this section is to describe the households and livelihood sources so that the findings in Chapters 4 and 5 can be discussed and considered in context. Most of the study findings presented in this section are based on the data collected during the 2006/07, 2007/08 and 2009/10 seasons.

3.10.1 Household demographics

The Hlabisa Municipality covers an area of approximately 1 417 square kilometres and has a population of about 150 557 people with 27 260 households (Hlabisa Municipality, 2010). It is clear from Table 3.5 below that the majority of households in the Hlabisa sample are headed by females. According to the 2008 Zululand District Municipality (ZDM) survey females account for 55% of the Hlabisa population and 53% in the Uphongolo Municipality where Simdlangentsha is situated. Even though there are more women than men in these two areas, Muhwava and Nyirenda (2008) found that in the general community, not necessarily farming households, most households are still headed by men. The low representation of males is attributed to migration to urban areas in search of employment opportunities.

According to the 2001 census, 61% of the households in Hlabisa have between 4 and 9 members. The household size estimations indicated in Table 3.5 are based on the 2007/08 season surveys and corresponds with the census figure. Household size levels varied slightly over the seasons as well as during seasons as family members leave for urban areas in search of employment or return for holidays, a visit or if sick. Children below 16 years of age make up the largest share of the household. Though high, this percentage has decreased in the last decade due to a negative population growth (Hlabisa Municipality, 2010 and Muhwava & Nyirenda, 2008). According to Chimbindi et al., (2010) it was estimated in 2005 that 40% of pregnant women in rural KZN lived with HIV and 27% of 15-50 year old females and 14% of males were HIV positive. The highest incidence levels are in the young adult groups.

The majority of household heads are adult or elderly and have little formal education. However most households have a member who completed matric (Grade 12) or even a diploma or after school training and these members assist with reading and interpretation of written documentation for maize production or in every-day life.

Table 3.5: Household demographics of Hlabisa surveyed households (2006/07 data)

	Hlabisa
Household size	
Min	2
Max	17
Average	6.7
Average age group contribution to household	
Percentage younger than 16	28%
Percentage between 16 and 25	23%
Percentage between 26 and 45	21%
Percentage between 46 and 59	13%
Percentage 60 and older	15%
Gender of household head	
Male	35%
Female	65%
House hold head age	
Younger than 35	3%
Older than 60	45%
House hold head education	
No formal education	41%
Grade 7	18%
Grade 11	3%
Grade 12	7%
Tertiary education	2%
Highest education level in household	
Grade 12 or tertiary education	80%

Note: Percentage indicating share of survey sample

3.10.2 Assets

Tables 3.6 and 3.7 present household asset, initial endowment and income indications for households in both Hlabisa and Simdlangentsha in order to show that Hlabisa farmers are comparable to smallholder farmers in other areas of KZN. The average maize plot size in Hlabisa is less than half a hectare (Table 3.6). This has been relatively consistent over the three seasons 2006/07, 2007/08 and 2009/10. Simdlangentsha farmers plant slightly larger plots and also tend to plant more than one maize plot. The majority of farmers in both areas also still plant traditional

or saved varieties – most only a couple of lines, but some on a slightly larger scale. Farmers consider all saved seed to be traditional seed and this includes open pollinated varieties or hybrid maize bought in previous seasons and replanted. Traditional maize is planted mainly for chicken feed and for use in specific dishes or for making traditional beer, but a number of farmers have indicated that they plant selected traditional maize for consumption as green maize as these have a sweeter taste than the bought hybrids. This makes sense as the hybrid maize varieties planted in these areas are predominantly “grain maize” and not specifically bred with fresh maize taste preferences in mind.

In Hlabisa 76% of farmers indicated that it would be difficult to acquire more land to produce maize and 24% said it was not possible. In Simdlangentsha 76% of farmers said it would be easy to acquire more land; 44% indicated that they can plant more of their own land to maize and 41% stated that it is possible to rent land from neighbours or people in the community. It is thus clear that land is relatively limited in the hilly Hlabisa area.

Maize is the crop that covers most land (88% of arable land in Hlabisa) but farmers also plant vegetables including potatoes, beans, sweet potatoes, tomatoes, spinach and pumpkins on a small scale. In 2007/08, 39% of the farmers in Hlabisa intercropped mainly beans or pumpkins with maize. This was done by only 7% of farmers in Simdlangentsha where land is more abundant. Intercropping and the effect on maize output will be discussed further in Chapter 5. A number of farmers are also involved in community vegetable gardens where surpluses are sold in the informal market.

In Hlabisa none of the farmers surveyed own a working tractor. In Simdlangentsha where more maize is planted and farmers can rent out their tractors to the community, a couple of farmers own tractors. Oxen are used as draught animals and these oxen teams are also rented out for land preparation. In 2003/04 few farmers in Hlabisa used herbicides to control weeds, but by 2009/10 21% owned their own knapsack sprayers for herbicide application. In Simdlangentsha where farmers had been using herbicides more extensively, even before the introduction of HT maize, 72% of the sample owned their own knapsack sprayers. Households on average have more than 3 hand held hoes and these can be used for land preparation, planting and weeding.

Table 3.6: Production and household assets (2007/08 data)

Assets	Hlabisa	Simdlangentsha
Land		
Average maize plot size	0.42 ha	0.54 ha
Minimum	0.17 ha	0.20 ha
Maximum	0.85 ha	2.62 ha
Percentage of farmers planting more than one plot	17%	86%
Percentage of arable land dedicated to maize	88%	n.a
Other production assets		
Percentage households with own tractor	0%	6%
Percentage households with draught oxen team	40%	26%
Percentage households with knapsack sprayers	21%	72%
Average number of hand hoes per household	3.4	3.1
Animals		
Percentage households with cattle	67%	62%
Average number of cattle per household	12.4	10.1
Percentage households with goats	52%	46%
Average number of goats per household	11.2	7.2
Percentage households with chickens	100%	98%
Average number of chickens per household	15.6	21.1
Other assets		
Percentage households with working car	3%	8%
Percentage households with cell phone	99%	98%
Percentage households with television	78%	88%
Percentage households with FM radio	100%	99%

Most households in both areas have cattle and chickens and about half of the households own goats. These are the main farm animals and only a few farmers have a couple of pigs, donkeys or some geese. Cattle are a valuable asset and besides being used for traction for land preparation or as a risk mitigating “savings account”, cattle are also presented to the bride’s family as “lobola” when a girl’s hand is asked in marriage. A number of farmers in both areas buy day old chicks to raise and these are either sold or slaughtered for home consumption. Though few households have a working motor vehicle most have electricity, a television, a radio and at least one working cell phone. This means that farmers have at least access to information sources and are able to communicate telephonically.

3.10.3 Income sources and expenditures

According to a Hlabisa Municipality report (2010), about 79% of the community receives an income of less than R2000 per month. The main income source to households in both Hlabisa and Simdlangentsha is government welfare grants in the form of old age pension, child grants and other government grants. Remittances from family members working in urban areas play a big role, especially where young children are being looked after by grandparents. Even though farmers in Hlabisa did not indicate remittances as important, 48% of households received remittances in the three months September to November in both 2007 and 2009. The households who receive remittances tend to get a couple of payments through the year of usually less than R800.

Wage income is the main income source for 16% of households in the Hlabisa sample and 19% for Simdlangentsha where 62% of households have a fulltime income earner. This can be linked to the increased employment opportunities in the larger surrounding towns of Piet Retief, Pongola and Vryheid compared to the smaller towns of Hlabisa, Nongoma and Mtubatuba.

Crop production is not a main income source for most of the households and considering that the income source indications in Table 3.7 are based on 2007/08 data when a substantial share of households sold maize grain, income generating propensity for crops are regarded as quite low by farmers. However, the value of crop production by these rural households should not be measured in the income it generates but in the replacement value of the food households do not need to buy, because they are self-sufficient. It is also clear from the percentage of households who sold grain that being a small-scale surplus producer or a subsistence farmer depends on the success of the season. In Hlabisa only 13% of farmers sold grain in the drier 2006/07 season, while 64% of households were able to sell grain in 2007/08 and 66% in 2009/10 when the area received a more rain. The same applies to Simdlangentsha.

Table 3.7: Income sources and expenditure levels

	Hlabisa	Simdlangentsha
Main income source		
Remittances	2%	17%
Wage income	16%	19%
Crop production	9%	18%
Other business	1%	3%
Pension	50%	28%
Child grants	10%	9%
Other government grants	11%	6%
Remittances		
Received remittances in Sept-Nov 2007	48%	38%
Received remittances in Sept-Nov 2009	48%	43%
Percentage households with a full-time income earner	32%	62%
Percentage of households who sold grain		
2006/07	13%	9%
2007/08	64%	28%
2009/10	66%	42%
Average income from sold grain		
2006/07	R 660	n.a
2007/08	R 2 236	R 908
2009/10	R 2 477	n.a
Household expenditure on school related		
Less than R250 per year	53%	10%
Between R250 and R450	39%	28%
More than R450	8%	62%
Household expenditure on food and festivities during Christmas-New Year period		
Less than R650	27%	17%
Between R650 and R1000	31%	67%
More than R1000	42%	17%

Note: Percentage indicating share of surveyed sample

By comparing the average income generated by selling grain with school expenses (clothes, books and stationary) and expenditure indications over the Christmas and New-Years period it is clear that though the income from sold grain contributed substantially to household income, it did not exactly result in affluence. The next section describes why rural households produce maize and the factors that limit maize production.

3.10.4 Maize production motivations and limitations

Farmers were asked to indicate a number of reasons why they produce maize. The answers differed quite substantially between the 2007/08 and 2009/10 seasons. It is suggested that due to the fact that the 2007/08 season was preceded by a number of dry seasons (see Chapter 4) when few farmers were able to sell a surplus and the 2007/08, 2008/09 and 2009/10 seasons enjoyed higher rainfall levels, farmers' motivations for production adjusted somewhat. Table 3.8 lists the reasons that were indicated the highest number of times in percentage terms, i.e. which reasons received the most votes. The reason that constantly received the highest vote in both areas was "Cannot afford to buy maize meal at the shop for the whole year". In other words, households produce maize for household consumption as a more economical alternative to buying maize meal. Though rural households are consuming more rice and bread (76% of households in Hlabisa consume rice more than three times a week) maize is still the staple crop. Interestingly, Hlabisa farmers indicated the health benefit of their own maize meal (flour) compared to bought meal as a reason for production. In commercially sold maize meal the germ is generally removed from the starchy endosperm in the milling process (to increase shelf life) and thus contains less protein and oils. "Own maize meal" is thus in all likelihood slightly healthier than bought meal. The income earning from grain sales indication links up with the percentage of farmers who sell grain (as discussed above) and will in all likelihood depend on the success of the season (rainfall).

Table 3.8: Why do households produce maize?

Reasons	Hlabisa	
	2007/08	2009/10
Own maize meal is more healthy	46%	27%
Cannot afford to buy maize meal at shop	50%	23%
It is a Zulu tradition	1%	0%
Want to produce own green maize	1%	18%
Selling grain brings in cash	1%	25%
Selling green maize brings in cash	1%	2%

When considering the "self-sufficiency" indications in Table 3.9 below, it is important to bear in mind the fact that due to storage problems and the need for cash in the household (possibly to also buy rice and bread), many farmers sell maize grain with the knowledge that they will have to buy maize meal later in the season. In 2007/08, 68% of Hlabisa households were able to supply in

at least 75% of household demand. Urgent demands for cash might force households to sell more maize grain. Though the indications in Table 3.9 can be interpreted as an indication of self-sufficiency, the reasons for maize production as indicated in Table 3.8 should be kept in mind.

Table 3.9: Self-sufficiency indication for last couple of seasons (2007/08 data)

Percentage maize meal consumed: own vs bought meal	Hlabisa
Less than 20 % own maize	6%
20 % own maize	6%
25 % own maize	5%
50 % own maize	14%
75 % own maize	55%
90 % own maize	13%
100 % own maize	0%

When considering the limiting factors in Table 3.10 it is again clear that small plot sizes and availability of additional arable land is a problem in the hilly and densely populated Hlabisa area. Labour is indicated as a major and secondary limiting factor but is in all likelihood still under emphasized as most farmers do not hire in extra labour. Hlabisa farmers stress the lack of markets to sell maize grain as a secondary limiting factor. The lack of a formal facility to store maize grain links up with the limited grain market and is also indicative of post-harvest losses due to insects. Though it will be shown that rainfall plays a substantial role in the success of a maize production season (Chapter 4), farmers did not indicate rain as a major issue, possible because of the fact that the 2007/8 and 2009/10 seasons were relatively “wet” and more conducive to maize production.

It is clear from the discussions that even though maize is not the main income source for the vast majority of farmers in Hlabisa, most households do not earn enough monthly income to consistently purchase maize meal. Farmers thus produce maize in order to provide for the direct nutritional requirements of the household but maize grain surpluses or a share is also sold in order to purchase other food stuffs, to pay for necessities and emergency expenditures and / or to recoup input costs.

Table 3.10: Factors limiting maize production

	2007/08	2009/10
Main limiting factor		
Not enough land	60%	53%
Not enough labour	36%	10%
Not enough money for inputs	3%	30%
No market to sell grain	1%	5%
Low rainfall	0%	0%
No storage for extra maize	0%	0%
Second most important limiting factor		
Not enough land	0%	1%
Not enough labour	10%	2%
Not enough money for inputs	69%	24%
No market to sell grain	17%	49%
Low rainfall	0%	0%
No storage for extra maize	2%	7%

Note: Percentage indicating the share of surveyed households

3.11 THE EARLY ADOPTERS

The farmers who first planted Bt seed were the farmers who attended the Monsanto workshops in 2001 and received free seed samples. So 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 few, so in order to shed light on who the early adopters were, the 2003/04 farmers are considered.

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, 15 planted two plots of conventional maize and two planted two Bt plots. These figures differ slightly from those indicated in Table 3.2 as not all farmers' production data was ultimately usable, but demographic and perception data was collected for 77 Bt planters and 111 conventional hybrid planters (Table 3.11).

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. The price difference will be discussed in detail in Chapter 4. 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.

It is dangerous to make decisive conclusions based on averages of a small sample in one area and it is not the objective of this study to do rigorous adoption analysis or to fit an adoption model. It is however possible to cautiously deduce from Table 3.11 that the households who first adopted Bt maize had household heads who were slightly older, with less formal education (linking up with the higher age and percentage male headed households) and had more household 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-square test showed the differences between the two groups to be statistically significant at the 99% confidence level.

Table 3.11: 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

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 slightly better farmers or just more motivated. However, more elderly decision-makers and a lower household income might serve as limiting factors to production.

HT maize was first adopted by a substantial number of farmers in 2005/06. Table 3.12 compares conventional hybrid, Bt and HT producers. In comparing this 2005/06 conventional maize and Bt adopter comparison with the 2003/04 comparison above, it is clear that some differences still exist but others are less pronounced. 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 and so is household head education levels and main income sources. This might mean that 4 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 apparent. By also keeping the early Bt adopters comparison in Table 3.11 in mind it is clear 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 (less 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 labour supply in the HT households and probably more means to purchase relatively more expensive HT seed and herbicides to control weeds.

Table 3.12: 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. A Chi-squared test showed most differences to be statistically significant.

When considering the 2007/08 season adopter figures in Table 3.13 even more caution should be taken as the relatively small number of farmers is now unevenly divided between four seed types with the effect that there are relatively few farmers in each group. 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.

However, the most notable difference that can be identified from the 2007/08 season data in Table 3.13 is that fewer female headed households have adopted GM varieties, a fact also observed in previous seasons. This issue requires more in-depth study but might be partially linked to a lower level of participation in farmer days, demonstrations and farmer association meetings due to the time demands of other household and child raising activities. Only 14% of conventional hybrid maize seed planters indicated that they receive seed information from seed companies, i.e. seed company organised farmer days.

Table 3.13: Comparison of conventional, Bt, HT and BR maize seed adopters (2007/08 data)

	Conventional hybrid	Bt	HT	BR
Households headed by males	21%	42%	39%	42%
Household head older than 60	50%	36%	58%	44%
Household head with no formal education	50%	42%	39%	32%
Average number of people in household	6.3	6.7	6.5	7.9
Main income source:				
Pension	50%	42%	55%	44%
Permanent wage income	11%	0%	24%	17%
Average maize plot size	0.43 ha	0.40 ha	0.42 ha	0.44 ha
Main constraint to maize production				
Land	65%	64%	56%	56%
Labour	31%	27%	41%	39%
Source of seed information				
Neighbours and other farmers	82%	75%	35%	68%
Government extension officers	0%	0%	0%	5%
Seed companies	14%	25%	65%	26%

Note: Percentage indicating the share of surveyed households

A lower household income might also play a role in adoption of new technologies, but there was not a substantial difference between the income or expenditure levels of the non-adopters and adopters. When non-adopters were asked why they planted conventional hybrid seed 11% indicated that they have used the conventional seed before and know that it performs well, 32% indicated that the conventional variety was the only seed type available at the shop and 54% indicated that the conventional variety was less expensive compared to the other seed types.

3.12 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 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, 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.

3.13 SUMMARY

This Chapter set the scene for Chapters 4 and 5 by describing the South African smallholder farmer history and explaining how smallholder farmers fit into the South African political and agricultural milieu. The evolution of the research project, approach and the research area, data collection methods and data were discussed in order to contextualise the research findings that will follow in Chapters 4 and 5.

It is important to stress again that data was collected from a relatively small sample of farmers as the population of GM seed adopters are still small. Gouse, et al., (2009) showed how dangerous it is to come to conclusions based on findings from a single season’s data for a small sample of farmers. It is for this reason that an effort was made to collect accurate and detailed data and though the sample groups are relatively small (<100 for most seasons) a nucleus of farmers constitute a large share of the sample. In especially the last couple of seasons the same group of farmers, using different seed types, were surveyed. Though an econometric panel approach is not fully employed in Chapter 5, the consistency of the sample adds to the credibility of the findings.

Hlabisa farmers' household demographics, assets and income sources were compared to that of farmers in the Simdlangentsha region of KZN in order to show that as can be expected there are some differences between the farmers in the two areas, but Hlabisa farmers are not vastly different to farmers in other areas of KZN.

Early adopters of Bt and HT maize were compared to non-adopters to identify possible differences that can explain adoption and shed light on the potential problem of self-selection bias. Adoption requires further research analysis that falls outside of the focus of this thesis, but some interesting differences between early adopters and non-adopters were identified. These differences disappeared to a certain extent as GM technologies became more “conventional” after a couple of seasons. Though self-selection bias in all likelihood plays a role in the study findings, it is argued that the impact in the last couple of seasons is minimal.

Chapter 4 will analyse the performance and profitability of GM maize over an eight season period, employing partial productivity measures and analysing how GM maize adoption impacted on input use, expenditure, farming practises and profitability.

CHAPTER 4

PERFORMANCE OF GM MAIZE

4.1 INTRODUCTION

This Chapter presents analysis and findings on the performance and farm-level impacts of Bt and HT maize as produced by smallholder maize farmers in the Hlabisa area of KZN for eight seasons 2001/02 to 2007/08 and 2009/10. The impact assessment section is preceded by a brief discussion on the pests the novel GM technologies control, i.e. maize stem borers and weeds. The yield impact of GM maize adoption is analysed and discussed in detail and output levels are also linked to seasonal rainfall distributions. This is followed by an assessment of GM maize adoption's impact on pest control, labour use and seed costs. The Chapter concludes with a summary of the different farm-level impacts in the form of season and seed technology specific production budgets and profitability calculations.

4.2 EXPECTED IMPACT LEVELS

As was indicated in Chapter 2, due to the nature of the insect resistant (Bt) and herbicide tolerant (HT) technologies, and based on the performance of these technologies in other countries, one can expect that adoption of these technologies will impact production in a number of ways (Gouse et al., 2003, Brookes & Barfoot, 2010, Qaim, 2009).

For Bt the main potential direct farm-level impacts are:

- Possible decrease in use of insecticides and associated insecticide expenditure and application labour
- Possible yield increase (damage decrease) due to more efficient insect control
- Possible increase in seed expenditure due to higher seed cost

For HT the main potential direct farm-level impacts are:

- Possible increase in use and expenditure on herbicides
- Possible decrease in weeding labour
- Possible yield increase due to more effective weed control
- Possible increase in seed expenditure due to higher seed cost

These possible farm-level impacts will be assessed and discussed in the next couple of sections by analysing Hlabisa smallholder production data for eight production seasons. Before discussing the farm-level impacts of the GM technologies it is important to set the scene by shedding light on the production problems these technologies address.

4.2.1 Pest pressure

As these two GM input technologies, imparting insect resistance and herbicide tolerance, control production problems or limitations (in this case pests) it can be expected that the performance of these technologies depend on the infestation levels of these pests (as was discussed in Chapter 2). The next two sections will discuss stalk borer pressure and weed infestation in South Africa and Hlabisa and the manner in which these pests are managed.

4.2.1.1 *Stalk borer pressure and control*

African maize stem borer (*Busseola fusca*) and the Chilo stem borer (*Chilo partellus*) are the most harmful pests to maize and grain sorghum in South Africa (Kfir, 1997). In the 1980s it was estimated that damage caused by *Busseola fusca* resulted in a 5 to 75 percent yield reduction. In the pre-Bt years it was generally accepted that *Busseola* annually reduces the South African maize crop by an average of 10% across years and regions (Annecke & Moran, 1982).

Hlabisa farmers indicated stem borers to be the main insect pest on maize. Farmers were asked about their stem borer pressure perception, not only on the maize plot under focus, but also on his/her other maize plots as well as on neighbours' maize fields and in the area. Even though some farmers did notice a couple of stem borers in their maize fields, borer pressure was

perceived to be low and the infestation level was not high enough in any of the study seasons to warrant substantial insecticide application (Figure 4.1). Farmers and extension officers indicated that stem borers have not been a major problem in the study years but that pressure had been high in previous years and that there had been some severe losses. Farmers' low borer pressure perception for the study years should thus be seen in context to previous seasons with higher pressure and related losses. This is necessary as in collection and studying of harvested maize cobs a varying but significant level of borer damage was in fact observed on cobs for many farmers and in most seasons. It is important to stress that the sum of the damage caused to the maize yield is not limited to the direct visible damage caused by the second generation borer to the maize cob but first generation stem borers also damage young leaves and tunnel into and down the stem / stalk of the maize plant (Anneck & Moran, 1982), interrupting vegetative growth and the flow of nutrients to the developing grain, resulting in underdeveloped cobs and grain.

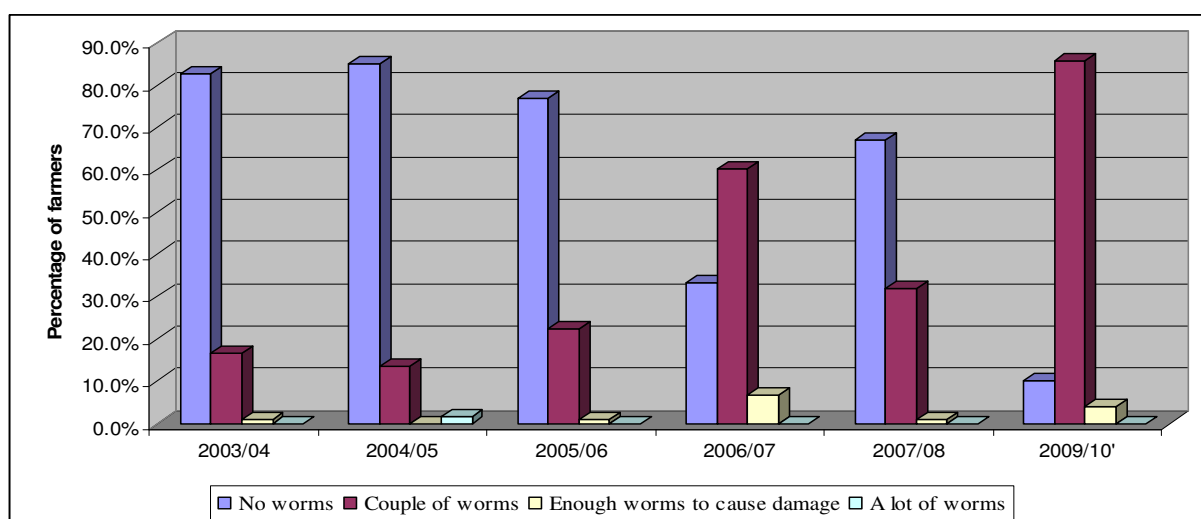


Figure 4.1: Stem borer infestation level indicated by Hlabisa farmers

More than 80% of the farmers surveyed in 2003/04 indicated that they did not observe any borers in their maize fields. Of these farmers, 59% indicated that the borer pressure in 2003/04 was “a lot” or “a bit” less than the borer pressure in 2002/03. So it would be correct to deduce that the stem borer pressure in 2002/03 was somewhat higher than in 2003/04 – a fact that will be referred back to in the yield comparison discussion below.

Annecke & Moran (1982) point out the complicated relationship between stalk borer infestation levels and rainfall, variable season dates, maize maturation rates, effects of borers on the maize plant as well as the effect of natural enemies. It is, however, generally accepted that stalk borer pressure is lower in drier production areas and seasons as the moths prefer moist conditions. A number of consecutive dry seasons usually cause a decline in stalk borer pressure. That is also why irrigated maize usually suffers higher stalk borer infestations than dry-land maize (Van Rensburg, 2004). The relatively low stalk borer infestation level in Hlabisa can to some extent be explained by lower than average rainfall in most of the study seasons. According to rainfall records maintained by the Hlabisa Department of Agriculture's offices, the four seasons preceding 2003/04, saw an average rainfall 20% less than the ten-year average. The rainfall for 2002/03 and 2003/04 were 25 and 24 percent lower respectively and the 2004/05 and 2005/06 seasons were even drier (see Figure 4.2 for rainfall indications).

4.2.1.2 *Weed pressure and control*

In contrast to insect pests that vary between seasons and regions, weed pressure in maize production is generally high and constant. According to Gianessi (2009), African soils contain between 100 and 300 million buried weed seeds per hectare of which a fraction germinate and emerge each year. Weeds compete with maize for space and light, but most importantly for South African dryland farmers, for nutrients and water. Under unweeded conditions in Africa, weeds can cause between 55 and 90 percent maize crop loss. Mabasa & Nyahunzvi (1995) found that the yield loss caused by uncontrolled weeds in communal maize production in Zimbabwe ranged between 34 and 96 percent. Kibata et al., (2002) showed that in Kenya, delayed weeding caused by a shortage of labour early in the season, result in maize yield losses of 15 to 90 percent. Marais (1987) showed that South African smallholders could lose up to 55% when delaying weed control by 40 days after emergence. Benson (1982) showed that in South Africa increased fertiliser use on weedy plots increased yield losses caused by weeds by 62%.

According to Marais (1992) poor weed control is the single biggest contributor to low maize yields for smallholder farmers. It is thus not a surprise that weeds are a major limiting factor also in Hlabisa. In 2005/06, 76% of farmers indicated weeding to be the maize production activity that

requires the most labour, while 22% of farmers indicated that land preparation and planting (which also has a weed control element) required the most labour. Only 30% of farmers made use of mechanised land preparation while 70% planted using hand and hoe and 20% used an animal drawn planter. Weeding is done manually using hand held hoes and hand pulling. In 2001/02 only 6% of farmers surveyed in Hlabisa used herbicide to control weeds in their maize fields. The use of herbicide was still minimal in 2003 (16%) but increased in 2004 with the marketing of “Combi-pack” input packages containing conventional maize seed and a broad spectrum herbicide (Roundup) and a selective herbicide (atrazine) in quantities suited for a quarter of a hectare. Herbicide use has increased with adoption of HT varieties with farmers adapting their production systems.

4.2.2 Impact on 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, kilogram fertiliser applied or per man hour. In this section the Hlabisa farmers’ outputs for the different seed varieties for the eight seasons are compared according to output per kilogram seed planted and for the more recent seasons also according to output per hectare of land.

Maize yield (output per land area planted) is influenced by a number of factors, including rainfall, fertiliser 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 taken for the more recent seasons, yield comparisons for the eight seasons are presented according to grain production per kilogram of seed planted (Figure 4.2 and Table 4.1). 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 fertiliser levels still have an influence, it does control for farmers’ different seeding rates.

Analysis of the input data for the different seasons show that fertiliser use by Bt adopting farmers are not substantially higher than that of conventional hybrid planting farmers. In fact, in a couple of seasons conventional hybrid farmers use slightly more fertiliser than both Bt and HT farmers (see Section 4.3 for comparisons). Econometrically estimated production functions (Chapter 5) are better suited to incorporate the effects of the “other” inputs, but for this section it should be sufficient to state that though fertiliser usage in all likelihood did influence yields slightly, the effect was not biased in favour of Bt or HT but rather in favour of the conventional maize planting farmers. However, the farmers who planted HT maize in the 2006/07 season are the exception. They applied just over 70 kg of fertiliser 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, as was done in the section on the counterfactual in Chapter 3, that in most seasons the performance of Bt and HT maize are compared to that of a relatively drought tolerant non-isoline (PAN 6043) as produced by mainly a different group of farmers in the same area. Bt and HT maize varieties are based on new high yielding varieties that performs best under high rainfall and high fertiliser 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. It is also important to keep in mind that we are dealing with real live scenarios and there are a number of variables influencing individual farmers’ production levels. Care was taken to compensate for events or to remove farmers from the data set where extraordinary externalities (cattle, bush pigs or fire destroying maize fields) had substantial negative impacts on output, but as will be seen in the next Chapter there still is substantial unexplained variability in output data.

Figure 4.2 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 4.2) covers the cob / ear forming stage. The impact of rainfall on the maize yields is obvious from Figure 4.2.

Before considering the yield differences it is probably necessary to say something about statistical significance. The means or averages presented in Figure 4.2 and Table 4.1 actually represent a distribution of sample observations as reported by individual farmers and these distributions are compared to one another to determine if the difference between the means are significant. The statistical significance indication supplies a measure of how confident one can be that the means and the difference between the means supply an accurate representation of the sample distribution. Even though yield differences might be economically substantial, it might be shown to not be statistically significant. This does not mean that the reported differences are incorrect or unsubstantial. What it means is that due to relatively small sample sizes (number of observations) and / or a high level of variability in the data it is not possible to conclude at a high level of confidence (99, 95 or 90 percent) that the yield difference is substantially different from zero, i.e. it is not possible to reject the null hypothesis (that the means are in fact equal) at a high confidence level. It is especially difficult to confirm relatively small yield differences when dealing with small sample sizes and in a number of seasons it is likely that the Type II error (not rejecting the false null hypothesis) is made. In other seasons (2003/04 for Bt and 2005/06 for HT maize) the yield difference was not statistically significant because the yields were in fact quite similar and the null hypothesis is correctly not rejected. By increasing the sample size it is possible to decrease the likelihood of a Type II error but the sample sizes for Bt and HT farmers were linked to the small populations and in a couple of seasons close to the total population was surveyed. It is also possible to improve the significance of the mean differences by removing outliers or limiting or smoothing the distribution, but that would remove an essential factor in smallholder production which is variability.

In interpreting Figure 4.2 it might be useful to keep in mind that the 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.

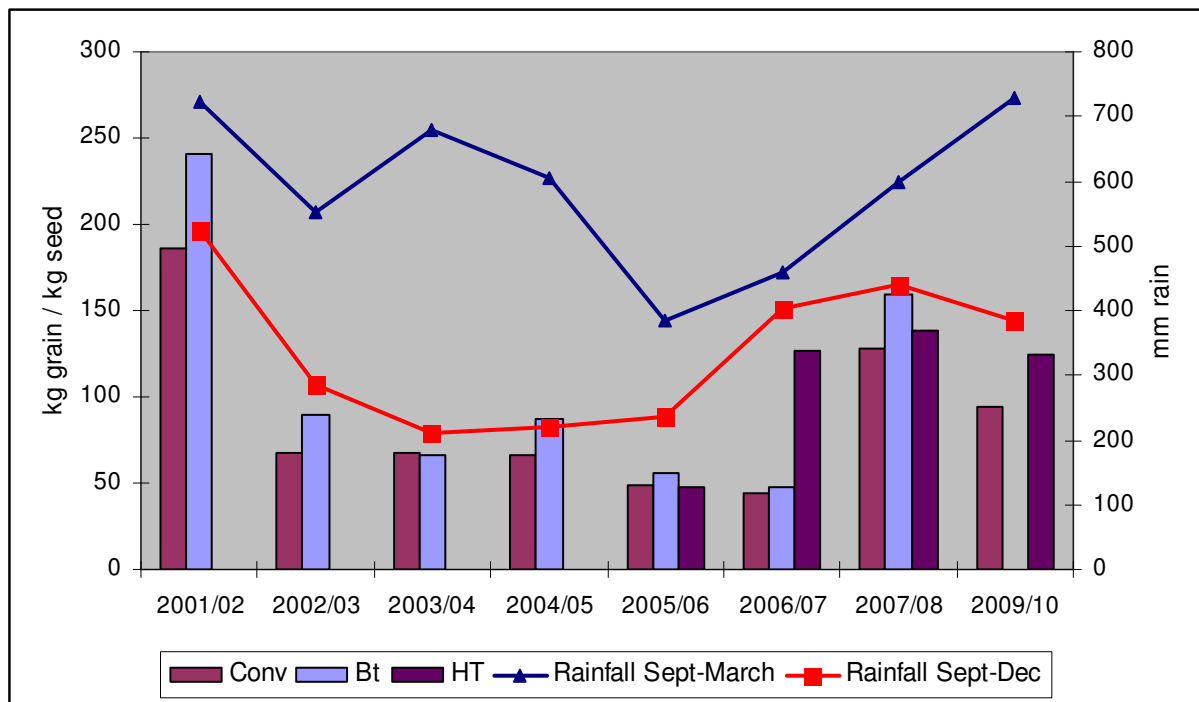


Figure 4.2: Yield comparison for conventional, Bt and HT maize for the eight seasons 2001/0 - 2007/08 and 2009/10

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. 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 and this could have influenced their production practises, 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

With limited Bt seed available for this season, close to the total Bt adopting population was surveyed in Hlabisa. As farmers had to buy the Bt seed, it can be argued that farmers were more critical about the performance of Bt maize. Farmers indicated an average yield advantage of 31% (statistically significant at 90% confidence level) with Bt maize compared to the average yield of predominately PAN 6043. Farmers indicated that the stem borer pressure for 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 and to get a more general figure for northern KwaZulu-Natal smallholder farmers, data was pooled for Hlabisa and Simdlangentsha and showed a 16% higher yield for Bt maize, statistically significant at 95% confidence level (Gouse, Pray, Schimmelpfennig & Kirsten, 2006). As seed was not widely available there can be an argument that it was the better farmers who were able to secure and purchase the Bt seed and this can partly explain the slightly higher than expected yield difference in Hlabisa. The seed was sold from the farmer co-operative in town and the Bt seed was sold on a first come first serve basis. Whether this arrangement increased or decreased the likelihood of self-selection bias is unclear.

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 apparent from Figure 4.2 that rain for the first part of the 2003/04 season was not sufficient and though the area received 470mm in the three months January to March it seems as if the maize was not able to recover. PAN 6043 made up a substantial share of the conventional counterfactual for this season and as PAN 6043 is considered to be a drought tolerant variety, possibly performed better than the CRN 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., 2006a). 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 fertiliser. 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 suffers 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 maize outperformed conventional maize by 32%. This yield advantage is statistically significant at 95% confidence level.

2005/06

With 186mm 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 the performance and production practises on the three HT maize demonstration plots in 2004/05, a number of farmers adopted HT maize seed and it was possible to survey close to the total population of Bt and HT planting farmers. 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 and some waited for government extension officers or other farmers to assist them with applications or to borrow knap-sack sprayers. This had an impact on the timing of herbicide applications (herbicide was applied late) and possibly on the effectiveness of weed control. Thus, in 2005/06 farmers using herbicides on average harvested the same amount of grain per kilogram of seed planted as conventional hybrid planting farmers making use of manual weeding.

Table 4.1: Yield comparison for Conventional, Bt, HT and BR maize (kg grain / kg seed)

		Conventional kg grain / kg seed	Bt kg grain / kg seed	HT kg grain / kg seed	BR kg grain / kg seed
2001/02	n	35	35		
	Min	20	12		
	Max	1000	1000		
	Mean	186	241		
	Mean difference to Conv		29%***		
	<i>t-Stat</i>		3.82 (0.003)		
2002/03	n	40	22		
	Min	9	32		
	Max	200	162		
	Mean	68	89		
	Mean difference to Conv		31%**		
	<i>t-Stat</i>		1.77 (0.042)		
2003/04	n	90	48		
	Min	20	23		
	Max	183	215		
	Mean	67	66		
	Mean difference to Conv		-1%		
	<i>t-Stat</i>		0.07 (0.472)		
2004/05	n	53	23		
	Min	17	25		
	Max	210	178		
	Mean	66	87		
	Mean difference to Conv		32%**		
	<i>t-Stat</i>		2.25 (0.015)		
2005/06	n	61	38	21	
	Min	4	4	9	
	Max	146	164	144	
	Mean	49	55	47	
	Mean difference to Conv		14%	-3%	
	<i>t-Stat</i>		0.86 (0.196)	0.2 (0.436)	
2006/07	n	38	22	35	
	Min	6	7	13	
	Max	206	152	268	
	Mean	45	48	126	
	Mean difference to Conv		8%	184%***	
	<i>t-Stat</i>		0.37 (0.358)	5.4 (0.000)	
2007/08	n	28	12	38	19
	Min	23	7	44	80
	Max	290	318	453	433
	Mean	128	159	138	170
	Mean difference to Conv		24%	8%	33%*
	<i>t-Stat</i>		0.97 (0.173)	0.5 (0.305)	1.58 (0.061)
2009/10	n	16	0	67	15
	Min	26		25	60
	Max	145		236	145
	Mean	94		124	114
	Mean difference to Conv			32%***	21%*
	<i>t-Stat</i>			2.7 (0.006)	1.59 (0.061)

* 90% statistical confidence level, ** 95% statistical confidence level, *** 99% statistical confidence level

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 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 120km one-way). A farmer in Hlabisa bought a couple of large bags of Bt and HT "commercial farmers seed" 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 downward by 20% as was discussed in Chapter 3, to compensate for the smaller seed weight ratio.

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 population), 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 99% confidence level). This considerable yield difference seems exaggerated and it is possible that due to the seed procurement problems it was mainly the better farmers who were able to buy and plant HT seed, with the effect that the yield comparison is distorted by self-selection bias.

However, in study findings feed-back discussions, extension officers and farmers were adamant that HT maize did perform substantial better than Bt and conventional maize, due to more effective weed control and the season's unusual rainfall distribution. When considering the rainfall for this season (Figure 4.2), it is clear that the area enjoyed good rain September to December but during January to March only 58mm was received. Due to good rain in the first half of the season both maize and weeds flourished but 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 fertiliser 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 utilise the higher fertiliser quantities and

substantially outperform Bt and conventional maize, produced with less fertiliser and manual weeding practises. It can be argued that without the more effective chemical weed control, the HT maize would not have been able to utilise the higher fertiliser application.

It is also thought that the yield comparison figures for this season are slightly distorted due to a couple of HT adopters only planting 2 kg of seed – i.e. small plots. However, even though a 184 and 176 percent yield advantage seems extraordinary it makes more sense when considering it in a near-zero weed damage approach. The HT technology using farmers' average yield was 126 kg output / kg seed planted (about 2500 kg / ha for farmers planting 20kg 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. Compared to the yield of 45 kg grain / kg seed for conventional maize this means that weeds caused 65% damage on conventional maize. When comparing these figures with the weed damage estimations of Gianessi (2009), Mabasa & Nyahunzvi (1995) and Marais (1987) as discussed under Section 4.2, the output differences between HT, conventional and Bt seem sensible for this unusual season.

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 5 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 seed with both the Bt and HT event. Bt, HT and BR outperformed conventional maize by 24, 8 and 33 percent respectively. Bt yielded 15% more grain on average than HT maize. BR maize yielded 7% more than Bt. These differences are substantial but not statistically significant at the 95% confidence level.

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 had again trouble sourcing Monsanto maize seed from suppliers and the

vast majority ended up planting HT and BR seed from Pioneer Hi-bred, 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 labour and this difference is statistically significant at the 95% level.

Table 4.2 supplies a yield comparison between Bt and conventional maize for the pooled data set for the six seasons 2002/03 to 2007/08. Findings for 2001/02 are not included as it is possible that farmers' output perceptions might have been influenced by the workshop and free seed and none of the farmers in the 2009/10 sample planted Bt seed. Based on six years of Bt maize production by smallholder farmers in Hlabisa, it can be concluded at the 90% confidence level that Bt maize yielded 12% more grain on average than conventional maize with a distribution of -0.004 and 24.7 percent. The average figure compares well with the 11 and 10.6 percent yield differences reported for commercial maize farmers by Gouse, et al. (2005), but is clear from Figure 4.2 and Table 4.1 that this average figure hides substantial variation between seasons and within seasons and that it is probably not a good idea to pool this data. Based on the data, the yield advantage of Bt maize will vary between the lower and upper limits depending on the stalk borer infestation level and farmers' ability to control the borers. As was discussed above, farmers indicated that borer pressure was not high in research seasons and it can be expected that in seasons with more substantial borer pressure the borer related damage (and Bt's borer damage limiting advantage) would be higher than what the six year comparison indicates.

Table 4.2: Yield comparison between Conventional and Bt maize for six seasons 2002/03 – 2007/08

	Conventional	Bt
	kg grain / kg seed	kg grain / kg seed
n	310	165
Min	4	4
Max	290	318
Mean	66.02	74.02
Mean difference to Conventional		12.12%
<i>t-Stat</i>		1.59 (0.056)
Yield advantage range	kg grain / kg seed	Percentage
Lower confidence level	-0.29	-0.004%
Upper confidence level	16.29	24.67%

Table 4.3 summarises 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 here 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) compared to the 14% (not statistically significant) with the kilogram grain per kilogram seed comparison (kg/kg). HT maize also showed a positive yield difference (9%) with kg/ha in compared to the -3% with kg/kg. The 2006/07, 2007/08 and 2009/10 seasons' comparison figures also showed some differences, some more substantial than others.

Table 4.3: 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	
	Min	54	64	117	
	Max	1650	1235	926	
	Std Dev	275	250	256	
	Mean	440	537	481	
	Mean difference to Conv		22%	9%	
	<i>t-Stat</i>		1.79 (0.039)	0.621 (0.269)	
2006/07	n	38	22	35	
	Min	44	54	115	
	Max	1360	1888	1835	
	Std Dev	335	376	477	
	Mean	451	470	875	
	Mean difference to Conv		4%	94%	
	<i>t-Stat</i>		0.192 (0.424)	4.359 (0.000)	
2007/08	n	28	12	38	19
	Min	432	118	873	1046
	Max	3496	4463	5464	6108
	Std Dev	839	1296	949	1205
	Mean	1869	2261	2062	2263
	Mean difference to Conv		21%	10%	21%
	<i>t-Stat</i>		0.963 (0.176)	0.869 (0.194)	1.236 (0.113)
2009/10	n	16	0	67	15
	Min	566		512	631
	Max	2586		3400	2676
	Std Dev	612		577	615
	Mean	1707		1880	1910
	Mean difference to Conv			10%	12%
	<i>t-Stat</i>			1.025 (0.158)	0.918 (0.183)

Though the kg grain / kg seed yield comparisons for HT maize vary too substantially to calculate an average figure for the four seasons, the kg grain / hectare comparison suggest a 10% yield benefit with the 2006/07 finding indicating that this benefit could be much higher in certain seasons and in conditions where weeds are not controlled effectively.

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.

4.2.3 Impact on insect control

The level of insecticide application to control stem borers supports the low borer pressure perception of the farmers indicated in Section 4.2.1.1 above. Only in 2003/04 and 2006/07 did 9 and 8 percent of farmers respectively, apply insecticides in the form of carbaryl granules. In 2004/05, 2005/06 and 2007/08 insecticide application on maize was almost non-existent. In 2009/10 more farmers indicated “a couple of worms” than in the preceding seasons, but still only 3 farmers applied a chemical insecticide. Farmers indicated that they sometimes do use other means of borer control like washing powder or ash, but have not done much of this in the study seasons.

None of the farmers applied insecticides on Bt maize but as few applied insecticides at all, the expenditure on insecticide and related labour saving benefit of Bt maize is minimal. Gouse (2005) showed that 40% of commercial maize farmers in the Northern Cape and 46% of commercial farmers in the North West Province did not use insecticides to control stem borers on conventional maize in 1999/00 and 2000/01 and that the other farmers generally only applied one organophosphate or pyrethroid spray. In seasons with higher stem borer infestation levels or under mono-cropping micro climate conditions on irrigation schemes, expenditure on insecticides to control stem borers can be expected to be considerable. Compared to Bt cotton, where control of boll worms on conventional cotton requires a number of chemical applications, chemical borer

control on especially smallholder maize is limited and thus the chemical saving advantage of Bt maize is minimal.

4.2.4 Impact on labour

In order to determine the impact of Bt and HT maize adoption on labour use, detailed labour data collected for the 2005/06 to 2007/08 and 2009/10 seasons is analysed. These seasons are used as the first substantial HT adoption only took place in 2005/06 and this is also the season when more accurate plot measurements were initiated. It is clear from the above discussion on insecticide application that Bt adoption had very little impact on saving on insecticides and the related application labour, so the insecticide application labour issue will not be considered further.

Before comparing the households' labour use according to farming activities and seed type, it is necessary to first shed light on the farming practises of the farmers, specifically land preparation, planting, weeding and harvesting and these activities' labour requirements. Most farmers make use of predominantly family labour for maize production activities, but as can be seen in Table 4.4 many farmers initially made use of a hired contractor to do land preparation with a tractor or a team of oxen. When it is kept in mind that it was essentially the same group of farmers that was surveyed for the four seasons, it is clear that there is substantial variability in land preparation methods between the seasons. Farmers' land preparation decision is influenced by the availability of tractors or oxen teams but it also seems as if, with the new HT technology, farmers are searching for the "best" (cost and labour effective) land preparation and planting method.

Starting in 2003, Monsanto presented farmers' days and demonstrations of minimum or no-till practises known as planting-without-ploughing (PWP). These practises had already previously been introduced in smallholder production areas by the Agricultural Research Council in order to limit tillage related soil erosion (Gouse et al., 2006b), but had not widely been adopted due to its labour intensive nature (compared with animal traction and tractor ploughing), because farmers generally struggle to afford and use selective herbicides and (more recently) partly due to government's mechanisation programmes. Under the mechanisation initiative local provincial Department of Agriculture offices received tractors to do land preparation and planting at a

minimal fee for smallholder farmers. Government spent millions on tractors and implements but little or nothing on training operators (drivers), with the effect that tractors rarely saw the next planting season.

In 2005/06 mainly Bt and conventional maize planting farmers made use of hired tractors and animal drawn ploughs for land preparation, while HT farmers mainly did land preparation and planting at the same time, using hand hoes. In 2006/07 and 2007/08 most HT and BR adopting farmers made use of animal drawn ploughs to open furrows and then planted by hand in the furrows. In 2009/10 96% of the farmers who combined land preparation and planting using hand and hoe, planted HT or BR seed.

Table 4.4: Land preparation method indication by Hlabisa farmers

Land preparation method	2005/06	2006/07	2007/08	2009/10
Hired tractor	30%	22%	10%	0%
Own oxen drawn plough	41%	44%	21%	9%
Hired oxen team	12%	20%	60%	7%
Hand and hoe with no herbicide	2%	7%	1%	0%
Hand and hoe with herbicide	15%	4%	8%	84%

Though this issue requires more in-depth study and analysis, it would appear as if HT adopters have decided that the most cost and labour effective way to plant is to just “open plant and close” using a hoe and no ploughing is done. This is in line with the PWP practises (*Ukutshala ungalimanga*) recommended by the Agricultural Research Council. From Table 4.5 it is clear that though some farmers made use of tractors or an animal drawn land preparation implement to prepare a seed bed, the majority planted by hand.

Table 4.5: Planting method indication by Hlabisa farmers

Planting method	2005/06	2006/07	2007/08	2009/10
Hired tractor drawn planter	5%	3%	0%	0%
Own tractor drawn planter	2%	0%	0%	0%
Hired oxen drawn planter	3%	0%	4%	4%
Own oxen drawn planter	20%	19%	6%	8%
Hand and hoe	70%	77%	89%	88%

Most farmers in Hlabisa make only use of family labour for weed control and harvesting. A number of farmers are part of working groups (*Ilima*) where a group of farmers take turns doing

mainly planting and weeding on each other's maize plots and members are "paid" with food and drink. In 2006/07, 11% of farmers planted their maize fields with help from the working group, 5% did weeding with the working group and 6% hired someone to help with weeding. In Simdlangentsha 9% of farmers did weeding as part of a working group and 73% harvested with working group assistance. In Hlabisa few farmers harvested as part of a working group and it seems as if it is more a social community activity in Simdlangentsha.

As discussed in Chapter 3, the family labour man-day figures (Table 4.6) do not include hired and working group labour as it is problematic separating tractor driver or oxen team leader man-hours from their machines or animals or adding these hours to manual labour man-hours. The efficiency levels of members of working groups are also questionable and probably not directly comparable to family labour. So hired services, working group labour and hired labour are separate and will be used in the production budget comparisons (Section 4.3), expressed in momentary terms. There is a negative correlation between family labour man-hours and the "hired services" expenditure as the less family labour is used, the more labour and / or services need to be hired. When considering the family labour man-days committed to specific maize production activities in Table 4.6, it is thus important to keep in mind that the figures are slightly distorted by hired labour and working groups as some farmers use hired labour, some work with the hired labour, some do not work with hired labour and others only use family labour. Table 4.6 indicates the man-hours per maize production activity for the farmers who performed the activities using some or only family labour, i.e. where farmers indicated zero family labour due to the fact that the activity was performed by hired labourers, the farmer is not included in the means calculations. However, in instances where a specific activity was not performed, the zeros are included, for example when no insecticide or herbicide application took place. Though the figures are slightly distorted it is possible to identify and quantify the differences between labour use for the different seed users.

Though the size (magnitude) of the labour use figures for the first three seasons seem relatively similar, it is dangerous to make comparisons across seasons as the detail of the collected labour data differed between seasons. Land preparation and planting are indicated together as for many farmers this is one activity. No harvesting data was collected for the 2005/06 season. The labour

commitment is expressed in 7 hour man days per hectare. Labour spent on a couple of very small plots resulted in exaggerated labour use indications per hectare, with a somewhat inflationary impact on the average figures.

Table 4.6: Family labour per hectare according to seed type (7 hour man-days)

Farming activities	Conventional	Bt	HT	BR
2005/06				
Land prep and planting	10.36	12.75	13.07	No plantings
Herbicide application	0.05	0.00	0.80	
Insecticide application	0.00	0.00	0.00	
Manual weeding	38.18	48.15	16.91	
Harvesting	n.a.	n.a.	n.a.	
Total number of man-days	48.85	62.48	38.68	
2006/07				
Land prep and planting	16.22	11.23	20.25	No plantings
Herbicide application	0.00	0.00	3.91	
Insecticide application	0.31	0.00	0.18	
Manual weeding	25.33	18.58	0.00	
Harvesting	10.90	8.69	14.28	
Total number of man-days	54.55	38.77	38.62	
2007/08				
Land prep and planting	14.58	14.74	6.66	7.81
Herbicide application	0.72	0.56	6.83	5.72
Insecticide application	0.14	0.00	0.00	0.00
Manual weeding	21.76	20.74	0.38	0.00
Harvesting	12.82	16.31	11.99	13.92
Total number of man-days	50.03	52.34	25.91	30.52
2009/10				
Land prep and planting	8.57	No plantings	3.72	4.40
Herbicide application	0.10		1.55	1.44
Insecticide application	0.00		0.04	0.00
Manual weeding	9.08		0.32	0.07
Harvesting	4.61		4.89	3.97
Total number of man-days	20.46		9.23	10.02

2005/06

The majority of conventional and Bt maize farmers made use of a hired tractor or own oxen to do land preparation, so the land preparation man-days mainly represent planting labour (Table 4.6). In this season HT adopters planted mainly by hand and hoe without doing substantial land preparation. HT farmers spent about one day on herbicide application while almost all Bt and conventional farmers did not apply any herbicide. HT farmers spent substantially less time on

manual weeding than conventional maize and Bt farmers but the fact that HT farmers had to spend about 17 days doing weeding does correspond with the yield findings. There was little difference between the performance of the HT and conventional maize in 2005/06 and it seems as if this was due to the fact that weeds were not controlled effectively with herbicides. As was discussed previously, this was the first season with 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. Out of the 22 HT planters, 6 farmers ended up not applying herbicide at all as they were either not able to find herbicide at a shop, was not able to afford the herbicide or were too late to apply the herbicide within the prescribed window after emergence.

2006/07

In this season Bt and conventional maize planting farmers did land preparation mainly with hired tractors, own oxen and hand and hoe and planted by hand, while HT farmers mainly opened furrows with own oxen and planted by hand, resulting in a relatively higher labour use. The labour commitment to herbicide application was more substantial this season for HT farmers and none of the HT farmers did any manual weeding as weeds were controlled effectively with the chemicals. Due to the substantially higher yield of the HT farmers for this season, HT farmers spent relatively more labour on harvesting.

2007/08

In 2007/08 most HT farmers made use of hired oxen teams to open furrows and then planted by hand. Bt and conventional farmers made use of hired tractors, hired oxen (so the land preparation man-day figure should be higher) but also own oxen with a higher family labour demand. HT farmers spent much more time on herbicide application than conventional and Bt farmers and a little or nothing on manual weeding. The labour commitment of conventional and Bt maize planting farmers were very similar in all activities except harvesting due to the labour impact of the 24% higher yield for Bt farmers. The higher yield labour use impact for HT and especially BR maize compared to conventional maize is less obvious.

2009/10

Though this season's labour-use indications are much lower than that of the previous seasons, the ratios remain similar. Conventional farmers in this season did land preparation using own and hired oxen and then planted by hand while the HT and BR farmers did land preparation and planting as one activity by opening and closing a seed station (hole) using a hoe and planting by hand.

Additional and more rigorous analysis of the labour data is necessary, but from indicated labour use hours and the discussion it is clear that the total labour saving impact of HT technology depends on the land preparation method of the farmers. In the first two seasons the weeding-labour saving benefit of HT was wiped out by the need to do additional weeding as herbicide use was ineffective (2005/06) and higher labour use for land preparation compared to the Bt and conventional maize planting farmers who used other less family-labour-intensive (but more cash intensive) hired services (2006/07). When labour is used to do land preparation (opening of furrows) with own oxen or funds are spent on hired oxen or tractors the labour or monetary commitment is higher as farmers still have to plant by hand. So there is need for labour (or cash) for the land preparation and then planting also still needs to be done. It is clear from the labour data in Table 4.6 that when no land preparation is needed to control weeds because weeds are killed with chemicals, farmers who plant by hand and hoe, according to the PWP method in that they just open the soil with the hoe, plant a seed and close again, have a substantial labour saving benefit. According to the 2007/08 and 2009/10 labour use data farmers that use herbicides and PWP can save about 50% on labour. This benefit will be quantified in Section 4.3.

4.2.5 Impact on seed expenditure

Comparing maize seed prices in South Africa is not straight forward, with some companies selling seed per kilogram and others according to seed quantity, i.e. 60 or 80 thousand seeds per bag. Seed sizes also influence comparisons as large seeds mean less seeds per kilogram. Table 4.7 indicates industry published seed prices in Rand per thousand seeds for PAN 6043, the variety that in most seasons made up the largest share of the conventional group, CRN 3505 the near-isoline conventional variety that were also planted by the conventional maize seed group,

the three Monsanto GM varieties and the two Pioneer Hi-bred GM varieties planted in Hlabisa in 2009/10. It is clear that the older PAN 6043 variety is substantially less expensive than the more recently released CRN 3505. Between 2005/06 and 2009/10 CRN 3505 was between 61 and 83 percent more expensive than PAN 6043.

Table 4.7: Seed prices in Rand/1000 seeds as published by industry

	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10
PAN 6043*	7.85	8.22	8.22	9.04	9.93	10.81	11.85
CRN 3505	12.83	13.75	13.75	14.82	16.02	18.57	21.72
DKC 7815 Bt	16.68	17.60	17.60	18.48	20.59	23.52	27.12
DKC 7835 RR	-	18.23	18.23	19.65	20.73	23.88	27.02
DKC 7845 BR	-	-	-	-	25.87	28.67	31.47
Phb 30D04 R	-	-	-	-	18.13	20.92	24.50
Phb 31M84 BR	-	-	-	-	-	25.67	26.33

Source: SA Graan/Grain

*The 25kg price for PAN 6043 was divided by 25 and 2.7 as it is assumed that this variety, popular with smallholders, has 2700 seeds per kilogram.

Because PAN 6043 made up a large share of the conventional maize group, the difference between the average seed expenditure on conventional and the GM varieties are considerable (Tables 4.8 and 4.9). Table 4.8 indicates both the average and the mode as outliers can influence the average value and the mode indicates the amount paid by most farmers. By considering the trend over the four seasons and comparing the average and the mode, it is possible to identify the Rand/kg that best represents farmers' seed expenditures. These are represented in percentage terms compared to the conventional in Table 4.9.

Table 4.8: Indicated seed expenditure according to seed type (Rand / kg)

	2005/06		2006/07		2007/08		2009/10	
Seed type	Average	Mode	Average	Mode	Average	Mode	Average	Mode
Conv.	25.88	30	31.14	15	32.35	43	49.71	48
Bt	44.22	44	57.55	52	52.39	51	-	-
RR	40.92	43	111.34	125	60.27	60	79.43	80
BR	-	-	-	-	62.60	62	82.53	84

As stated above the seed price difference is influenced by the conventional varieties that make up the conventional seed group. The differences that are thought to be closest to reality are indicated in grey. The 2006/07 RR difference should probably be closer to 300% as 125 R/kg should be

compared with the 31.14 R/kg. What is apparent from the seed price differences is that the leader farmer in 2006/07 made a considerable profit from selling seeds to the community – even though it should be kept in mind that it was smaller (more/kg) seeds.

Table 4.9: Difference in per kilogram seed expenditures compared to conventional

	2005/06		2006/07		2007/08		2009/10	
Seed type	Average	Mode	Average	Mode	Average	Mode	Average	Mode
Bt	71%	47%	85%	247%	62%	19%	-	-
RR	58%	43%	258%	733%	86%	40%	60%	67%
BR	-	-	-	-	94%	44%	66%	75%

Table 4.10 indicates the difference between the prices of the conventional near-isoline and the GM varieties as annually published by the seed sector. When comparing the official figures in Table 4.10 with farmer' indications in Table 4.9 it is clear that the official price differences are not as pronounced as indicated by farmers. This is because the GM varieties are compared to the more expensive conventional near-isoline and not to the older less expensive PAN 6043. However, for these smallholders in KZN, PAN 6043 was in most cases the alternative to GM varieties and thus for them GM seed was substantially more expensive.

Table 4.10: Difference in seed cost compared to the near-isoline CRN 3505 according to published seed prices

	2005/06	2006/07	2007/08	2009/10
DKC 7815 Bt	28%	25%	29%	25%
DKC 7835 RR	33%	33%	29%	24%
DKC 7845 BR	-	-	61%	45%

How much more farmers had to spend on seed per hectare and whether the higher seed expenditure was worth the investment, will be analysed in the next section.

4.3 PRODUCTION BUDGETS AND PROFIT CALCULATION

This section combines the partial impacts of GM crop adoption as discussed in the sections above, to supply a more complete picture measured in monetary terms. This section departs somewhat from the usual partial budget and gross margin calculations in that the budget also includes labour, an input generally not included in partial budgets and net farm income can thus

be calculated. As labour and more specifically family labour is an important input in a smallholder production system care was taken to record accurate labour hours (as discussed above) and these labour hours are expressed in monetary terms in the production budget. The only input that is not quantified in pecuniary terms in the budget is land. All the farmer households and maize plots are on communal land and farmers do not pay for the land. There is little to no short term rental demand for land and thus little to no opportunity cost of using the land.

Table 4.11 presents the enterprise budgets according to the different seed technologies for the four seasons 2005/6 to 2007/08 and 2009/10. The inputs and outputs are indicated according to unitary area and yield benefits would thus correspond with those indicated in Table 4.3 and the value of family labour with the man-days indicated in Table 4.6. The expenditure values in South African Rand (ZAR) have not been deflated to a base year as particular comparisons across seasons are not recommended due to small differences in the detail captured in the figures and the observable inflationary effect adds to the value of the Table.

In Table 4.11 the net farm income and gross margins of the seed types are presented according to three categories. Category A refers to net farm income as all expenditures are subtracted from the value of output. Categories B and C represent two different gross margin calculations as different directly allocated expenditures are included:

A – Value of output minus all indicated expenditures (net farm income)

B – Value of output minus only direct expenditures and hired services and labour (family labour is thus not included as an expenditure)

C – Value of output minus only the direct expenditures (seed, fertiliser, herbicide and insecticide)

Table 4.11: Net farm income / gross margin calculation for Hlabisa farmers for the four seasons 2005/06-2007/08 and 2009/10

	Unit	2005/06			2006/07			2007/08				2009/10		
		Conv.	Bt	HT	Conv.	Bt	HT	Conv.	Bt	HT	BR	Conv.	HT	BR
Inputs														
Seed quantity	kg	11	13	11	11	10	8	21	17	20	17	19	16	17
Seed exp.	ZAR	279	575	464	334	546	843	652	889	1,199	1,058	924	1,248	1,376
Fertiliser quantity	kg	137	140	127	110	109	181	182	137	191	208	197	139	158
Fertiliser exp.	ZAR	389	395	366	436	410	600	739	511	672	727	907	645	727
Herbicide exp.	ZAR	27	0	340	0	0	457	146	121	970	834	152	1,396	1,608
Insecticide exp.	ZAR	0	0	0	20	0	11	0	0	0	0	0	8	0
Hired services and labour	ZAR	161	241	80	498	302	279	542	544	491	436	550	362	461
Value of family labour applied	ZAR	1,777	2,234	1,041	1,897	1,454	1,545	2,001	2,094	1,027	1,221	1,332	618	622
Land preparation and planting	ZAR	343	505	333	614	429	810	583	590	260	312	380	197	231
Herbicide application	ZAR	2	0	32	0	0	156	29	22	273	229	8	122	114
Insecticide application	ZAR	0	0	0	12	0	7	6	0	0	0	0	3	0
Manual weeding	ZAR	1,432	1,729	676	880	709	0	870	829	15	123	717	25	5
Harvesting	ZAR	n.a	n.a	n.a	390	316	571	513	652	480	557	227	271	272
A: Total exp. on inputs	ZAR	2,633	3,445	2,291	3,185	2,712	3,735	4,081	4,159	4,360	4,276	3,864	4,278	4,794
B: Total exp. without family labour	ZAR	856	1,211	1,250	1,289	1,258	2,190	2,080	2,065	3,333	3,055	2,533	3,659	4,171
C: Total exp. on direct inputs (without services or any labour)	ZAR	695	970	1,170	790	956	1,911	1,537	1,521	2,841	2,619	1,983	3,297	3,711
Output														
Output quantity	kg	440	537	481	451	470	875	1,869	2,261	2,062	2,263	1,707	1,880	1,910
Value of output at community sales price of R150/50kg	ZAR	1,321	1,611	1,444	1,353	1,410	2,625	5,607	6,783	6,186	6,789	5,121	5,640	5,730
Net farm income / gross margins														
A: Including all expenditures	ZAR	-1,312	-1,834	-847	-1,832	-1,302	-1,110	1,526	2,624	1,826	2,513	1,257	1,362	936
B: Excluding family labour	ZAR	465	400	194	64	152	435	3,527	4,718	2,853	3,734	2,588	1,981	1,559
C: Including only direct inputs	ZAR	626	641	274	563	454	714	4,070	5,262	3,345	4,170	3,138	2,343	2,019

While Table 4.11 supplies a more complete picture, caution should be taken when the net or gross margin levels are compared as it is clear that seed quantities and fertiliser levels per hectare differ for the different seed types, with an effect on the performance and resulting bottom line of the different seed types. When interpreting Table 4.11, it is also important to keep in mind the use of hired contractors with tractors or oxen and the use of hired labour or working groups as discussed under Section 4.2.4.

Family labour was priced at R40/man-day for all four seasons. This is an average assumed amount based on farmer interviews, survey data and discussion with extension officers. Over the four seasons a number of farmers sold their grain in the community at between R100 and R180 for a 50 kg bag, but the majority of farmers sold 50 kg at R150 in most of the seasons, so this price is used for all four seasons. This price is substantially higher than the commercial farmer South African Futures Exchange (SAFEX) derived price and closer (but still less) than the maize meal (flour) price. Consumers in the community is willing to pay this inflated grain price because they do not have to travel to town to buy maize meal (usually by expensive taxi) or carry the heavy bag home from the nearest road (i.e. convenience), they perceive the meal from the locally bought grain to be more healthy and they have some cash available from the pension day pay-outs. The commercial farmer maize price fluctuates through the season and seasons but will have been closer to half (R75/50kg) the price the smallholders received from their local community. It is thus clear that at the actual domestic maize grain price, the smallholder farmers' profits will have been even smaller. However, it is important to remember that most of these farmers do not produce maize to make a profit, but to feed their families. It is thus possible that even in a season when a loss was made, the households' welfare could have been increased through subsistence maize production, compared to having to have purchased all the maize meal required. This issue requires further analysis but falls outside the scope of this thesis.

By comparing the output levels in Table 4.11 with the rainfall figures in Table 4.12, the impact rainfall has on smallholder dryland production is apparent. It is interesting to note farmers' willingness to invest in maize production in seasons when good early rainfall suggests a favourable maize production season. When kept in mind that to a large degree the same farmers were surveyed in all four seasons, it is clear to see that farmers invested more in seed and fertiliser in the seasons with higher rainfall in September and October. In the wetter early-season 2007/08 and 2009/10 farmers planted close to the recommended 20 kg of seed

per hectare while in the drier 2005/06 and 2006/07 farmers planted about half of that. Farmers applied about 30% more fertiliser in the seasons with higher early-season rainfall.

Table 4.12: Rainfall for Hlabisa for the crucial maize production months (mm)

Months	2005/2006	2006/2007	2007/2008	2009/10
September	34	32	35	34
October	17	87	159	108
November	100	102	133	122
December	86	181	112	120
January	88	40	71	120
February	0	8	0	127
March	59	10	90	98
Total	384	460	600	729

It is clear from Table 4.11 that in a number of seasons, conventional maize planting farmers applied more fertiliser than especially Bt adopters. The reason for this is not totally clear and one would expect that a farmer would be willing to invest in more fertiliser for a production risk reducing seed type like Bt. A couple of farmers did indicate that the higher price of Bt seed meant that there were less funds available for fertiliser. Though affordability of the GM seed might have an impact on the budget available for other inputs, this finding was not consistent over the seasons and also seems less applicable to HT seed.

2005/06

In this, the driest of the four seasons, farmers planting Bt maize made the biggest loss, followed by conventional farmers and then HT farmers. The reason for this is that, despite the higher yield with Bt seed, the Bt farmers spent more on hired services and labour and family labour (land preparation and planting and manual weeding). When family labour is not included as a cost (gross margin B), conventional maize did better than both Bt and HT and when only the direct purchased inputs are included (gross margin C), Bt maize users had the highest profit, despite paying more for seed. It is thus clear that Bt maize was not the least profitable in this season because of the increased seed price but because of other higher, seemingly not Bt-technology related, expenditures. In this season when not all HT adopters were able to control weeds effectively with herbicides, HT was still the most profitable due to mainly saving on labour and hired services.

2006/07

In this season again all three seed type farmer groups made a loss on average due to the low rainfall and resulting low yield level. HT adopters made the smallest loss despite spending 152% more on seed per hectare (for 3 kg seed less), than conventional farmers. HT adopters had a substantially higher yield and used less family labour and hired services and performed best in all three profit calculation categories. Bt adopters also made a smaller loss than conventional farmers despite spending more on seed, due to a slightly higher yield but mainly a lower expenditure on land preparation and planting and harvesting, i.e. activities that are again not linked to the Bt technology.

2007/08

In 2007/08, the “wettest” of the four seasons, Bt adopters showed the highest profit, followed by the BR adopters. Conventional and Bt farmers had similar levels of expenditure on family labour and hired services, as did the HT and BR farmers. The HT technology users (both HT and BR) spent substantially less on both land preparation and planting and manual weeding family labour. Bt maize was more profitable than the other seed types, in all three profit categories, because Bt farmers had the highest yield and spent less on seed (compared to HT and BR farmers) and fertiliser.

2009/10

In this season conventional maize farmers planted more seed and applied substantially more fertiliser than the HT and BR farmers. As was the case in 2007/08, HT and BR farmers used only about half as much family labour as conventional farmers, with the main saving on manual weeding, but at the cost of spending a substantial amount on herbicide tolerant seed and chemical herbicides. When the expenditure on all the inputs are taken into consideration, HT maize adopters showed a slightly higher profit than conventional maize planting farmers. When family labour and hired services are not included in the profit calculation, conventional maize farmers’ profit was higher.

Table 4.13 below summarises the highest profit (smallest loss) seed types according to the different margin calculation approaches / categories. In 2005/06, HT rendered the smallest loss when saving on family labour is included in the profit calculation; conventional does best when family labour is not included and Bt does best when only the direct inputs (seed, fertiliser, herbicide and insecticide) are included, mainly due to a 22% yield advantage over

conventional maize. In 2006/07, HT maize performed the best in all three “profit” categories because of the large yield increase and despite paying 152% more for their seed and not saving much on family labour - due to comparatively more land preparation and planting labour. Bt maize was superior in 2007/08 in all three categories due to a 21% yield advantage over conventional maize despite a lower fertiliser level and higher seed expenditure. Though the production of Bt maize (and conventional) required close to double the amount of family labour and BR rendered a slightly higher yield than Bt, HT and BR farmers spent substantially more on seed, fertiliser and herbicide. In 2009/10, BR maize rendered the highest yield but due to a higher expenditure on fertiliser and herbicide HT delivered the highest profit when all inputs are taken in consideration. When family labour and hired labour and services are not included as expenditures, conventional maize was most profitable.

Table 4.13: Seed types with highest net or gross margins (or smallest loss) for the four seasons

	2005/06	2006/07	2007/08	2009/10
A – Highest net farm income	HT	HT	Bt	HT
B – Highest gross margin (without family labour)	Conv.	HT	Bt	Conv.
C – Highest profit with only direct expenditures	Bt	HT	Bt	Conv.

In all four seasons a GM variety was superior when all expenditures were taken into consideration. In three out of the four seasons HT rendered the highest profit or smallest loss. This is due to a higher yield in some seasons but predominately the labour saving on weeding labour. The labour saving benefit of the herbicide tolerant technology is substantial and farmers indicated that they value it highly. Even though Bt seed rendered a higher yield than HT seed (in most of the seasons when a comparison was possible) and does not require an additional expensive input (herbicide) farmers seem to value the weed control benefit of HT maize higher than the borer control benefit of Bt maize. In a community where the majority of farmers are elderly and HIV/Aids and out-migration limit household labour, and profit driven surplus production is not the main objective, the convenience of production seems to be more important.

In 2005/06 and 2006/07 the saving on manual weeding family labour was considerable and in 2007/08 the value of the saving (R880) was quite close the difference spent on herbicides (R824). However in 2009/10, HT adopters spent R1 244 more than conventional farmers on herbicides but only saved family labour to the value of R692. The land preparation and planting labour should also be included in the calculation but it is clear that the profitability of

HT maize will to a large extent depend on the shadow price of family labour or market price of hired labour. Willingness to pay for the convenience of not having to do manual weeding and the value of “saved time” activities will also play an important role. High HT seed and herbicide prices might push farmers towards conventional seed with selective herbicides as has been observed in Simdlangentsha, but selective herbicides do not kill all weeds and might require additional manual weeding.

An important issue not addressed in this thesis is whether a labour saving technology will enable maize production expansion. Due to farm size and output market limitations and importantly farmers’ motivation for production, Hlabisa has not been the ideal area to study possible production expansion. Future research using also Simdlangentsha data will study this important issue.

4.4 CONCLUSION

This Chapter assessed the farm-level impacts of Bt and HT maize as produced by smallholder maize farmers in the Hlabisa area of KZN for eight seasons and with specific focus on the last four seasons 2005/06 to 2007/08 and 2009/10. This Chapter employed partial productivity measures and shed light on the impact adoption of these new technologies had on the use of and expenditure on other production inputs.

The partial productivity measures showed that Bt and HT maize generally rendered higher yields than conventional maize due to the more effective manner in which pest damage (stem borer and / or weeds) is managed and limited. Bt farmers did not benefit from saving on insecticides as insecticide usage on conventional maize is limited. These findings partly address the first hypothesis stipulated in Chapter 1.

It is clear that though the different seed technologies confer certain pest control advantages, resulting in yield increases and / or labour saving, these technologies come at an additional cost (increased seed and herbicide expenditure). However, it is apparent from the production budget that the level of “profitability” to a large degree depended on the production system of the farmer. In a couple of seasons Bt maize was the least profitable not because of the increased seed price but because of other higher, seemingly not Bt-technology related expenditures. This finding is even more applicable to HT maize as a HT adopting farmer who

make use of family labour for land preparation and planting with hand held hoe will benefit more from the HT technology than a farmer who spends cash on contract land preparation or a farmer who open furrows with oxen and then plant by hand. This finding clearly supports the second hypothesis of this thesis.

The complete budget presents a more comprehensive picture of the Hlabisa farmers' experience with the GM events, but there are still too many variables moving in different directions. The situation is complicated even further by the fact that farmers make use of different farming practices - mainly different land preparation and planting with hired tractors, hired oxen teams, own oxen and hand and hoe. Currently these farmers are included in the same groups and averages hide the detail and differences.

The partial productivity measures and the enterprise budget used in this Chapter are useful to present the basic farm-level picture and to identify differences between the different seed users. However, fluctuating application levels of other inputs (mainly fertiliser and seed) can play a substantial role in the different seed type's yield levels and it is difficult to isolate the GM event's impact. To deal with this shortcoming, the next Chapter fits production functions and a stochastic frontier model to the final four seasons' data. Individual farm efficiencies will be estimated in order to be compared across seed technologies and production approaches.

CHAPTER 5

PRODUCTION FUNCTIONS, STOCHASTIC FRONTIERS AND EFFICIENCY

5.1 INTRODUCTION

The partial productivity measures used in Chapter 4 are useful, but like most partial approaches, can be misleading because they do not present the aggregate or total picture. The production budget approach is beneficial to identify impact levels and is convenient for interpretation, but with fluctuating input levels for different seed types it is difficult to identify or isolate the GM-technology-specific output effect. To deal with this shortcoming Chapter 5 employs a production function approach in order to model the impacts of adoption of the different seed technologies for the four Hlabisa seasons as analysed in Chapter 4. A production function is fitted to data for the different technology adopters in order to identify the salient variables that contribute to the output level of the adopters and non-adopters. Though the ordinary least squares approach incorporate the contributions of all included production factors it still fits an average line to the data and variability in individual farmer performance is not captured or illustrated. The production function approach assumes that all farmers produce at the same level of technical efficiency and this is an obvious error. In order to calculate individual farmer's efficiency levels, stochastic production frontiers are estimated for the four Hlabisa seasons using the maximum likelihood approach. Farmers' season specific relative efficiency estimates are compared according to seed type as well as other production practice variables like land preparation method and whether intercropping was used.

A brief literature review on production functions, stochastic production frontiers and efficiency estimations is supplied next. It is followed by production function estimations using two different functional forms and a test to determine which functional form supplies the superior presentation of the survey data. The selected functional form is then fitted to the Hlabisa farmers production data for the four seasons 2005/06, 2006/07, 2007/08 and 2009/10. The production function estimations are followed by stochastic production frontier estimations for the four seasons and efficiency scores are calculated and compared for the different seed technology users in each of the four seasons.

5.2 BACKGROUND ON PRODUCTION FUNCTIONS AND FRONTIERS

The production function approach is widely used in the assessment of the farm-level effects of adoption of genetically modified crops (Huang et al., 2002, 2005, Qaim & De Janvry, 2005 and Qaim & Zilberman, 2003). This is mainly because farm-level benefits are a precondition for the adoption of the new technology and the producer-level impact is the basis for other methods that evaluate costs and benefits on a more aggregate level, like surplus and equilibrium models (Pemsl, 2006).

5.2.1 Production functions and functional form

A production function expresses the relationship between a firm, industry or entire economy's inputs and its outputs. It indicates, in a quantitative or mathematical form, what outputs can be obtained from various amounts and combinations of factor inputs. In particular it shows the maximum possible amount of output that can be produced per unit of time with all combinations of factor inputs, given current factor endowments and the state of available technology. A production function can also be defined as the specification of the minimum input requirements needed to produce designated quantities of output, given available technology (Aigner, Lovell & Schmidt, 1977). Theoretically it is possible that a unique production function can be constructed for every production process and technology. Production in natural systems or agricultural production is influenced by numerous and dynamic factors and in positive studies, where the aim is to explain observed behaviour or uncover underlying parameters, analysis approaches are frequently limited to simpler and more general functional forms due to computational complexities and data requirements (Lichtenberg & Zilberman, 1986).

The most common form is the ubiquitous Cobb-Douglas (CD) originally proposed by Wicksell (1851-1926) and fitted to US manufacturing data by Cobb and Douglas (1928) (Enaami, Ghani & Mohamed, 2011). This functional form is widely used in econometrics, biometry and other research fields and agricultural production functions are often assumed to have a CD form (Carpentier & Weaver, 1997; Pemsl, 2006; Huang et al., 2002; Ceddia, Gómez-Barbero & Rodríguez-Cerezo, 2008). This is not because this functional form is particularly applicable to agricultural production but because it seems to supply a reasonable description of most data sets, has attractive mathematical characteristics like the fact that the

function is relatively easy to handle, coefficients can be directly interpreted as elasticities, the shape suits the expectation of diminishing marginal returns to either factor of production (Heady and Dillon, 1961) and the main advantage is that it can be linearly estimated after a simple logarithmic transformation (Horna et al., 2007). However, due to its restrictive form the CD production function has important limitations. It imposes unitary elasticities of substitution between all input pairs, which is not likely in agricultural production. Another problem with the CD form (same for the Translog) is that when being estimated in the linear form, observations with a zero explanatory variable are excluded as the logarithm of zero is not defined.

Equation (5.1) shows the CD functional form and notation most frequently seen in literature, slightly adjusted so that output or production is a function of land, seed and fertiliser (labour and capital are used as the example inputs in most literature). The other inputs like insecticide, herbicide, labour for different activities and hired services are omitted at this stage as the corresponding Translog functional form becomes cumbersome to express in notation when more inputs are included.

$$Q = AL^{\alpha} S^{\beta} F^{\delta} \quad (5.1)$$

Where L = land input, S = seed input, F = fertiliser input, Q = output, α = output elasticity with regard to land, β = output elasticity with regard to seed, δ = output elasticity with regard to fertiliser and A = total factor productivity

Through a logarithmic transformation equation (5.1) can be written in the log-linear format, equation (5.2).

$$\ln Q = \ln A + \alpha \ln L + \beta \ln S + \delta \ln F \quad (5.2)$$

The transcendental logarithmic or Translog production function is a generalization of the CD production function and was developed to circumvent some of the restrictions of the CD functional form. One of the main differences between the more flexible functional form of the Translog and the CD is that the Translog incorporate parameters to capture the interactions between production factors. Though the Translog functional form is less restrictive than the

CD, it is more difficult to mathematically manipulate and easily suffers from degrees of freedom problems (Coelli, Rao & Battese, 1998). The linearised form of the Cobb Douglas and Translog functions can be estimated by means of an ordinary least squares regression. Equation (5.3) illustrates the Translog production function for the same inputs used in the CD above, i.e. land seed and fertiliser:

$$\begin{aligned} \ln(q) = & \ln(A) + \alpha_L \ln(L) + \alpha_S \ln(S) + \alpha_F \ln(F) + \beta_{LL} \ln(L) \ln(L) + \\ & \beta_{SS} \ln(S) \ln(S) + \beta_{FF} \ln(F) \ln(F) + \beta_{LS} \ln(L) \ln(S) + \\ & \beta_{LF} \ln(L) \ln(F) + \beta_{SF} \ln(S) \ln(F) \end{aligned} \quad (5.3)$$

A number of studies on Bt cotton and maize have implemented a damage abatement approach in which a separate insect damage control function is linked to the production function (Shankar & Thirtle, 2005, Huang et al., 2002, Qaim & De Janvry, 2005 and Qaim & Zilberman, 2003). This approach builds on work by Lichtenberg & Zilberman (1986) and argues that including pest control inputs such as insecticides and the use of Bt into a standard production function implicitly assumes that their mode of action is the same as that of other inputs. Damage control inputs are different from conventional inputs in that they affect output only indirectly by limiting the extent of damage in the event that damage occurs. In contrast conventional inputs like fertiliser and seed quantity generally increase output directly (Shankar & Thirtle, 2005). Using a traditional production function specification with damage abatement inputs can lead to overestimation of the productivity of pest control agents (Lichtenberg & Zilberman, 1986). However, in a review of Lichtenberg and Zilberman's work, Hall and Moffitt (2002) showed that the direction of bias in comparing a traditional Cobb Douglas production function with one with a damage control specification cannot be predicted. This means that while one can expect that a conventional Cobb Douglas production function or other conventional functional form will wrongly estimate the productivity of pesticides, it cannot be predicted whether it will be over or under estimated, before the estimation is actually done (Shankar & Thirtle, 2005).

This smallholder GM maize study does not make use of the damage abatement approach to model the production impact of Bt maize. Due to a lack of reliable data on stalk borer pressure in the study area and seasons and the fact that the vast majority of farmers do not apply insecticide, a damage abatement component will not add much, if any, to the conventional production function specification. Based on a review of the literature, no study

has been done on the use of a damage abatement production function in the analysis of HT maize. Modelling the weed control component with labour, broad spectrum herbicides, selective herbicides and HT seed might add to the conventional production function. This type of study might be possible with the Hlabisa data set but falls outside the scope of this thesis.

As was mentioned above, the use of a Cobb Douglas or Translog specification is problematic when data points include zero values as observations. The CD and Translog is usually estimated in their linearised form and the logarithm for zero is not defined. The Hlabisa farmer data set contains a number of zeros as many farmers for instance do not use insecticides or herbicides. The zero-observation problem has been addressed in a number of different ways. Some researchers exclude the farmers with zero values from data sets while others replace the zero value with a comparative small value (Battese, 1997). However, excluding the farmers with zero observations for variables like insecticide or herbicide use would totally defeat the purpose of this study and Battese (1997) indicates that using a small value to replace zero's does have an impact on estimations as the zero is replaced by a value that is not independent of the units of measurement of the variable concerned. This study uses the approach suggested by Battese (1997) in that zero values are replaced by a zero dummy variable.

5.2.2 Stochastic production frontier and technical efficiency

Farrell (1957) suggested that economic efficiency can be divided into technical efficiency, that reflects a firm's ability to obtain maximum output from a given set of inputs and, allocative efficiency that reflects the ability of the firm to use the inputs in optimal proportions given the inputs' respective prices. An implicit assumption of production functions is that all farmers produce at a technical efficient manner and that the average firm (farmer) defines the function. Variations from the function are assumed to be random and associated with measurement errors or excluded production factors. Production functions (frontiers) as suggested originally by Aigner, Lovell & Schmidt (1977) and Meeusen & Van den Broeck (1977) discriminate between random errors and firm (farm) level differences in efficiency. In the production frontier approach it is assumed that the boundary of the production function (frontier) is defined by the "best" firms. The frontier therefore indicates the maximum potential output for a given set of inputs along a ray from the origin. Some random error is accommodated as the estimation approach is stochastic but an additional one

sided error term represents the other reasons why firms would be below the established boundary. Observations below the frontier are deemed inefficient. Using the estimated production frontier it is thus possible to estimate the relative efficiency of individual firms from the relationship between the observed individual production and the “best” or potential production level (Green, 1993 as seen in Pascoe et al., 2003).

A general stochastic production frontier can be represented by:

$$\ln q_j = f(\ln x) + v_j - u_j \quad (5.4)$$

where q_j is the output produced by firm j , x is the vector of input factors, v_j is the stochastic error term and u_j is a one-sided error term representing the technical inefficiency of firm j .

As the individual production of each firm j can be estimated as:

$$\hat{\ln q_j} = f(\ln x) - u_j \quad (5.5)$$

and the efficient level of production is defined as:

$$\ln q^* = f(\ln x) \quad (5.6)$$

the technical efficiency (TE) can be given by:

$$\ln TE_j = \hat{\ln q_j} - \ln q^* = -u_j \quad (5.7)$$

Hence, $TE_j = e^{-u_j}$, and is constrained to be between zero and one in value. If u_j equals zero, then TE equals one and the firm is said to be producing in a technically efficient manner. The technical efficiency of the firm is therefore a relative measure of its output as a proportion of the corresponding frontier output (Pascoe et al., 2003), i.e. the potential maximum output.

The stochastic production frontier approach to efficiency analysis has been used across the total spectrum of sectors of the economy, including management, finance, medicine, mining and even sports. Because the approach allows for comparing the technical efficiency of individual firms (farms) making use of different production technologies, practises or with specific characteristics, this approach has also been popular in analysis of farming systems. A number of researchers have used the approach to analyse the practises of farmers in Africa; some of the more recent publications include Ngwenya, Battese & Flemming (1997), Sherlund, Barrett & Adesina (2002), Binam, et al., (2004), Tijani (2006), Conradie, Cookson & Thirtle (2006) and Idiong (2007).

To date, the use of stochastic production frontiers in analysis of the efficiency impact of genetically modified crops has been limited. Thirtle, Beyers, Ismael & Piesse (2003) estimated and compared the technical efficiency of Bt cotton adopting and non-adopting smallholder farmers in South Africa and Kambhampati, Morse, Bennett & Ismael (2006) did the same for farmers in India. Gouse, Piesse & Thirtle (2006) use a stochastic frontier model to make efficiency comparisons between Bt and conventional seed types for one production season and also made some ex ante predictions on the labour impact of HT maize. Gouse, Piesse, Thirtle & Poulton (2009) use the frontier approach to analyse the efficiency impact of Bt and HT maize adoption by smallholder farmers in three sites for the 2006/07 season. Based on a review of the literature the latter two studies remain the only published research where the stochastic frontier approach is used to estimate and compare efficiency levels of smallholder farmers planting a genetically modified subsistence crop. Both these publications however apply the frontier approach to a single season. This thesis estimates the efficiency impacts for four seasons.

5.3 PRODUCTION FUNCTION APPROACH

Before fitting a production function to the data it is important to specify a functional form for the production function. It is not uncommon in the “impacts of GM crops” literature for authors to simply assume a certain production function, usually basing their decision on data limitations (Qaim & De Janvry, 2005, Ceddia et al., 2008 and Jorobe & Quicoy, 2006). This study uses two potential functional forms, the Cobb Douglas and Translog generalisation to test the adequacy of the Cobb Douglas representation of the data.

5.3.1 Test for functional form

Data for the 2006/07 season will be used to test for the functional form as the larger number of farmers in the 2005/06 season might lead to a functional form choice that is not suited for the smaller samples in 2007/08 and 2009/10. The production functions and frontiers in the next section were estimated using the STATA software package.

For the Translog, each explanatory variable is divided by its sample mean. By deflating by the sample mean the unit of measure changes and the advantage of normalising the data is that the first order coefficients can be interpreted as elasticities evaluated at the sample mean (Barros, Del Corral & Carcia-del-Barrio, 2009). To illustrate this approach, one can consider the Translog function presented on page 35 of Coelli, Rao & Battese (1998):

$$\ln y = b_0 + b_1 \ln x_1 + b_2 \ln x_2 + (1/2)[b_{11}(\ln x_1)^2 + b_{22}(\ln x_2)^2] + b_{12} \ln x_1 \ln x_2 \quad (5.8)$$

By deflating each variable by the sample mean, the mean of each variable is now equal to 1. The first order partial derivatives can be interpreted as elasticities at the sample mean as the natural log of 1 is 0 and equation (5.9) is simply equal to b_1 , i.e. the first order derivative and output elasticity with respect to input x_1 .

$$\frac{\partial \ln y}{\partial \ln x_1} = b_1 + b_{11} \ln x_1 + b_{12} \ln x_2 \quad (5.9)$$

A number of Cobb Douglas estimations were run and the best fit (most number of significant variables with correct coefficient signs) is presented in Table 5.1. The variables used in the Cobb Douglas function were then included in a Translog functional form in order to generate comparable log likelihood statistics.

The natural log of output in grain is hypothesised to be a function of:

lseedkg = natural log of kilograms seed planted

linsectexp = natural log of insecticide expenditure

ltotalhired = natural log of expenditure on total hired labour and services

lplotsize = natural log of the size of the planted maize plot

lprepplantfl = natural log of land preparation and planting family labour expenditure

lharvestfl = natural log of the harvest family labour expenditure

seeddumBt = whether a farmer planted Bt seed

seeddumHT = whether a farmer planted HT seed

intercropdum = whether a farmers made use of intercropping

Table 5.1: Cobb Douglas and Translog production functions for the 2006/07 season

Variables	Cobb Douglas	Translog
constant	3.49 (0.000)***	-0.11 (0.793)
lseedkg	0.32 (0.181)	-0.10 (0.696)
linsectexp	0.13 (0.077)*	-0.26 (0.705)
ltotalhired	0.07 (0.106)	-0.06 (0.582)
lplotsize	0.05 (0.848)	0.58 (0.057)
lprepplantfl	-0.02 (0.035)**	-0.09 (0.378)
lharvestfl	0.34 (0.004)***	0.47 (0.000)***
lseedkg ²		-0.52 (0.266)
linsectexp ²		0.08 (0.75)
ltotalhired ²		-0.06 (0.09)*
lplotsize ²		0.31 (0.665)
lprepplantfl ²		-0.02 (0.841)
lharvestfl ²		-0.18 (0.22)
lseedkg x linsectexp		-0.21 (0.583)
lseedkg x lttotalhired		0.32 (0.027)**
lseedkg x lplotsize		0.59 (0.532)
lseedkg x lprepplantfl		0.57 (0.011)**
lseedkg x lharvestfl		-0.54 (0.142)
linsectexp x lttotalhired		0.1 (0.605)
linsectexp x lplotsize		0.53 (0.188)
linsectexp x lprepplantfl		0.03 (0.826)
linsectexp x lharvestfl		0.03 (0.841)
lttotalhired x lplotsize		-0.39 (0.011)**
lttotalhired x lprepplantfl		-0.13 (0.116)
lttotalhired x lharvestfl		-0.04 (0.528)
lplotsize x lprepplantfl		-0.03 (0.929)
lplotsize x lharvestfl		0.28 (0.466)
lprepplantfl x lharvestfl		-0.20 (0.213)
seeddumBt	0.43 (0.037)**	0.11 (0.604)
seeddumHT	1.16 (0.000)***	0.30 (0.318)
intercropdum	0.64 (0.001)***	0.29 (0.156)
R-squared	0.538567	0.714784
Adjusted R-squared	0.487297	0.581090
S.E. of regression	0.655777	0.599777
Sum squared resid	34.83354	23.02285
Log likelihood	-85.43073	-67.47315
F-statistic	10.50446	5.346387
Prob (F-statistic)	0.000000	0.000000

* 90% statistical confidence level, ** 95% statistical confidence level, *** 99% statistical confidence level

For the functional form tests the null hypothesis (H_0) is that $\beta_{ij} = 0$, $i, j = 1, \dots, n$, meaning that the cross terms are not significantly different from zero and that the more flexible Translog reduces to the Cobb Douglas (CD). It is however clear from Table 5.2 below that the H_0 hypothesis has to be rejected as the generalised log likelihood ration (LLR) test statistic is larger than the χ^2 critical value at 95% probability. According to the LLR test the inclusion of the squared and cross terms thus improve the production function fit to the data and the Translog functional form is a more adequate representation of the data than the more restrictive CD.

Table 5.2: Hypothesis test for functional form

Hypothesis	Log likelihoods		LLR Test statistic	Degrees of freedom	χ^2 critical value
	H_0 : Cobb Douglas	H_1 : Translog			
H_0 : All $\beta_{ij} = 0$	-85.431	-67.473	35.915	21	32.67

Intuitively this makes sense as in maize production there are clear examples of interaction between variables like land size and seed and labour quantity. This interaction and the fact that in a production function these independent variables will in many instances move in the same direction (a larger plot size requires more seed, insecticides and labour) is however also the problem with Translog production functions (Pavelescu, 2010). The Translog's symptoms of a relatively high adjusted R^2 but few significant variables compared to the CD points to multicollinearity. Use of the CD functional form avoids some of the collinearity problems that are inherit to the Translog production function (Kawagoe, Hayami & Ruttan, 1985). This study will thus fit Cobb Douglas production functions to the 2005/06, 2006/07, 2007/08 and 2009/10 smallholder production data in order to identify and estimate the output impact of GM maize adoption.

5.3.2 Production function estimations for Hlabisa farmers

By considering the production function estimates in Table 5.3 it is apparent that the variables that played a significant role in output were not constant over the four seasons and it is clear that some variables that one would have expected to be significant, were not. When all the main variables were included, few or none were statistically significant, possibly due to collinearity. Herbicide application labour, herbicide expenditure and weeding labour are for instance strongly correlated (positive for application labour and expenditure and negative for

weeding labour) and for this reason only some salient variables ended up in the production functions.

An effort was made to try and test whether the data for the four seasons could be pooled to have a larger data set for more rigorous analyses but due to the fact that variables were not constant over the four seasons econometric analysis and comparison made little sense. Solely based on the rainfall indications previously discussed it is clear that it is not necessary to rely too much on statistics to conclude that pooling is not a good idea. With a larger sample of farmers (>400) it would have been possible to estimate separate production functions for each seed technology, but due to relatively small seed type specific sample sizes, this thesis, like Huang et al., (2002) and Qaim & De Janvry (2005), uses dummy variables in the production function to distinguish between farmers using different seed types and other production practices and conditions.

The adjusted R-square supplies a measure of the proportion of the variation in the dependent variable accounted for by the explanatory variables. In 2005/06 the specified CD production function is thus able to explain 31% of the variation in output, while the functions for the 2007/08 and 2009/10 seasons fit the data slightly better and in 2006/07 the production function is able to explain 50% of the variation in output which is more than acceptable for cross-section data analysis.

2005/06

In this the driest of the four seasons output is dominated by the size of the maize plot planted. Herbicide application had a significant and positive impact on output and it was predominately the HT adopters that used herbicides. The HT dummy variable however is not found to be significant possibly due to correlation with herbicide expenditure though some HT adopters did not apply herbicides in this season. The use of Bt maize had a positive and statistically significant impact on output. The dummy variables cause a shift in the intercept of the fitted function and the use of Bt maize thus increased output, compared to conventional maize farmers, by 0.5/6.77 or 7.4%. Bt farmers thus produced 7.4% more grain with the same level of inputs as conventional farmers. Expenditure on fertiliser was not found to contribute significantly to output in any of the seasons. It seems as if fertiliser's effect is muddled / diluted by the correlating effect of other variables like plot size and seed expenditure and quantity.

Table 5.3: Cobb Douglas production function estimates for Hlabisa farmers for the four seasons

	2005/06	2006/07	2007/08	2009/10
Number of observations	120	95	96	98
R-squared	0.3743	0.5507	0.4609	0.4707
Adjusted R-squared	0.3106	0.5031	0.4189	0.4098
constant	6.77 (0.000)***	3.75 (0.000)***	8.18 (0.000)***	5.35 (0.000)***
lplotsize	0.90 (0.000)***	0.10 (0.701)	1.23 (0.000)***	-
lseedexp	-0.15 (0.222)	-	-	-
lseedkg	-	0.33 (0.145)	-0.46 (0.018)**	0.62 (0.003) ***
lfertexp	-0.06 (0.414)	-	-	-0.01 (0.945)
ltotalherbexp	0.11 (0.099)*	-	-	-
linsectexp	-	0.15 (0.035)**	-	-
llandpreplantfl	0.04 (0.612)	-0.19 (0.014)**	-	-0.06 (0.327)
linsectfl	-	-	-	-0.68 (0.836)
lweedfl	0.08 (0.224)	-	0.16 (0.052)*	-
lharvestfl	-	0.36 (0.002)***	-	0.26 (0.001) ***
ltotalhired	-0.04 (0.384)	0.05 (0.214)	-	-0.08 (0.268)
landprepandplantfl	0.05 (0.887)	-	0.27 (0.113)	0.02 (0.859)
nointercropdum	-0.06 (0.635)	0.64 (0.000)***		0.03 (0.748)
seeddumbt	0.50 (0.004)***	0.28 (0.148)	0.26 (0.102)	-
seeddumht	-0.09 (0.390)	1.06 (0.000)***	0.4 (0.017)*	0.38 (0.005) ***
seeddumbr	n.a	n.a	0.34 (0.062)*	0.31 (0.048)**

* 90% statistical confidence level, ** 95% statistical confidence level, *** 99% statistical confidence level

Key: plotsize – size of area planted to maize, seedexp – expenditure on seed, seedkg – weight of seed planted, fertexp – expenditure of fertiliser, totalherbexp – total expenditure on herbicide, insectexp – expenditure on insecticide, landprepandplantfl – value of family labour spent on land preparation and planting, insectfl – value of family labour spent of insecticide application, weedfl – value of family labour spent on manual weeding, harvestfl – value of family labour spent on harvesting, landprepandplantfl – farmers that planted using hand and hoe without any mechanised or animal draught services or assistance, nointercropdum – farmers who did not practice intercropping, seeddumbt – farmers who planted Bt seed, seeddumht – farmers who planted HT seed, seeddumbr – farmers who planted BR seed

2006/07

Farmers who applied insecticides in 2006/07 performed better than farmers who did not. This might explain Bt maize's slightly higher yield in this season but as the Bt dummy is not significant it might rather be a sign of endogeneity – better farmers controlling borers. Land preparation and planting labour had a negative impact on output which is difficult to explain as the HT adopters (with the higher yield) spent more family labour on this activity. Not surprisingly higher output required more harvesting labour. Farmers who did not make use of intercropping harvested 17% more maize in this second driest season (but intercropping was not significant in the previous drier season and also not in the following seasons). According to the production function approach HT farmers' output was 28% higher than that of

conventional farmers in this season, which is statistically significant but much lower than the estimations in Chapter 4.

2007/08

In this season plot size again had a substantial and significant impact. As Bt and BR farmers planted less seed than the conventional farmers, and had higher yields, there is a significant negative relationship between seed quantity (kg) planted and output. Interestingly manual weeding labour has a positive impact possibly due to Bt farmers using slightly more weeding labour (see production budget in Chapter 4). HT and BR had a significantly positive impact on output but Bt just missed the critical significance level. HT increased output by 5% and BR by 4% – again much lower than the partial productivity yield impact estimations.

2009/10

In this season the only significant variables besides the HT and BR dummies are seed quantity which now has a positive impact on output and harvesting labour. HT increased output by 7% and BR increased output by 6%. Total hired labour has not been significant in any of the seasons with land preparation and planting, weeding and harvesting labour moving in different directions and the total impact on labour being distorted.

Though the production function results generally support the partial productivity findings of Chapter 4 (Bt and HT maize render higher yields than conventional maize), the findings are less than enlightening. The production function approach it is meant to present a more complete aggregated picture but a number of explanatory variables that ought to be significant are not, mainly due to a large level of variability and small seed-type-specific farmer groups with heterogeneous production practises. In 2007/08 for instance there are 96 farmers and four seed types. It is suggested that with a farmer sample three or four times larger, more convincing results could have been found. With a larger group of farmers it might also be able to estimate different production functions for each seed type, identifying the specific impact of each variable, which at the moment are lost in a general average function. Additionally the production function approach assumes rather unrealistically that all farmers produce at the same level of technical efficiency. In order to calculate individual farmer's efficiency levels, stochastic production frontiers are estimated next for the four Hlabisa seasons using the maximum likelihood approach.

5.4 STOCHASTIC PRODUCTION FRONTIER APPROACH

Estimated stochastic production frontiers with a Cobb Douglas functional form for the four seasons are presented in the next four Tables. Different distributions, normal or half-normal, exponential and or truncated-normal, were assumed in order to identify inefficiency. A number of these are presented in Appendix B. The best fit frontiers for each season are presented below. The main aim of this section is to present the estimated frontiers and to determine if the frontier approach is more appropriate than the OLS functions estimated above. The aim is not to run an inefficiency model to determine which variables increased or decreased inefficiency. The objective of running the frontiers is to calculate farmers' individual efficiency scores so that farmers can be compared across different seed technologies.

For most of the seasons the maximum likelihood estimations of the explanatory variables correspond with the ordinary least square estimations discussed in section 5.3.2 above. For some seasons a different specification is used, i.e. other variables are included in order to add variables that ought to be affected by adoption of different seed technologies and it is clear from the tables in Appendix B (especially for 2007/08 and 2009/10) that inclusion of these effect the relative efficiency levels. However, the frontier estimations suffer from the same limitations as the OLS production functions, in that some main and disaggregated variables are too strongly correlated to be included together in the frontier specification. Variables like seed expenditure, herbicide expenditure and manual weeding are strongly correlated with the seed dummy variables. The frontiers (like the mean functions) have more explanatory value with the dummy variables and a couple of salient variables included than with all the variables.

The estimated efficiency scores for each seed specific farmer group are indicated in the Tables for each season. These scores will be summarised and discussed in more detail in section 5.5. The key test parameter in the frontier estimation is $\gamma = \sigma_u^2 / (\sigma_u^2 + \sigma_v^2)$, which is the ratio of the errors in equation (5.4). Gamma (γ) is defined between zero and one, where if $\gamma = 0$, technical inefficiency is not present, and if $\gamma = 1$, there is no random noise. If $\gamma = 0$ the mean response production function (OLS) is an adequate representation of the data, whereas the closer γ is to unity, the more likely it is that the frontier model is appropriate (Battese &

Coelli, 1995). The relative importance of inefficiency is measured by $\lambda = \sigma_u / \sigma_v$ which indicates to what extent inefficiency is the source of deviation from predicted outputs (Berg, Lin & Tsaplin, 2005). The null hypothesis test that there is no inefficiency and deviation off the frontier is due to random error, i.e. $\sigma_u=0$ is tested with the likelihood-ratio test and the outcome indicated by the Prob>=chibar2 where a value below 0.01 means that the null hypothesis can be rejected at a 99% confidence level.

For the 2005/06 season the maximum likelihood estimations for the variables correspond to a large degree with the ordinary least square estimations. However, the significantly different to zero γ suggest that the production frontier is a more adequate representation of the data than the OLS production function as there is a substantial inefficiency component. The null hypothesis is rejected at the 95% confidence level ($p=0.012$). It is clear that Bt and HT adopting farmers were more efficient than conventional seed planting farmers.

Table 5.4: Stochastic production frontier for 2005/06

	Normal / half-normal distribution
Number of observations	120
Wald Chi ²	85.47
Log likelihood	-100.61
constant	6.81 (0.000)***
lplotsize	0.80 (0.000) ***
lseedexp	-0.06 (0.627)
lfertexp	-0.08 (0.278)
ltotalherbexp	0.1 (0.063)*
llandpreplantfl	0.10 (0.202)
lweedfl	0.06 (0.298)
ltotalhired	-.03 (0.481)
landprepdum	0.15 (0.652)
nointercropdum	-0.05 (0.641)
seedumbt	0.42 (0.009) ***
seeddumrr	-0.12 (0.206)
sigma_v	0.3733
sigma_u	0.7116
lambda	1.9062
gamma	0.7842
Likelihood-ratio test of sigma_u=0:	
chibar2(1)	5.08
Prob>=chibar2	0.012
Average efficiency scores by seed type	
Bt	0.653
HT	0.615
Conv	0.598

For 2006/07 (Table 5.5) the high λ and γ statistics confirm the presence of technical inefficiency and the null hypothesis is rejected at a 90% confidence level. Corresponding to the production function's findings, farmers who adopted HT and / or did not intercrop, produced substantially and significantly more maize. According to the estimated efficiency scores Bt and conventional farmers performed more or less at the same level of efficiency while HT farmers performed better.

Table 5.5: Stochastic production frontier for 2006/07

	Normal / half-normal distribution
Number of observations	95
Wald Chi ²	68.27
Log likelihood	-87.81
constant	4.92 (0.000)***
lplotsize	0.24 (0.356)
lseedkg	0.22 (0.362)
linsectexp	0.12 (0.062)*
ltotalhired	0.03 (0.468)
llandprepandplantfl	-0.21 (0.004)***
lharvestfl	0.31 (0.004)***
nointercropdum	0.60 (0.000)***
seeddumbt	0.25 (0.170)
seeddumrr	0.92 (0.000)***
sigma_v	0.3857
sigma_u	0.8092
lambda	2.0980
gamma	0.8149
Likelihood-ratio test of sigma_u=0: chibar2(1)	2.51
Prob>=chibar2	0.057
Average efficiency scores by seed type	
Bt	0.575
HT	0.611
Conv	0.567

For the 2007/08 season (Table 5.6) with four seed groups in a relatively small sample the production function model specification in Table 5.3 does not converge as a frontier. As was clear from the production budget in Chapter 4 the production system for Bt maize is very similar to that of the conventional and the HT and BR are similar. However only 4 Bt and BR farmers made use of intercropping and when the intercropping dummy is included it dominates the effect of the seed dummies (see Appendix B). A large number of frontier estimations were run for all three distributions but most specifications did not converge. The comparatively best fit exponential distribution frontier is presented in Table 5.6 but it is clear from the low λ and γ statistics that for 2007/08 the frontier is not a more appropriate model

than the OLS production function. The null hypothesis that there is not a significant level of technical inefficiency cannot be rejected. When one considers the small difference between the efficiency levels of the different seed groups, it would appear as if the test statistics are correct and that there is little technical inefficiency to be identified with the frontier specifications used in 2007/08.

Table 5.6: Stochastic production frontier for 2007/08

	Exponential distribution
Number of obs.	96
Wald Chi ²	46.75
Log likelihood	-61.23
constant	5.31 (0.000)***
lplotsize	
lseedkg	0.42 (0.006)***
lfertexp	0.08 (0.616)
ltotalhired	0.01 (0.881)
ltotalfl	
nointercrop	0.48 (0.000)***
seeddumbt	0.02 (0.913)
seeddumrr	-0.03 (0.802)
seeddumbr	0.03 (0.869)
seeddumconv	
sigma_v	0.4032
sigma_u	0.2206
lambda	0.5470
gamma	0.2304
Likelihood-ratio test of sigma_u=0:	
chibar2(1)	0.60
Prob>=chibar2	0.220
Average efficiency scores by seed type	
Bt	0.821
HT	0.826
Conv	0.802
BR	0.831

The frontier for 2009/10 is better behaved and the high λ and near unity γ statistics show that the frontier is a more appropriate representation of the data than the mean response production function. The exponential distribution gave the best fit and a different specification, than the one used for the production function, are presented in Table 5.7. The land preparation dummy variable (landprepdum) represents farmers that planted using hand and hoe without any mechanised or animal draught services or assistance. According to the calculated efficiency scores HT farmers and BR farmers were more efficient than conventional farmers. The efficiency scores are discussed in more detail in the next section.

Table 5.7: Stochastic production frontier for 2009/10

	Exponential distribution
Number of obs.	98
Wald Chi ²	161.39
Log likelihood	-33.20
constant	5.53 (0.000)***
lseedkg	0.82 (0.000)***
lfertexp	0.004 (0.978)
ltotalhired	-0.10 (0.011)**
llandprepdplantfl	-0.06 (0.169)
linsectfl	0.004 (0.986)
landprepdum	0.15 (0.018)**
nointercrop	0.079 (0.282)
seeddumrr	0.26 (0.003) ***
seeddumbr	0.17 (0.09) *
sigma_v	0.1513
sigma_u	0.3650
lambda	2.4124
gamma	0.8534
Likelihood-ratio test of sigma_u=0:	
chibar2(1)	26.81
Prob>=chibar2	0.000
Average efficiency scores by seed type	
HT	0.736
Conv	0.706
BR	0.759

5.5 EFFICIENCY COMPARISON

Table 5.8 presents a comparison of the average efficiency scores for the four seasons based on the above stochastic production frontiers. Like with the yield comparisons, some of the differences are substantial but due to the small sample sizes and a high level of variation, only one mean difference was found to be statistically significant at an acceptable level.

For the 2005/06 frontier it was possible to include most of the important explanatory variables. On average Bt planting farmers were 9.4% more efficient than conventional maize planting farmers, despite paying more for seed. This difference is statistically significant at a 95% level. In this season when some HT adopters did not use herbicide and others struggled with application, HT adopters on average were 3.2% more efficient than conventional maize producers, despite paying more for seed and the majority spending money on herbicides. This difference is however not statistically significant. Bt maize farmers were more efficient due to

a higher yield and while HT farmers' yield were only slightly higher than that of conventional farmers, substantially less labour was used for especially weeding control.

In 2006/07 the “nointercropping” and HT dummies had a substantial impact on the estimated frontiers and it was not possible to include variables like herbicide expenditure, herbicide application family labour or manual weeding due to the strong correlation with the HT dummy. Some labour variables were however included (land preparation and planting and harvesting) along with hired services. The efficiency difference between conventional and Bt farmers is small and statistically insignificant. HT farmers were 7.7% more efficient than conventional farmers but this difference was also not statistically significant ($p=0.13$). This finding is slightly surprising as in this season HT farmers had a yield 94% higher than that of the conventional farmers (the kg grain per kg seed planted yield was 184% higher).

By referring back to the production budget of Chapter 4 one may be tempted to argue that the efficiency gains of higher yield and no weeding labour were cancelled out by the increased expenditure on seed, fertiliser and family labour for land preparation and planting. It is however important to judge the efficiency scores based on the variables included in the production frontier, i.e. the variables that gave the best fit. Seed expenditure, fertiliser expenditure and family manual weeding were not included in the frontier estimation as these variables were not found to be significant and prevented the frontier from converging. Seed expenditure for instance was too strongly correlated with fertiliser expenditure and the HT dummy variable. The increased expenditure on seed and fertiliser is thus not included in the efficiency estimation, but neither is the substantial saving in weeding labour.

With the 2007/08 production frontier struggling to converge the frontier specifications that were eventually used were not able to make much of a distinction between random noise and technical inefficiency. As a result the average efficiency scores for the four seed types in 2007/08 are very similar with Bt, HT and BR farmers producing 2.5, 3.1 and 3.6 percent more efficiently than conventional farmers. The BR mean difference to conventional maize only just misses the 90% statistical significance level with $p=0.11$.

Table 5.8: Average efficiency scores for farmers using different seed technologies

		Conventional farmer efficiency	Bt farmer efficiency	HT farmer efficiency	BR farmer efficiency
2005/06	n	60	38	21	
	Min	0.12	0.23	0.34	
	Max	0.91	0.83	0.80	
	Mean	0.60	0.65	0.62	
	Mean difference to Conventional		9.4%	3.2%	
	<i>t-Stat</i>		1.75 (0.04)	0.48 (0.32)	
2006/07	n	38	22	35	
	Min	0.15	0.19	0.15	
	Max	0.89	0.85	0.78	
	Mean	0.57	0.57	0.61	
	Mean difference to Conventional		1.3%	7.7%	
	<i>t-Stat</i>		0.14 (0.44)	1.12 (0.13)	
2007/08	n	28	11	38	19
	Min	0.42	0.70	0.68	0.76
	Max	0.91	0.90	0.91	0.91
	Mean	0.80	0.82	0.83	0.83
	Mean difference to Conventional		2.5%	3.1%	3.6%
	<i>t-Stat</i>		0.66 (0.26)	1.03 (0.15)	1.23 (0.11)
2009/10	n	16	0	67	15
	Min	0.24		0.17	0.47
	Max	0.93		0.96	0.91
	Mean	0.71		0.74	0.76
	Mean difference to Conventional			4.2%	7.6%
	<i>t-Stat</i>			0.45 (0.33)	0.73 (0.24)

In 2009/10 when none of the farmers in the sample planted Bt maize, HT and BR farmers on average produced 4.2 and 7.6 percent more efficiently than conventional farmers, but neither is statistically significant. Though it was possible to estimate appropriate production frontiers for this season, the explanatory variables included again were not ideal to explain the variation in inputs and production practices caused by adoption of especially HT maize.

From Table 5.9 below, it is also clear that the averages hide substantial variation within the seed groups. Slightly different averages were used for Table 5.9 than what were presented in Table 5.8, but the ratios between the different seed types remain the same. Care should be taken when interpreting these averages as some are based on only a couple of farmers. The main objectives is to show that there is a high level of variation within the seed type groups, that mechanised and animal drawn land preparation is not necessarily more efficient than manual land preparation and that intercropping's influence on output is not all that clear.

Table 5.9: Comparing average seed technology specific efficiency levels according to land preparation method and whether farmers did intercropping or not

Season	Seed type	Land preparation method	Efficiency score	Intercropping	Efficiency score
2005/06	Bt	hired or own tractor or oxen	0.648	Yes	0.663
		manual hand and hoe	-	No	0.639
	HT	hired or own tractor or oxen	0.725	Yes	0.630
		manual hand and hoe	0.656	No	0.690
	Conv	hired or own tractor or oxen	0.677	Yes	0.692
		manual hand and hoe	0.665	No	0.658
2006/07	Bt	hired or own tractor or oxen	0.764	Yes	0.585
		manual hand and hoe	0.478	No	0.624
	HT	hired or own tractor or oxen	0.663	Yes	0.668
		manual hand and hoe	-	No	0.514
	Conv	hired or own tractor or oxen	0.659	Yes	0.604
		manual hand and hoe	0.580	No	0.614
2007/08	Bt	hired or own tractor or oxen	0.827	Yes	0.847
		manual hand and hoe	0.796	No	0.822
	HT	hired or own tractor or oxen	0.832	Yes	0.823
		manual hand and hoe	-	No	0.836
	Conv	hired or own tractor or oxen	0.813	Yes	0.811
		manual hand and hoe	0.888	No	0.839
	BR	hired or own tractor or oxen	0.830	Yes	0.821
		manual hand and hoe	0.839	No	0.834
2009/10	HT	hired or own tractor or oxen	0.791	Yes	0.719
		manual hand and hoe	0.714	No	0.731
	Conv	hired or own tractor or oxen	0.655	Yes	0.714
		manual hand and hoe	0.697	No	0.674
	BR	hired or own tractor or oxen	0.691	Yes	0.757
		manual hand and hoe	0.770	No	0.733

5.6 CONCLUSION

The main objective of this Chapter was to analyse the performance of GM maize as produced by smallholder farmers in the Hlabisa area of KZN in a more aggregated and econometrically rigorous manner through production functions and production frontiers. Like with the partial analysis presented in Chapter 4 the analysis and discussion in this Chapter show that Bt farmers benefit through higher yields due to more effective (or actual) stem borer control and HT farmers through higher yields due to more effective chemical weed control and labour saving. In all four seasons the GM seed adopting farmers produced at a higher level of efficiency than conventional seed planting farmers. The impacts on insecticide use, seed expenditure and labour were however less clear and Chapter 5's findings thus only partially support the hypotheses stated in Chapter 1. Similar to Chapter 4, measuring the extent of the

benefit introduced by the particular GM traits is complicated by farmers' varying production systems and small seed specific sample sizes.

Though the production function approach employed in this Chapter made it possible to present a more aggregate impact picture, it was not possible to include all applicable explanatory variables partly due to problems of collinearity. Another major problem is that an average line is fitted for the total group of farmers. Though it was possible to identify the output impact of the different seed types through the seed dummy variables, it was not possible to sufficiently model the impact of especially HT maize adoption on labour as the labour requirements for different activities move in different directions, according to the seed type and production practises, and the average impact does not explain much and thus does not enter into the production function. It is clear that production functions for each seed type (and over the four seasons) would look different as farmers adapt and use different production practises. It is argued that the use of the stochastic production frontier approach is a step in the right direction to estimate individual farmers' efficiency levels. However these efficiency scores are calculated based on the farmer's relative position to the best performing farmers and all these performance levels are based on a production frontier estimated using, again, a general specification for the total group of farmers. In the estimation of the production frontiers it was in most cases not possible to include sufficient efficiency-explaining explanatory variables as the models just did not converge.

Due to the small sample sizes it is not possible to estimate seed type specific production functions and due to the large level of variability between the seasons, pooling across seasons is not an option. With seed specific production frontiers seed type efficiency comparisons would also not be possible.

CHAPTER 6

SUMMARY AND CONCLUSIONS

6.1 INTRODUCTION

This Chapter summarises the salient findings of this dissertation and how it addressed the hypotheses specified in Chapter 1. The study's shortcomings, need for further research and the applicability of the study's findings to smallholder maize farmers in Sub-Saharan Africa are discussed. Recommendations based on lessons learnt from the research and study findings are suggested for GM crop impact assessment practitioners, agricultural biotechnology- and seed companies as well as the South African Government.

6.2 SUMMARY

The South African smallholder GM maize experience has to date and internationally been the only example of where a subsistence crop is produced by subsistence farmers using GM seed. South African smallholders' experience with GM crops is thus of great interest to amongst others African decision makers and international food, agricultural and development organisations. Research and literature on the use of GM subsistence crops by African smallholder farmers is scarce and the current existing international body of literature is limited to four publications by the author of this thesis and research collaborators. Current publications' findings are limited and inconclusive because analyses were based on three or less seasons and findings fluctuated substantially between seasons. This thesis is an substation improvement on previous work in that it uses data collected from smallholder maize producers in the Hlabisa district of KwaZulu-Natal for the eight seasons 2001/02 to 2007/8 and 2009/10. This thesis comprehensively answers the general research question: Taking into consideration the immense variability in production conditions between seasons and in production practises between farmers, have smallholders benefited from the adoption of insect resistant (Bt) and or herbicide tolerant (HT) maize seed?

The first part of the study supplied background information on agricultural biotechnology, genetically modified crops and international and national adoption of these transgenic crops. Peer reviewed international literature show that farmers who have adopted GM seeds have

benefitted and the aggregated financial impacts on farm income have been quite substantial in countries where adoption had taken place. The farm-level impacts of insect resistant (Bt) and herbicide tolerant (HT) maize were discussed by considering impacts in other countries, South African commercial farmers' experience and based on the experience with similar traits in other crops.

The next part of the study set the scene for the analytical sections by describing how smallholder farmers fit into the South African historical and agricultural milieu. The evolution of the research project and approach, the research area and the data collection methods and challenges were discussed. Adoption of the new GM seed varieties by smallholder farmers has been limited by seed availability and farmers' different motivations for maize production. Hlabisa is the only area in South Africa where smallholders have been planting GM maize relatively continuously for the last eleven years. With farmers also adopting HT and BR seed in the latter seasons the seed specific sample groups became even smaller even though close to the total population was surveyed. Though the sample is small (<100 for most seasons) a nucleus of farmers made up a large share of the sample and in especially the last couple of seasons the same group of farmers, using different seed types, were surveyed. This adds to the credibility of the study findings as it controls for observed and un-observed farmer-specific effects. However, throughout the analytical sections the small sample problem persisted. Due to the small sample size and relatively high level of variability (heterogeneity) within the seed groups, in some seasons substantial performance and input use differences were found not to be statistically significant.

Early adopters of Bt and HT maize were compared to non-adopters to identify possible differences that can explain adoption and shed light on the potential problem of self-selection bias. It was cautiously deduced that 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 larger households (more mouths to feed). Early HT adopters on the contrary had smaller households (less labour) and more off-farm income (more cash but less weeding time). Substantially more male headed households than female headed households adopted GM maize. However, adoption requires more in-depth and econometrically rigorous analysis.

The first empirical analysis section of the study employed partial productivity measures like output per quantity seed planted or per unit area and also highlighted the impact adoption of these new technologies had on the use of and expenditure on other production inputs. The partial productivity measures showed that Bt and HT maize generally rendered higher yields than conventional maize due to the more effective manner in which pest damage (stem borer and / or weeds) is managed and limited. Table 6.1 summarises the yield assessment findings according to output per kilogram seed planted and output per hectare land, compared to that of the conventional maize seed group, for the final four seasons.

Table 6.1: Yield indications for Bt, HT and BR maize compared to conventional maize

Seed type	Yield measure	2005/06	2006/07	2007/08	2009/10
Bt	kg/kg	14%	8%	24%	-
	kg/ha	22%**	4%	21%	-
HT	kg/kg	-3%	184%***	8%	32%***
	kg/ha	9%	94%***	10%	10%
BR	kg/kg	-	-	33%*	21%*
	kg/ha	-	-	21%	12%

* 90% statistical confidence level, ** 95% statistical confidence level, *** 99% statistical confidence level

It is clear that the magnitude of results from the two approaches are different and that with both approaches some substantial yield advantages with GM maize were not found to be statistically significant. It is notoriously difficult to find statistically significant yield differences with small samples sizes, especially where the actual difference is relatively small. It is argued that due to the small sample sizes a Type II error is made for some seed types and seasons in that the null hypothesis, that the means are in fact equal, is wrongly not rejected. This is especially the case where yield differences are clearly substantial (but possibly based on outliers). One can conclude that where the yield differences are substantial but not statistically significant, GM maize had a yield advantage over conventional maize, but probably by less than the indicated percentage. Small sample single season findings should however be considered with great care and be interpreted in context irrespective of whether findings are statistically significant or not. For an average figure and considering six years of Bt maize production by smallholder farmers in Hlabisa, it was concluded at the 90% confidence level that Bt maize yielded 12% more grain on average than conventional maize. Though it was showed that pooling data across seasons is not a good idea and that an average

figure hides substantial variation, this figure compares well with the 11% yield benefit found with commercial farmers.

Bt farmers did not benefit much from saving on insecticides as insecticide usage on conventional maize is limited and there is also no insect-control related labour saving. The use of HT maize and herbicide has resulted in a substantial saving in especially weeding labour. However the total labour saving impact of HT maize depends on the land preparation and planting method of the farmers. When labour is used to do land preparation with own oxen or funds are spent on hired oxen or tractors the labour or monetary commitment is higher as farmers still have to plant by hand. However when weeds are killed with chemicals and farmers plant by hand and hoe according to the PWP method, in that they just open the soil with the hoe, plant a seed and close again, they have a substantial total labour saving benefit. According to the 2007/08 and 2009/10 labour use data farmers that use herbicides and PWP saved about 50% on labour.

Based on the production budget, different seed type adopters' level of "profitability" depends to a large degree on the production system of the farmer. In a couple of seasons Bt maize was the least profitable seed type, not because of the Bt technology related increased seed expenditure but because of other higher, seemingly not Bt-technology related expenditures like mechanised contract land preparation. This finding is even more applicable to HT maize as a HT adopting farmer who make use of family labour for land preparation and planting with hand held hoe will benefit more from the HT technology than a farmer who spends cash on contract land preparation or a farmer who open furrows with oxen and then plant by hand.

The complete budget presented a relatively complete picture of the Hlabisa farmers' experience with the GM events, but this approach is not ideal to isolate the effect of the different seed technologies with a number of variables moving in different directions. The situation is complicated even further by the fact that farmers make use of different farming practices and with the production budget these farmers are included in the same groups and averages hide the detail and differences.

In order to address this problem ordinary-least-squares production functions and stochastic frontiers were fit to the final four seasons' data and individual farm efficiencies were calculated to be compared across seed technologies. Like with the partial analysis, the

production function and frontier approaches found that Bt farmers benefit through higher yields due to more effective (or actual) stem borer control and HT farmers through higher yields due to more effective chemical weed control and labour saving. In all four seasons the GM seed adopting farmers produced at a higher level of efficiency than conventional seed planting farmers. GM seed adoption's impact on output according to the production function approach and the average efficiency scores (relative to conventional maize planting farmers) are summarised in Table 6.2.

Table 6.2: GM seed adoption output effect and average efficiency score comparison

		2005/06	2006/07	2007/08	2009/10
Bt	Output effect	7%***	7%	3%	
	Efficiency comp.	9%**	1%	3%	
HT	Output effect	-1%	28%***	5%*	7%**
	Efficiency comp.	3%	8%	3%	4%
BR	Output effect			4%*	6%*
	Efficiency comp.			4%	8%

* 90% statistical confidence level, ** 95% statistical confidence level, *** 99% statistical confidence level

As with the partial productivity impact approach, measuring the extent of the particular GM traits' benefit is complicated by farmers' varying production systems. Though the production function approach made it possible to present a more aggregate impact picture, it was not possible to include all applicable explanatory variables partly due to problems of collinearity. Another major problem is that an average line is fitted for the total group of farmers. Though it was possible to identify the output impact of the different seed types through the seed dummy variables, it was not possible to sufficiently model the impact of especially HT maize adoption on maize production labour. Land preparation and planting-, weeding-, herbicide application- and harvesting labour move in different directions, according to the seed type and production practises, with the effect that the average impact does not explain much output variation and thus does not enter into the production function. It is clear that production functions for each seed type (and over the four seasons) would look different as farmers adapt and use different production practises. It is argued that the use of the stochastic production frontier approach is a step in the right direction to estimate individual farmers' efficiency levels. However these efficiency scores are calculated based on less than ideally specified general production frontiers as in the estimation of the production frontiers it was in most cases not possible to include sufficient efficiency-explaining explanatory variables as the models did not converge – again to a large degree a result of the small farmer samples and production practice heterogeneity.

6.3 ADDRESSING THE HYPOTHESES

Despite the above mentioned limitations, the study was able to satisfy the stated hypotheses:

The first hypothesis on Bt maize stated:

Smallholder maize farmers in South Africa benefit from adoption of Bt maize varieties in seasons with significant stalk borer pressure, due to higher yields (less borer related damage), and despite paying more for the Bt seed and not saving substantially on insecticide application.

From the partial productivity and production function analysis it is clear that smallholder Bt adopters did enjoy higher yields than their conventional maize planting counterparts, Bt maize planting farmers did pay more for their seed and did not save substantially on insecticide use. The yield advantage attributed to Bt maize was in most seasons enough to cover the additional seed expenditure. However, the net welfare gain from the use of Bt maize in some seasons were distorted to a large degree by increased expenditure by Bt adopters on other inputs not related to the Bt technology.

An additional issue captured in the hypothesis and not optimally addressed in this study is the issue of “significant stalk borer pressure”. Farmers’ indications of their borer pressure perceptions were insightful but not very useful to explain yield increases with Bt maize. With few farmers making use of insecticides, this could also not be used as a proxy for borer pressure or potential damage. This study could have benefitted from seasonal plot-specific or even area-specific quantitative borer pressure indications and damage assessment. Though significant borer damage on maize ears was observed for most seasons, first generation borer damage to maize plant stems could not be quantified and farmers’ indication of borer pressure remained relatively low throughout the study period.

The second hypothesis on HT maize stated:

Smallholder maize farmers in South Africa benefit from the adoption of HT maize through higher yields (due to more effective weed control), a decreased need for weeding labour and despite spending more on chemical herbicides and HT seed. The labour saving benefit of HT maize however depends on the farmer’s production system.

From the partial productivity and production function analysis it is clear that HT maize seed adopting smallholder farmers benefitted through higher yields brought about by more effective chemical weed control, compared to the manual weed control practices of conventional maize planting farmers. HT seed adopters spent considerably more on herbicide than conventional farmers as few conventional maize farmers actually make use of herbicides. In Hlabisa, HT adopting farmers spent substantially more on seed than their conventional counterparts, with one or two informal seed distributors also benefitting from the growing demand for HT seed. In seasons when HT farmers were able to control weeds effectively with herbicide, HT farmers spent no or very little labour on manual weed control. As stated in the hypothesis the total labour saving benefit of HT maize however depends on farmers' production system with farmers making use of conservation / minimum tillage or "planting without ploughing" using significantly less labour than farmers doing land preparation with tractors or oxen and only then planting.

HT maize rendered the highest net farm income in three of the four latter study seasons. Farmers were able to increase their net farm income through a higher yield and considerable saving on manual weeding family labour. It is clear that farmers have realised this as by the final study season (2009/10) none of the farmers in the sample still planted Bt, few still planted conventional maize and the rest all planted HT or BR maize. Though the additional expenditure on HT seed and herbicide outstripped the saving on manual weeding labour, farmers seem to be willing to pay for the weed control convenience. It would seem as if farmers value the yield increasing and labour saving benefit of HT maize higher than the borer control insurance of Bt maize, though a couple of farmers were willing to pay the higher price for both the traits (BR).

6.4 STUDY LIMITATIONS AND FUTURE RESEARCH

As indicated above it is thought that this study could have benefitted from the involvement of an entomologist to measure and quantify borer pressure and damage.

However, the biggest limiting factor in this study is the small sample size as linked to the small GM maize adopting farmer population. In a number of seasons farmers struggled to obtain GM seed. This was partly due to mismanagement at the farmers' coop in Hlabisa (2003/04) but mainly due to seed multiplication and distribution problems on the side of

Monsanto (2002/03 and again in 2006/07). In many seasons close to the total population of Bt maize seed adopters were surveyed but with farmers also opting for HT and later BR seed, the number of farmers in each seed group became too small despite the addition of new adopters. This had an adverse impact on the statistical significance of a number of findings. In order to address this an effort was made to survey the same farmers each season in order to remove some farmer-specific variation and it is argued that though some findings were not found to be statistically significant, substantial differences cannot be discarded. The value of adding a time-series component to the cross-section analysis is however not directly observable in the partial productivity analysis or single season production functions and frontiers. It is thought that it might be possible to add some analytical power to the individual season analyses by analysing the latter four seasons as a panel. Additionally, though this study endeavoured to limit the effects of self-selection bias by following the same group of farmers for a number of seasons, it should be possible to compensate for selection bias in an econometric fashion in a panel analysis approach. This approach however falls outside the scope of this thesis.

An important issue not reported on in this thesis is the question of whether the labour saving benefit of HT technology leads or could lead to an expansion of maize production by smallholder farmers. The focus area of the study (Hlabisa) is not ideal to test this hypothesis as the hilly nature of the topography limits expansion of crop fields. It is argued that output market limitations and farmer motivations for production will also play a role in an expansion decision. Future research will test these hypotheses by also analysing data collected in the more land abundant Simdlangentsha area.

A number of other important issues were touched on in the study but not analysed to a satisfactory level. These require more in-depth research and analysis. Some of these include:

- Adoption analysis
- Gender issues
- Labour use analysis
- Food security impact
- Three year panel data analysis - comparison between Hlabisa and Simdlangentsha
- Modelling weed control with a damage abatement function

6.5 APPLICABILITY OF STUDY FINDINGS TO SMALLHOLDER MAIZE FARMERS IN SUB-SAHARAN AFRICA

South Africa's history of racial segregation has translated into the geographically inequitable establishment of key support services such as roads, input distribution outlets, and research, extension and financial services. Small-scale and subsistence farmers in certain areas in the former homelands have faced and still face various production and marketing constraints that are similar to those of other smallholder farmers in Sub-Saharan Africa (SSA). To suggest that South African smallholders' and rural households' production and living conditions are identical or directly comparable to that of farmers in the rest of SSA would not be correct. Two main differences are discussed.

South Africa has a well-developed agricultural input sector. Even though this input sector historically focussed and currently still focuses on the large-scale commercial farming sector, smallholder farmers generally has access to agricultural inputs like fertiliser and certified hybrid seed, albeit a smaller selection or at a higher cost (due to transport, small volume packaging and middle-man profit-taking). Though this situation is far from ideal and Hlabisa farmers indicated that they struggle to find the seed of their choice (especially at the right time) and herbicides, it is suggested that South African smallholder farmers' access-to-inputs situation is superior to that of most farmers in SSA countries.

Agriculture is not the main source of income or livelihood for most surveyed Hlabisa farmers and it would be accurate to suggest that this is the case for most South African smallholder farmers. Even though maize plays a major role in the rural household and contributes considerably to food security, most households' main income source is government grants (old age pension and child grants), remittances and off-farm income. If the household runs out of maize grain there generally is enough cash in the household to buy from neighbours or there is maize flour available (produced by the commercial farmer sector) at the shop in town. In contrast, in many SSA countries, rural households have to be self-sufficient and a failed crop or shortage leads to malnourishment or worse.

However, the maize pests smallholders in South Africa and the rest of SSA face are quite similar. *Busseola fusca* (African stem borer) is considered to be the most important insect pest of maize in SSA (Bosque-Perez, 1995) while *Chilo partellus* causes severer damage in

especially the warmer lower regions (Mugo et al., 2002). As was discussed in Chapter 4, weeds cause severe damage to maize crops in Africa and in effect sentences farmers and rural households to a life of drudgery.

Based on the performance of Bt and HT maize as used by South African smallholder maize farmers, farmers in the rest of SSA will definitely be able to benefit from these new seed technologies. It can be argued that farmers in the rest of SSA are probably more motivated to produce a larger crop than South African smallholders. With most SSA smallholder farmers producing a number of different crops (risk diversification) weeding labour is a limiting factor. Insect pressure in higher rainfall countries is also more severe. It is thus possible that SSA farmers stand to benefit more than South African smallholder farmers. The challenge however would be to make the seed technology accessible to SSA farmers in an affordable and sustainable manner along with necessary and complimentary inputs like herbicide and fertiliser. Functioning output markets are also essential to stimulate production and to enable farmers to sell surpluses to recoup additional input costs. Without functioning input and output markets adoption and benefits of GM crops will be short-lived and minimal.

6.6 OBSERVATIONS, LESSONS AND RESULTING RECOMMENDATIONS

This study has stretched over a period of nine years. Throughout this period a number of observations were made and lessons learnt. Some of the lessons learnt might be useful to other practitioners studying the socio-economic and farm-level impacts of genetically modified crops. A couple of recommendations are also made to agricultural biotechnology / seed companies and the South African Government.

6.6.1 Recommendations to GM crop impact assessment practitioners

- Recall data on especially input type, input quantities, labour and output can be quite useless and is generally more an indication of the enumerators' knowledge or perceptions. It is important to collect data on production practices (especially labour use) as close to the event as possible. Though it might be possible to verify farmer indications through group meetings, individual farmer variation might be lost.

- South African smallholder farmers are not able to supply accurate information on the size of their maize plots. Whether this fallacy is caused by mechanised contractors, a low education level or the fact that the plots were never actually measured is not clear.
- Using enumerators living in the community greatly benefitted the project. As enumerators know the area and are known by the community, they were able to find farmers (based on seed sales lists) and farmers generally trusted them with household information. Enumerators were able to supply additional information on the area, community, events, concerns and perceptions regarding seed types and input suppliers. This type of information is not easily captured in a general questionnaire. By employing people from the area, farmers also saw the project as beneficial to the community and this further added to the sentiment of good-will and cooperation.
- By visiting farmers a number of times through the season, data could be collected as production activities took place, but enumerators were also able to return to farmers with earlier questionnaires that had been reviewed to correct, confirm and collect additional information on interesting or questionable answers. This ensured accurate and contextualised data.
- Feedback of research findings to farmers, already after two or three seasons, through presentations at farmer association meetings was well received. The feedback enabled farmers to better understand the study objectives and how their information was used.
- The collaboration of provincial Department of Agriculture extension officers was vital in the planning, implementation and running of the surveys as well as in interpretation of survey answers and explanation of anomalies.

6.6.2 Recommendations to agricultural biotechnology- and seed companies

In 2001 Monsanto made an effort to introduce Bt seed to South African smallholder farmers by conducting workshops in nine areas in the four provinces where the majority of smallholders are situated. Approximately 3 000 farmers were invited and were informed 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 containing Bt seed and the conventional near-isoline. The idea was for farmers to go and try the Bt seed and decide for themselves.

In 2002 farmers had to purchase their own seed, basing their decision on their experience of the previous season. The 2002/03 season did see an impressive demand for Bt seed from various sites but only a limited number of small-scale farmers were able to buy Bt seed due to a limited seed supply caused by seed multiplications problems on the side of Monsanto and an increased demand for Bt seed by large-scale farmers.

In 2003/04 and 2004/05 HT demonstration plots were planted in Hlabisa and Simdlangentsha. In 2005/06 a number of farmers in Hlabisa bought HT seed and according to extension officers and enumerators this was also the case in Simdlangentsha. However, in 2006/07 there was no HT seed available for Simdlangentsha farmers despite a substantial demand. If it was not for a leader farmer in Hlabisa who took initiative and sourced some commercial farmer HT seed, there would have been few HT planting farmers in Hlabisa as well.

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 in smallholder maize production areas (prior to Bt's introduction) it can probably be argued that they are still learning how to service this market. The profits made on small GM maize seed bags sold to a relatively small number of farmers in remote areas are also probably marginal. However, it is likely that GM maize adoption by smallholder maize farmers would have been higher now, ten years after first introduction, if they had more constant access to Bt and HT seed.

The South African smallholder farmer experience with GM maize is viewed with great interest by the rest of the world and especially the rest of Africa. From this study it is clear that smallholder maize farmers can and do benefit from Bt and HT seed and a substantial level of adoption by smallholders could have illustrated how much smallholders value these technologies. Though it cannot be expected that smallholder adoption of GM maize will reach the high level observed with commercial farmers, due to differences in production motivations, adoption is still minimal because a constant and predictable seed supply to smallholders was not prioritised.

A second issue regards seed varieties. The GM varieties bought and planted by the smallholder farmers are commercial high yielding but input intensive varieties. A couple of farmers expressed the wish to have especially the HT event in the inexpensive, older and drought tolerant PAN 6043. For adoption of GM maize by smallholder farmers to increase, seed companies might have to insert the GM events into less expensive but better adapted maize hybrids or develop new germplasm suited to smallholder conditions.

6.6.3 Recommendations to the South African Government

The South African Government played an enabling role in the introduction and adoption of GM crops in South Africa by instituting a biosafety regulatory body under the GMO Act (15/1997). This Act, as amended in 2006, provides a comprehensive biosafety framework to manage research, development, application, production, and trade in genetically modified organisms. The GMO Secretariat is housed in the Department of Agriculture and decision-making is vested in the GMO Executive Council that represents eight government departments. The Council is advised by a national Advisory Committee of scientific experts.

Since implementation, the GMO legislation has served the country well in its balanced approach to modern biotechnology and its applications. The economic welfare increase due to the use of approved GM technologies on soybeans, cotton and maize over the last decade has been immense (see aggregate figures in Chapter 2). However, more recently there have been a number of unclear delays in the biosafety decision-making process and the scientific community and academia have expressed concern that decision making has become less scientific. A lack of transparency in the process could lead to an increase in the cost of regulation, serve as a deterrent for basic biotechnology research and increase opportunity cost for research institutions and innovators, ultimately to the detriment of South African consumers.

The South African Government has indicated rural poverty alleviation as priority and has identified agriculture as a main driver of development (DAFF, 2011). Based on this study's findings, Bt and especially HT technology can be a great tool to increase efficiency, decrease need for weeding labour or expand maize plantings (with same amount of labour). This seed technology however should only form part of a larger production approach with functioning and sustainable input and output markets.

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APPENDIX A



GM maize vs. Conventional Maize Questionnaire 1 for South African Small Holders

This questionnaire is part of a research project conducted by the University of Pretoria and a number of international collaborators including Imperial College in London. The aim of this survey is to collect necessary information from farmers to evaluate the performance and efficacy of genetically modified maize as produced under smallholder conditions. All information will be treated with utmost confidentiality.

1. Personal Information and Information on the Household Head

1.1	Respondent Number								
1.2	Name of Enumerator								
1.3	Date of interview	2	0	0	7				
1.4	Village								
1.5	Farmer surname								
1.6	Farmer name								
1.7	What is the household position of the farmer you are talking to?								
Information on the Head of Household									
1.8	Gender of household head	Male				Female			
1.9	Age category of household head	<20	20-35	36-45	46-59	60-65	65+		

2. Household Background

2.1 Has any household members passed away or moved out of the household since December 2006?

Yes	No		
	Number	Male / Female	Age
Passed away			
Moved out of household			

2.2 Current number of people in the household?

2.3 Have you received any remittances (money) from a family member not living in the house in the last three months? Yes / No

If yes, please indicate the how much your have received:

Rand <100	101-200	201-400	401-600	601-800	801-1000	>1000
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2.4 What is the main source of income for the household?

Remittances	Wage income	Crop production and sales	Business
Pension	Child grants	Other government payments	Other:

2.5 When you started planting your maize this season, did you still have some maize grain or meal left of the 2007 harvest?

Yes / No If yes, how much? Number of bags..... .., size of bags.....kg

2.6 How many months were (will) your household (be) able to consume the maize you harvested in 2007 before it was (will be) finished? months.

2.7 Did you buy in extra maize meal? Yes / No If Yes, why?

Bought meal is better quality	Did not harvest enough maize	Other?
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Maize Cultivation

3.1 How many varieties of maize have you planted (or are you planning to plant) this season?

3.2 Have you planted (or will you plant) these varieties on the same plot or different plots?

Same / different

3.3 Were you able to buy your first choice of maize seed this season? Yes / No

3.4 If no, why not?

Not enough cash	Seed too expensive	Seed not available	Other?
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3.5 What was your first choice of seed? Bt / RR / Pan 6043 / other.

Please indicate.....

For All maize

4. For the following table, if the farmer is planting more than one plot of maize, fill in the details of one plot per column. If the farmer is only planting a single plot, but is planting more than one variety within this plot, fill in the details of one variety per column:

		PLOT OR VARIETY 1	PLOT OR VARIETY 2	PLOT OR VARIETY 3
4.1	Name of maize seed planted			
4.2	Area of plot (farmer estimate) (ha)			
4.3	How was (will) the land (be) prepared for maize production? 1= prepared by a contractor with tractor 2= prepared using own tractor 3= ploughed using own oxen 4= ploughed using hired oxen 5= prepared land with hand hoe <u>without</u> using herbicide 6= prepared with hand hoe and <u>used herbicide</u>			
4.4	Indicate plot or variety to be tracked during 2007/08			

For selected Plot only

For the plot or maize variety selected in Q4.4, please also supply the following information:

4.5	How was / will the maize seed (be) planted? 1= planted by contractor with tractor and planter 2= planted using own tractor and planter 3= planted with hired animal drawn planter 4= planted with own animal drawn planter 5= planted using hand and hoe	
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4.6	When was the land prepared? (Date)	
4.7	When did / will the farmer plant this maize? (Date)	
4.8	What quantity of maize seed did the farmer <u>buy</u> ? (kg)	
4.9	What quantity of maize seed did the farmer <u>plant</u> ? (kg)	
4.10	Where did the farmer buy the maize seed? 1 = coop; 2 = private wholesaler or retailer 3 = other (describe other)	
4.11	Where did you get the money to buy seed? 1 = savings; 2 = wage income; 3 = remittances; 4 = pension; 5 = livestock sales; 6 = other	
4.12	Did the farmer (will the farmer) apply herbicide to kill weeds before planting?	Yes / No
4.13	Did the farmer (will the farmer) apply herbicide after planting?	Yes / No
4.14	Will this maize crop be intercropped?	Yes / No
4.15	If yes to 4.14, with what other crop?	
4.16	What do you intend to do with this maize once you have harvested it? 1 = consume at home; 2 = sell; 3 = both	

Input use for selected Plot only

For the plot or maize variety selected in Q4.4, please supply the following information on inputs so far applied to the plot this season:

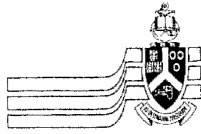
Input	Input name / type	Quantity	Cost
Tractor hire			
Own tractor			
Hired oxen			
Own oxen			
Seed			
Fertilizer			
Kraal manure			
Top dressing			
Herbicide			
Insecticide			
Other			

Enumerator's Name..... Farmer Number Farmer Name

Labour Activities only on Selected Plot

			Family Labour					
Farming Activity	Date Started	Number of days	No. of Children (<15 years)	Hours Per Child	No. of Adult Males	Hours Per Man	No. of Adult Females	Hours Per Woman
Land preparation								
Planting								
Herbicide application before planting								
Herbicide application after planting								
Weeding								
Insecticide application								
Other								

		Hired Labour			Working Groups			
Farming Activity	Date Started	No. of People	Days Per Person	Total Cost (Rand)	No. of People	No. of days	Hours Per Person	Means of Payment
Land preparation								
Planting								
Weeding								
Other:								



GM maize vs. Conventional Maize Questionnaire 2 for South African Small Holders

This questionnaire is part of a research project conducted by the University of Pretoria and a number of international collaborators including Kansas State University. The aim of this survey is to collect necessary information from farmers to evaluate the performance and efficacy of genetically modified maize as produced under smallholder conditions. All information will be treated with utmost confidentiality.

1. Identification information

1.1	Respondent Number								
1.2	Name of Enumerator								
1.3	Date of interview	2	0	1	0				
1.4	Village								
1.5	Farmer surname								
1.6	Farmer name								

2. Farming activities

2.1 If your household has any livestock, please indicate the number of animals currently owned.

Livestock	Number owned
1. Cattle	
2. Goats	
3. Chickens	
4. Sheep	
5. Donkeys	
6. Other	

2.2 Did you sell or slaughter any livestock over the Christmas- New Year period?

Yes		Type of animal	Number
No			
Sold			
Slaughtered			

2.3 What is the estimated total size of the arable land (land the farmer can work and plant) the household has access to for the

2009/2010 season hectares

2.4 Please indicate all the crops that are currently being produced by the household (including all maize and vegetables)

Crop	Estimated crop size (meters x meters or Hectare)

2.5 What is the measured size of the maize plot / plots? (to be measure by the enumerator with drawing at the back of this paper indicating dimensions and distances in steps). Only measure and draw the “selected” plot or plots.

3. Income and expenditure

3.1 Has the household received any remittances (money) from a family member not living in the household since we last came to ask questions? Yes / No

3.2. If Yes please indicate the value of these remittances in Rand

<150	150-350	351-650	651-1000	1001-1500	>1500	Don't know
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3.3 Has the farmer / household had to spend money on school fees, school clothes, stationary and books for the 2010 school year?

Yes / No

3.4 If Yes please indicate the one that best describe your expenditure

Rand <50	51-150	151-250	251-450	451-650	651-850	>850
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3.5 How much money did the household spend on food and festivities during the Christmas- New Year period?

<150	150-350	351-650	651-1000	1001-1500	>1500	don't know
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Enumerator's Name..... Farmer Number Farmer Name

Labour Activities on which plot?.....

			<i>Family Labour</i>					
Farming Activity	Date Started	Number of days	No. of Children (<15 years)	Hours Per Child	No. of Adult Males	Hours Per Man	No. of Adult Females	Hours Per Woman
Land preparation								
Planting								
Herbicide application before planting								
Herbicide application after planting								
Weeding								
Insecticide application								
Other								

		<i>Hired Labour</i>			<i>Working Groups</i>			
Farming Activity	Date Started	No. of People	Days Per Person	<u>Total Cost</u> (Rand)	No. of People	No. of days	Hours Per Person	Means of Payment
Land preparation								
Planting								
Weeding								

This questionnaire is part of a research project conducted by the University of Pretoria and a number of international collaborators including Imperial College in London. The aim of this survey is to collect necessary information from farmers to evaluate the performance and efficacy of genetically modified maize as produced under smallholder conditions. All information will be treated with utmost confidentiality.

1. Identification information

1.1	Respondent Number								
1.2	Name of Enumerator								
1.3	Date of interview	2	0	0	8				
1.4	Village								
1.5	Farmer surname								
1.6	Farmer name								

2. House hold information

2.1 Education level of adult household members (living in the household)

[illegible]

2.2 Has any household members passed away or moved out of the household since December 2007?

Yes	No				
	Number	Male / Female		Age	
Passed away					
Moved out of household					

2.3 How many new babies born in the household since December 2007?

2.4 Current number of people in the household?

2.5 Has the household received any remittances (money) from a family member not living in the household since January 2008?

Yes / No

2.6. If Yes please indicate the value of these remittances in Rand

<150	150-350	351-650	651-1000	1001-1500	>1500
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2.7 Please rank your household's **top three** sources of income?

(1 = most important, 2 = second, 3 = third)

Source	
Maize Production	
Production of other crops (beans/vegetables/other?)	
Livestock sales	
Wage earner (permanent employment living in house)	
Wage earner (casual employment living in house)	
Migrant workers (remittances from family not living in house)	
Other business	
Pension	
Child grants	
Other government payments	
Other	

3. Employment and labour

3.1 Did you hire labour in the current (2007/08) maize production season? (Not including tractor or oxen land preparation and planting contract workers.) (Also not *Ilima*)

Yes / No

3.2 If yes, what did these hired labourers do?

Land preparation by hand	Planting by hand	Weeding
Insect control	Harvesting	Something else?

3.3 Did you hire any labourers to help with maize production last year (2006/07)? Yes / No

3.4 Did you or any family members work as hired labour on neighbouring farms in the current maize production season? (not including *Ilima*). Yes / No

3.5 Did you or any family members work as hired labour on neighbouring farms last season (2006/07)? Yes / No

3.6 Household member employment (members living in the house)

	Number
How many household members have a full-time job? (living in the house)	
How many household members have worked part-time on a neighbouring farm in the last year?	
How many household members have worked part-time on a commercial farm in the last year?	
How many household members have worked part-time in a job outside agriculture?	
How many household members are willing to work but cannot find a job?	

3.7 On average how many bags of maize cobs do an adult male harvest in a day (also how long is average harvest day)?

Harvest by 1 man in 1 day	Bag size	Number of bags	Hours in harvest day

4. Maize production

4.1 What was the level of stalk borer infestation like this maize production season? How many worms did the farmer observe on conventional maize (all varieties but not Bt maize)?

No worms	A couple of worms	Enough worms to cause damage	A lot of worms
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4.2 How did the number of stalk borers on conventional maize this season, compare to the number of stalk borers on conventional maize last season?

A lot less than last season	A bit less than last season	Same as last season	A bit more than last season	A lot more than last season
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4.3 Did the farmer apply any insecticides this season? If yes, for which pest?

No	Yes	Stalk borer	Cut worm	Beetles	Other? What?
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4.4 Did the farmer apply any insecticides after the harvest? (Inside the Nkholobane or bags?)

Yes	No
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4.5 How much grain did the farmer expect to harvest? (Estimation / Guess before farmer started to harvest)

Nothing	Less than 2 x 50kg bags of cobs	Less than 5 x 50kg bags	Less than 10 x 50kg bags	More than 10 x 50kg bags
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4.6 Which of the following farming equipment / implements / tools / resources do the household **own**? Please also indicate the quantity?

	X	How many?
Working tractor		
Oxen for land preparation		
Tractor drawn plough / disk / ripper		
Animal drawn plough		
Tractor drawn planter		
Animal drawn planter		
Knapsack sprayer		
Hand hoe		
Small wagon / trailer		
Working small truck / bakkie		
Working Car		
Hand mill for milling maize		
Electric or petrol/diesel powered mill		
Other:		

4.7 Did the household buy, sell or slaughter any livestock from January till April?

Yes			
No			
	Type of animal	Number	
Bought:			
Sold:			
Slaughtered:			

5. Grain harvest:

Please fill in the table. Indicate the yield of the selected plot according to number of maize meal bags harvested. Please specify the size of the bags and the number of the bags and also what the bags were filled with.

	Selected plot	Extra plot Only for use in Simdlangentsha
5.1 Name of maize seed		
5.2 What were the bags filled with? Cobs or grain?		
5.3 Total number and size of bags filled? Example: 6 x 50 kg bags		
5.4 How many green mealies did you harvest through the season?		
5.5 Will any of the grain be sold? If yes how much will be sold and at what price?		
5.6 What was the quality of the green mealies? 1=Not tasty 2=Tasty 3=Very tasty		
5.7 What was the quality of the grain? 1=Bad 2=Some good some bad 3=Good 4=Excellent		

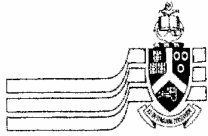
Enumerator's Name..... Farmer Number Farmer Name

Labour Activities on selected plot. Variety?.....

			<i>Family Labour</i>					
Farming Activity	Date Started	Number of days	No. of Children (<15 years)	Hours Per Child	No. of Adult Males	Hours Per Man	No. of Adult Females	Hours Per Woman
Harvesting								
Other								

		<i>Hired Labour</i>			<i>Working Groups</i>			
Farming Activity	Date Started	No. of People	Days Per Person	<u>Total</u> Cost (Rand)	No. of People	No. of days	Hours Per Person	Means of Payment
Harvesting								
Other								

Add extra for Simdlangentsha



GM maize vs. Conventional Maize Questionnaire 4 for South African Small Holders

This questionnaire is part of a research project conducted by the University of Pretoria and a number of international collaborators including Imperial College in London. The aim of this survey is to collect necessary information from farmers to evaluate the performance and efficacy of genetically modified maize as produced under smallholder conditions. All information will be treated with utmost confidentiality.

Livelihoods Questionnaire

1. Identification information

1.1	Respondent Number								
1.2	Name of Enumerator								
1.3	Date of interview	2	0	0	8				
1.4	Village								
1.5	Farmer surname								
1.6	Farmer name								

2. Maize Production: Motivations and Constraints

2.1 Would you like to grow more maize than you do? Yes / No

2.2 If no, why not?

Not able to sell extra maize	Insects destroy extra maize so cannot use	Only wish to have enough maize to feed family	It is too hard work to produce maize
Other?			

2.3 If yes, what would you hope to do with the additional maize?

Eat it	Sell it	Both
--------	---------	------

2.4 If yes, please rank the **two** main constraints to increasing your maize production. (Why do you not produce more maize than you do?)

Constraint	Rank (1 = greatest constraint; 2 = second)
Not enough land	
Not enough labour	
Not enough money for seed or other inputs	
Cannot obtain good seed	
No market to sell extra maize	
No good storage for extra maize	
Poor / unreliable rainfall	
Pests or diseases	
Do not need to produce more maize – maize only for subsistence	

2.5 Why do you prefer to grow your own maize instead of buying maize grain or maize meal? (list multiple answers if possible)

It is part of farmer's tradition	Cannot afford to buy maize meal for whole year	It makes economic sense as farmer has land and labour and maize meal is expensive
Farmer would like to be known as a farmer	Like to grow own green mealies	Own maize meal is more healthy
Selling green mealies brings in cash	Selling grain brings in cash	Other:

2.6 Would you like some of your children to be maize farmers one day? (view of future and feeling towards maize production?)

I hope so	I do <u>not</u> hope so
Why?	

2.7 Does anyone in the household receive a pension? **[note in advance]** Yes / no

2.8 If yes: As a result of having income from a pension, has the household increased or decreased its own maize production?

Increased	No change	Decrease
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Reason why?

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2.9 Did the household increase or decrease its maize production as a result of receiving child grants?

Do not receive child grants	Increased	No change	Decreased
Why?			

3. Land Access

3.1 If the farmer wanted to plant more land to maize, how easily could he get more land?

Easily	With difficulty	It is not possible
--------	-----------------	--------------------

3.2 Would you expect this additional land to be:

Close to your house	Close to current land	Much further from your house than current land
---------------------	-----------------------	--

3.3 What can the farmer do to get more land?

Use own land that is not currently used	Borrow land from neighbour/family/friend without payment	Rent land from neighbour/family friend and pay	Ask the chief for more land
Other			

3.4 If land would have to be rented, how much would you expect to pay as rent (per season)?

--

4. Labour

4.1 During which part of the agricultural production season is it most difficult to find labour (family, hired labour, contractor or working groups)?

Land Preparation	Planting	Weeding	Harvesting
Other			

Reason

--

4.2 Which agricultural production activity do you least like having to do?

Land Preparation	Planting	Weeding	Harvesting
Herbicide Application	Pesticide Application	Other	

Reason

--

4.3 Did the household hire manual labour for maize production in 2007/08 [**note in advance**]?
Yes / No

4.4 If yes, where did the labour that you hired come from?

Neighbours	Other people known to you	People from outside the area	Other:
------------	---------------------------	------------------------------	--------

4.5 If you want to hire labour for maize production, how easy is it to find someone?

Easy	Difficult	Don't know
------	-----------	------------

4.6 What is the main characteristic that you are looking for in a hired worker?

Willing to work for amount you will pay	Worker with experience	Hard worker
Someone you trust	Someone you would like to help by giving him a job	Other

4.7 How many days in advance do you have to ask someone to come and work on your farm?

1 day	3 days	1 week	2 weeks	More than 2 weeks
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5. Seed

5.1 Seed used in 2007/08 [**note in advance**]:

(Selected plot)

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5.2 What was your main reason for choosing this seed for the current season?

I have used this seed before and found it good	It was the only seed available	Compared to other seed this seed had a good price
Maize from this seed is not attacked by stalk borer	Seed is not killed by herbicide	I had heard of it and wanted to try it out
Other		

5.3 Where did you get your information about maize seed?

No information	From other farmers	Government extension officer
Seed company farmer's days	At the shop / container where I buy my seed	Other

5.4 Were you satisfied with the performance of the seed this season?

Yes	No
-----	----

5.5 If no, what was not good about the performance of the seed?

Does not perform well with little rain	Low yield despite good rain	Green mealies not tasty	Grain / maize meal of low quality
Maize was affected by stalk borer	Other		

5.6 Do you hope to buy the same seed next season?

Yes	No
-----	----

5.7 If no, why not?

Not satisfied with performance this season (see above)	Too expensive	Want to try a GM variety (Bt,RR or BR)	Other
--	---------------	--	-------

5.8 Please indicate the benefits of the following seed (multiple answers are possible for each seed type)

	Pan 6043 or other Pannar seed	DKC 7815 / Yieldgard / Bt seed	DKC 7835 / Roundup Ready seed	DKC 7845 / Stacked gene / BR seed	Traditional seed
Don't know this seed					
Not expensive					
High yield					
Not / less effected by drought					
Maize is not effected by stalk borers					
Maize is not killed by herbicide					
Save labour					
Save on insecticides					
Maize grows fast					
Get better price of green mealies					
Get better price for grain					
Good quality grain and maize meal					
Good quality green mealies					
Other					

5.9 Please indicate the disadvantages of the following seed (multiple answers are possible for each seed type) (What do you not like about the seed)

	Pan 6043 or other Pannar seed	DKC 7815 / Yieldgard / Bt seed	DKC 7835 / Roundup Ready seed	DKC 7845 / Stacked gene / BR seed	Traditional seed
Don't know this seed					
Expensive					
Not available when I want it					
Low yield					
Easily effected by drought					
Needs fertiliser					
Maize is damaged by stalk borers					
Maize is damaged by herbicide					
Have to buy herbicide					
Have to use insecticide for stalk borers					
Maize grows slow					
Maize is not white					
Maize cobs are damaged by rain					
Low price for green mealies					
Low price for grain					
Bad quality grain and maize meal					
Green mealies not tasty					
Less food for the cattle after harvest					
Other					

Only for farmers who planted Bt (DKC 7815) / RR (DKC 7835) or BR (DKC 7845) seed

5.10 How has your maize yield changed as a result of using this type of seed?

Increased	Unchanged	Decreased
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Reasons

5.11 Has using this type of seed enabled you to change the area that you plant to maize? Yes / No

If yes, how has it changed?

Increased	Unchanged	Decreased
-----------	-----------	-----------

Reasons

6. Herbicide

6.1 Herbicide used in 2007/08 [**note in advance**] - Before planting: Yes / No
After planting: Yes / No

6.2 Where do you get information on how to use herbicide?

No information	From other farmers	Government extension officer
Seed company farmer's days	Herbicide company farmer's days	At the shop / container where I buy my herbicide
Other		

6.3 Where do you get information on which herbicide to use?

No information	From other farmers	Government extension officer
Seed company farmer's days	Herbicide company farmer's days	At the shop / container where I buy my herbicide
Other		

6.4 What was your main reason for applying herbicide this season?

No need for ploughing / protect the soil	Less weeding labour when doing land preparation and ploughing	Less weeding labour later in the season	Other
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Herbicide before planting

6.5 What was your main reason for choosing the brand of herbicide/ herbicides for the current season?

It was recommended by info source	Was the only one available at shop	It was the cheapest one	I had some left of last season
It is the one that is recommended for the seed I planted			Other

6.6 When did you apply the herbicide?

More than a week before land preparation	Just before land preparation	At same time as land preparation
Just after land preparation	Just before planting	At same time as planting
Just after planting	Other	

Herbicide after planting

6.7 What was your main reason for choosing the brand of herbicide/ herbicides for the current season?

It was recommended by info source	Was the only one available at shop	It was the cheapest one	I had some left of last season
It is the one that is recommended for the seed I planted			Other

6.8 How tall was the maize when you applied the pesticide?

Ankle high	Calf high	Knee high	Waist / belt high
Chest high	Shoulder high	Head or above head high	Other

6.9 Describe how you applied the herbicide to your maize plot.

Only in rows taking care not to get chemical on maize	In rows and between maize taking care not to get chemical on maize	In rows, between maize and on maize (without taking care)
Other		

6.10 Did application of the herbicide damage the

Yes	No
-----	----

 maize? If yes, how much?

Only very slightly	A bit of damage	Enough damage to effect harvest	Killed the maize
--------------------	-----------------	---------------------------------	------------------

6.11 Were you satisfied with the performance of the herbicide this season?

Yes	No
-----	----

6.12 If no, what was disappointing about the performance of the herbicide?

Does not kill weeds	Too much damage to maize	Other
---------------------	--------------------------	-------

6.13 Do you hope to buy the same herbicide next season?

Yes	No
-----	----

6.14 If no, why not?

Not satisfied with performance this season (see above)	Too expensive	Want to try a new brand (specify)	Do not expect to apply herbicide next season
Other			

Question for farmers who use herbicide (after planting) but do not plant Roundup Ready (RR) or BR seed:

6.15 Have you heard of Roundup Ready seed?

Yes	No
-----	----

6.16 If yes, can you tell me what is special about it?

Is not killed by RoundReady Plus	Is not killed by any herbicide	It is not damaged by stalkborers
Other		

6.17 If yes, why did you choose conventional seed and herbicide instead of Roundup Ready (RR) seed and Roundup herbicide for this season?

RR seed is too expensive	RR seed was not available	Roundup herbicide is too expensive
There is no advantage to use RR seed above conventional seed	Other	

7. Gender Dimensions of Weeding Labour and Herbicide

[only ask if household applied herbicide *after* planting]

7.1 As a result of the household applying herbicide after planting, whose labour was saved? (who was able to spend less time in the field?)

Males	Females	Children	Males and females
Males and Children	Females and children	All	

7.2 What did they do with the saved time?

Males	
Females	
Children	

8. Maize Marketing Opportunities

8.1 Did household sell maize in 2007/08?

Yes	No
-----	----

8.2 If no, why not?

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8.3 If yes, where did you sell your maize?

To people in the community who do not produce maize	To another farmer	To community miller
Other - explain		

8.4 Please complete the table below so as to answer the following questions:

- How many places do you know where you *could* sell maize? Please list.
- This past season, how have the prices available from these places compared?
- What are the problems with selling to each place (e.g. need transport, delay in payment, do not buy small quantities)

Where can you sell maize?	Price (1 = highest, 2 = second etc)	Problems with selling

Appendix B

Frontier estimations for four seasons with different assumed distributions and explanatory variables

Stochastic production frontiers for 2005/06

	Normal / half-normal distribution	Exponential distribution
Number of observations	120	120
Wald Chi ²	85.47	85.08
Log likelihood	-100.61	-99.18
constant	6.81 (0.000)***	6.6 (0.000) ***
lplotsize	0.80 (0.000) ***	0.79 (0.000) ***
lseedexp	-0.06 (0.627)	-0.05 (0.648)
lfertexp	-0.08 (0.278)	-0.08 (0.320)
ltotalherbexp	0.1 (0.063)*	0.10 (0.048)* *
llandpreandplantfl	0.10 (0.202)	0.11 (0.164)
lweedfl	0.06 (0.298)	0.06 (0.248)
ltotalhired	-.03 (0.481)	-0.03 (0.508)
landprepdum	0.15 (0.652)	0.16 (0.603)
nointercropdum	-0.05 (0.641)	-0.04 (0.742)
seedumbt	0.42 (0.009) ***	0.41 (0.008) ***
seeddumrr	-0.12 (0.206)	-0.13 (0.163)
sigma_v	0.3733	0.4086
sigma_u	0.7116	0.3966
lambda	1.9062	0.9707
gamma	0.7842	0.3997
Prob>=chibar2	0.012	0.002
Efficiency scores		
Bt	0.653	0.749
HT	0.615	0.719
Conv	0.598	0.697

Stochastic production frontiers for 2006/07

	Normal / half-normal distribution	Exponential distribution	Truncated-normal distribution
Number of observations	95	95	95
Wald Chi ²	68.27	74.29	73.63
Log likelihood	-87.81	-87.26	-87.19
constant	4.92 (0.000)***	4.98 (0.000)***	5.01 (0.000)***
lplotsize	0.24 (0.356)	0.29 (0.263)	0.29 (0.260)
lseedkg	0.22 (0.362)	0.16 (0.494)	0.16 (0.493)
linsectexp	0.12 (0.062)*	0.11 (0.057) *	0.11 (0.06) *
ltotalhired	0.03 (0.468)	0.026 (0.553)	0.03 (0.555)
llandpreplantfl	-0.21 (0.004)***	-0.22 (0.002)***	-0.22 (0.002)***
lharvestfl	0.31 (0.004)***	0.3 (0.004)***	0.3 (0.004)***
nointercropdum	0.60 (0.000)***	0.6 (0.000)***	0.6 (0.000)***
seeddumbt	0.25 (0.170)	0.27 (0.127)	0.27 (0.141)
seeddumrr	0.92 (0.000)***	0.88 (0.000)***	0.88 (0.000)***
sigma_v	0.3857	0.3866	3.6535 0.1437 0.9622 0.163
sigma_u	0.8092	0.5172	
lambda	2.0980	1.3378	
gamma	0.8149	0.6415	
Prob>=chibar2	0.057	0.029	
sigma_u2			
sigma_v2			
gamma			
Prob<=z			
Efficiency scores			
Bt	0.575	0.631	0.618
HT	0.611	0.698	0.681
Conv	0.567	0.638	0.621

Stochastic production frontier for 2007/08

	Normal / half-normal 1	Exponential 1	Truncated normal 1	Normal / half-normal 2	Exponential 2	Truncated normal 2	Exponential 3
Number of obs.	96	96	96	96	96	96	96
Wald Chi ²	69.93	67.46	67.50	48.42	46.75	46.77	112.75
Log likelihood	-54.75	-54.68	-54.68	-61.36	-61.23	-61.23	-43.06
constant	8.59 (0.000)***	8.51 (0.000)***	8.51 (0.000)***	5.41 (0.000)***	5.31 (0.000)***	5.32 (0.000)***	6.91 (0.000)***
lplotsize	1.25 (0.000)***	1.24 (0.000)***	1.24 (0.000)***				0.81 (0.000)***
lseedkg	-0.49 (0.016)**	-0.48 (0.018) **	-0.48 (0.018)**	0.42 (0.006)***	0.42 (0.006)***	0.42 (0.006)***	-0.30 (0.104)
lfertexp	0.042 (0.772)	0.05 ((0.757)	0.04 (0.757)	0.08 (0.622)	0.08 (0.616)	0.08 (0.616)	0.01 (0.916)
ltotalhired	-0.02 (0.611)	-0.02 (0.601)	-0.02 (0.601)	0.006 (0.887)	0.01 (0.881)	0.01 (0.881)	0.02 (0.501)
ltotalfl							0.34 (0.000)***
nointercrop				0.49 (0.000)***	0.48 (0.000)***	0.48 (0.000)***	0.32 (0.001)***
seeddumbt	0.26 (0.098)*	0.25 (0.104)	0.25 (0.104)	0.15 (0.879)	0.02 (0.913)	0.02 (0.913)	
seeddumrr	0.14 (0.204)	0.13 (0.234)	0.13 (0.234)	-0.16 (0.871)	-0.03 (0.802)	0.03 (0.802)	
seeddumbr	0.17 (0.208)	0.16 (0.229)	0.16 (0.228)	0.23 (0.821)	0.03 (0.869)	0.3 (0.869)	
seeddumconv							-0.14 (0.165)
sigma_v	0.3944	0.3953		0.3894	0.4032		0.3522
sigma_u	0.2761	0.1642		0.4047	0.2206		0.1404
lambda	0.7000	0.4156		1.0395	0.5470		0.3986
gamma	0.3289	0.1472		0.5193	0.2304		0.1371
Prob>=chibar2	0.405	0.331		0.281	0.220		0.352
sigma_u2			10.3171			27.2082	
sigma_v2			0.1562			0.1625	
gamma			0.9851			0.9941	
Prob<=z			0.433			0.296	
Efficiency scores							
Bt	0.813	0.859	0.859	0.745	0.821	0.821	0.852
HT	0.814	0.862	0.862	0.748	0.826	0.826	0.885
Conv	0.811	0.853	0.853	0.734	0.802	0.801	0.873
BR	0.813	0.861	0.861	0.752	0.831	0.830	0.881

Stochastic production frontier for 2009/10

	Exponential distribution-1	Exponential distribution-2
Number of obs.	98	98
Wald Chi ²	161.39	161.18
Log likelihood	-33.20	-36.26
constant	5.53 (0.000)***	5.57 (0.000)***
lseedkg	0.82 (0.000)***	0.91 (0.000)***
lfertexp	0.004 (0.978)	
ltotalhired	-0.10 (0.011)**	-0.09 (0.012)**
llandpreandplantfl	-0.06 (0.169)	-0.07 (0.060)*
linsectfl	0.004 (0.986)	
landprepdum	0.15 (0.018)**	
nointercrop	0.079 (0.282)	
seeddumrr	0.26 (0.003) ***	0.23 (0.006)***
seeddumbr	0.17 (0.09) *	0.13 (0.160)
sigma_v	0.1513	0.1301
sigma_u	0.3650	0.4051
lambda	2.4124	3.1134
gamma	0.8534	0.9065
Prob>=chibar2	0.000	0.000
Efficiency scores		
HT	0.736	0.716
Conv	0.706	0.677
BR	0.759	0.738