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Genetically modified (GM) maize cultivation by smallholders in the Eastern Cape Province of South Africa: Effects on target and non-target organisms and adoption challenges

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Declaration

I, KOTEY, Daniel Ashie, hereby declare that this research is an outcome of my own investigation under the supervision of Prof. Yoseph Assefa Armide, Prof. Johnnie Van den Berg and Dr. Niall G. Vine. This thesis has not been previously presented in any application for a higher degree of this or any other University. All citations and sources of information are clearly acknowledged by means of references.

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Declaration of research ethics clearance

I, Daniel Ashie Kotey, with student number, 201415537, hereby declare that I am fully aware of the University of Fort Hare's policy on research ethics and I have taken every precaution to comply with the regulations. I have obtained an ethical clearance certificate from the University of Fort Hare's Research Ethics Committee and my reference number is ARM011SKOT01

Abstract

The use of genetically modified (GM) maize technology is subject to compliance with stewardship requirements and the adoption of specific management practices that promote the long-term effectiveness and environmental sustainability of the technology. For smallholders to comply with these requirements and adopt the desired management practices to ultimately benefit from the technology, they require information that creates awareness of the value of these requirements. To determine what information farmers receive about GM maize and how this information is disseminated to farmers, face to face interviews were conducted with 81 extension personnel and 210 smallhoder GM maize farmers in the Eastern Cape Province of South Africa. The effect of Bt maize introduction and management practices in smallholder maize agro-ecosystems in the Eastern Cape on Bt maize target [*Busseola fusca* (Fuller) (Lepidoptera: Noctuidae)] and non-target insect pests [*Agrotis segetum* (Denis & Schiffermüller) (Lepidoptera: Noctuidae), *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae)] and a snail species, [*Cornu aspersum* (Müller) (Gastropoda: Helicidae)] was determined through laboratory, field and cage experiments. The effect of smallhoder farmers' GM maize cultivation practices on the profitability of GM maize technology was also determined through on-farm trials in different localities of the Eastern Cape identified as hot-spots for stem borer and weed infestation. Results of surveys indicated that extension personnel had a low level of awareness of GM maize technology stewardship requirements. GM maize technology was also largely disseminated to smallholder farmers through non-participatory approaches and print media sourced from GM seed companies. Although farmers had a high level of contact with extension services, they lacked access to information about GM maize technology. Smallholder farmers' level of awareness about GM maize and compliance with the requirement for the planting of non-Bt maize refuge areas adjacent to Bt maize was also very low. While Bt maize event (MON810) commonly cultivated by smallholder farmers in the Eastern Cape Province had a variable effect on *A. segetum* under laboratory conditions, it had no effect on the incidence of plants damaged by *A. segetum* and *C. aspersum* under field conditions. The incidence of *H. armigera* damage on Bt maize plants was however significantly affected by Bt maize. Populations of *B. fusca* collected from smallholder maize fields in the province were observed to be still highly susceptible to Bt maize. Results of on-farm evaluation of the profitability of GM maize revealed that stem borer pressure, growing conditions, input supplies and market access affect the productivity and profitability of GM maize cultivation. Challenges within the extension and advisory services of the Eastern Cape which can militate against smallholder farmers' ability to benefit from GM maize technology and sustain the long-term efficacy of the technology were identified during this study. Given these challenges and the fact that the cultivation of GM maize may not be profitable under typical smallholder maize cultivation conditions and management practices, dissemination approaches that provide farmers the opportunity to evaluate GM maize technology alongside alternate technologies under their conditions, may prove beneficial.

Key words: *Dissemination, Eastern Cape Province, GM maize technology, profitability, smallholders*

List of Abbreviations

Bt	*Bacillus thuringiensis*
BR maize	‘Stacked’ traits GM (Bt insect resistance + herbicide tolerance) maize
CIMMYT	International Maize and Wheat Improvement Centre
DAFF	Department of Agriculture Forestry and Fisheries
DRDAR	Department of Rural Development and Agrarian Reform
DEDEAT	Department of Economic Development, Environmental Affairs and Tourism
ECDA	Eastern Cape Department of Agriculture
ECRDA	Eastern Cape Rural Development Agency
F1	First Filial Generation of Offspring
FAO	Food and Agricultural Organisation
GMO	Genetically modified organism
Ha	Hectare
HIV/AIDS	Human Immunodeficiency Virus/Acquired Immunodeficiency Syndrome
IAASTD	International Assessment of Agricultural Knowledge, Science and Technology for Development
IFAD	International Fund for Agricultural Development
IPM	Integrated Pest Management
IRM	Insect Resistance Management
IRAC	Insecticide Resistance Action Committee
MFPP	Massive Food Production Programme
OPV maize	Open Pollinated Variety
PGDP	Provincial Growth and Development Plan
PSPPD	Programme to Support Pro-poor Policy Development in South Africa

RR maize	Roundup Ready maize
Stats SA	Statistics South Africa
USEPA	United States Environmental Protection Agency
WAE	Weeks after Emergence
ZAR	South African Rand

Dedication

To Bonnie Naa Adei Kotey and Ché Benjamin Amon Kotey, may you be inspired to pursue excellence.

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2. Kotey, D.A., Obi, A., Assefa, Y., Erasmus, A. & Van den Berg, J. (*In press*). Monitoring resistance to Bt maize in field populations of *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) from smallholder farms in the Eastern Cape Province of South Africa. *African Entomology*

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CHAPTER 1: General introduction and justification

1.1. Introduction and justification

Genetically modified (GM) maize was first introduced to smallholder farmers in South Africa during the 2001/02 cropping season (Gouse, 2012a). GM maize has enhanced genetic traits that confer insecticidal and herbicidal properties to it. Thus, GM seeds are patent-protected by the Plant Breeders' Rights Act, 1976 (No. 15 of 1976) and also regulated by the Genetically Modified Organisms Act (No. 15 of 1997). Smallholder farmers traditionally cultivate maize using self-generated seeds that are not subject to use restrictions or regulations. Adoption of GM maize and compliance to GM maize regulations therefore requires new management practices (Jacobson & Myhr, 2012) and attitudinal changes of smallholder farmers (Ozowa, 1997).

Extension and advisory support plays a key role in engendering attitudinal change and promoting the adoption of new technologies and good agricultural practices by smallholder farmers (Ozowa, 1997; Mafabia & Obi, 2011; Taye, 2013). The relevance of information transferred by extension services to smallholder farmers is an important determinant of its utilization (Opara 2010). The public agricultural extension system of South Africa is noted to pursue a fundamentally top-down transfer of technology (TOT) approach that promotes the delivery and adoption of universally designed modern technologies, without considering local knowledge and resource endowments (Hart & Aliber, 2012). Majority of smallholder farmers in the Eastern Cape are illiterate and live in rural areas with poor road infrastructure (Assefa & Van den Berg, 2010; DAFF, 2012a; Jacobson & Myhr, 2012). These challenges limit smallholder farmers’ access to and comprehension of information necessary for creating awareness about GM maize technology and the adoption of improved practices (DAFF, 2012a; Jacobson & Myhr, 2012). Lack of information about new innovations (Lim & Heong, 1994) may result in poor stewardship of the technology by farmers (Assefa & Van den Berg, 2009; Kruger *et al*., 2012a; Jacobson & Myhr, 2012). Poor perception of GM maize as a pest management tool coupled with little awareness of pests targeted by GM maize may lead to farmers applying insecticides against pests targeted by GM maize technology (Mannion & Morse, 2013). This may adversely affect the cost-effectiveness of GM maize cultivation by smallholder farmers. Poor perception of GM technology can also result in farmers not adopting all aspects of the technology, including non-compliance to biosafety management practices and repeated application of herbicides used in conjunction with GM maize at the wrong time or application rates. These may compromise both insect resistance management (IRM) and weed resistance management (WRM) strategies. Kruger *et al.* (2009) reported non-compliance to GM maize stewardship requirements as a key factor for resistance development by *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) to Bt maize in South Africa. Further, farmers may not recognize the potential for target pests and weeds to evolve resistance to GM maize and herbicides to which the technology is enabled until resistant insect and weed biotypes appear in their fields (Johnson *et al.*, 2009).

Cry1Ab proteins expressed by Bt maize bind to mid-gut receptors and cause lethal septicemia when they are activated by the strongly alkaline mid-gut of target Lepidoptera (Chambers *et al.*, 2010). Non-target pests that belong to the same taxonomic order as Bt maize targeted species have been reported to suffer reduced developmental and survival rates when exposed to Bt proteins (Naranjo, 2009). Species such as *Agrotis segetum* (Denis & Schiffermüller)

(Lepidoptera: Noctuidae) and *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) belong to the same family (Noctuidae) as *B. fusca*, a target pest of Bt maize in South Africa. They are also closely associated with Bt maize cropping systems. This may therefore increase the likelihood that they may get exposed to Bt toxin leading to possible changes in their pest status. Cry proteins are produced in all plant tissues and are also reported to persist in maize plant residues deposited on the field following harvest (Zwahlen *et al*., 2003). Snail species such as *Cornu aspersum* (Synonyms: *Helix aspersa*; *Cantareus aspersus*; *Cryptomphalus aspersus*) (Müller) (Gastropoda: Helicidae) which feeds on both maize seedlings and decomposing organic matter (Mason, 1970; Kramarz *et al.*, 2009; Elove, 2013) may therefore be exposed to Bt maize leading to adverse effects on their occurrence and role in nutrient cycling.

In evaluating extension personnel's and farmers' perceptions about GM maize technology, surveys can play a crucial role (Grieshop *et al*., 1988). Information from such surveys, coupled with information from laboratory screenings, field trials and monitoring of fields can help to identify farmers' attitudes, inappropriate GM maize management practices and challenges to the adoption of GM maize technology by smallholder farmers. Such information may reflect more realistically, the conditions of smallholder GM maize production in the Eastern Cape and serve as baseline data for enhancing the long-term sustainability and profitability of GM maize technology in the province.

1.2. Research questions

i. What extension approaches are employed by extension personnel to disseminate GM maize technology to smallholder farmers? Is the level of awareness of extension personnel about GM maize technology and its stewardship requirements adequate to ensure smallholder farmers' compliance to these requirements?

ii. Are smallholder farmers aware of prescribed GM stewardship requirements? If they are, what is their level of compliance to these requirements?

iii. Does Bt maize cultivation by smallholder farmers in the Eastern Cape Province have an effect on the incidence and activities of on non-target Lepidoptera species (*Agrotis segetum* and *Helicoverpa armigera*) and the common garden snail (*Cornu aspersum*)?

iv. Is the efficacy of GM maize against *Busseola fusca*, the main target pest of GM (Bt) maize in South Africa affected by smallholder GM maize cultivation practices?

v. Is smallholder cultivation of GM maize in the Eastern Cape Province profitable?

vi. What are the challenges that smallholder farmers in the Eastern Cape face in adopting GM maize?

1.3. Research objectives:

i. To determine extension personnels' awareness of GM maize technology stewardship requirements and identify the practices used to disseminate GM maize technology to smallholder farmers

ii. To assess smallholder farmers' awareness of prescribed GM stewardship requirements and their level of compliance to these requirements.

iii. To evaluate the effect of Bt maize cultivation in smallholder farms on non-target Lepidoptera species *Agrotis segetum, Helicoverpa armigera* and the common garden snail *Cornu aspersum*

iv. To determine the level of susceptibility of field collected populations of *Busseola fusca* to GM maize in the laboratory.

v. To assess the profitability of GM maize cultivation by smallholder farmers.

vi. To determine the challenges that constrains the adoption of GM maize technology by smallholder farmers in the Eastern Cape Province.

CHAPTER 2: Literature review

2.1. Smallholder agriculture in South Africa

Smallholders are described as farmers with less than two hectares of cropland that practice a mixture of commercial and subsistence agriculture and mostly depend on family labour for farm operations (Narayanan & Gulati, 2002; World Bank, 2003). Smallholder farming activities generally occurs in the world's most ecologically and climatically vulnerable landscapes, namely hillsides, dry lands and floodplains and relies on weather-dependent natural resources (IFAD, 2012). Smallholder agriculture has been reported to play an important role in improving the livelihoods and household food security of poor rural and urban households in South Africa (Baiphethi & Jacobs, 2009). Two categories of smallholder farmers, namely, emerging smallholder farmers and subsistence producers are recognised in South Africa (DAFF, 2012b). Emerging smallholders are more commercially inclined (Hall & Aliber, 2010; Tihanyi & Robinson, 2011) whilst subsistence producers only produce agricultural goods for household consumption (DAFF, 2012b). Smallholder agricultural activities in South Africa are undertaken mainly in the former homelands and rural areas (Pienaar, 2013) of Eastern Cape, KwaZulu-Natal and Limpopo Provinces (Cousins, 2013). There are about 1.3 million smallholder farmers in these areas and they are thought to collectively own about 14.5 million hectares out of the estimated 100.7 million hectares of land in South Africa (DAFF, 2015). Although pulses, pumpkins, groundnuts, onions, carrots and sweet potatoes are commonly grown by smallholders in these areas, the main activity is the production of maize for grain (Joubert, 2000; Mathews & Saxena, 2005; Regier *et al.*, 2012). Production usually takes place in gardens, demarcated fields or on open rangelands using simple outdated technologies (Williams *et al.*, 2008; Pienaar, 2013). Livestock farming is also a common farming activity engaged in by smallholders in these areas

(Lahiff & Cousins, 2005). It is estimated that 30.1%, 24.5% and 15.7% of households in the Eastern Cape, KwaZulu-Natal and Limpopo Provinces respectively own livestock (Stats SA, 2016). Commonly reared livestock include cattle, small stock-sheep and goats, pigs, chickens, ducks and geese (Lahiff, 1997; Andrew *et al*., 2003). Crop residue left over after harvest may serve as a cheap source of supplementary nutrition to grazing livestock particularly during winter months (Manona, 2005). Apart from meat and cash derived from slaughter or sale, manure obtained from livestock is an important source of soil nutrients for crop production particularly in farming households with limited access to inorganic fertiliser (Bryndum *et al*., 2007). Cattle may also be used to provide draught for cultivation and planting (Andrew *et al*., 2003). Nationally, agriculture contributes 1.9% to the gross domestic products of South Africa (DAFF, 2013a). The smallholder sector however contributes just about one percent to total food production in the country (Chikazunga & Paradza, 2013). With regard to smallholder households, agriculture constitutes about 15% of household income (Aliber, 2005).

2.2. Smallholder maize production in South Africa

The maize industry in South Africa consists of a commercial sector and a non-commercial sector made up of smallholder farmers (DAFF, 2013a). Although the total number of smallholder maize farmers in South Africa is unknown (DAFF, 2013b), the main smallholder maize production areas are located in the Eastern Cape, Limpopo, Mpumalanga and KwaZulu-Natal Provinces (DAFF, 2013a). Generally, white maize is produced mainly for human consumption, whilst yellow maize is mostly used for animal feed production. It is estimated that 320 105 ha of white maize and 136 795 ha of yellow maize was cultivated by the non-commercial sector in 2012/13

(DAFF, 2013a). The maize cultivated by the non-commercial sector constitutes only 5% of the total maize produced in the country (DAFF, 2013a).

The Eastern Cape is distinguished by the fact that all maize produced in the province is by the non-commercial sector (DAFF, 2013a). Maize produced in the province constitutes approximately 55% of the total maize produced by the non-commercial sector in South Africa (Crop Estimates Committee, 2014).

2.3. Smallholder maize cultivation in the Eastern Cape Province

Most of the maize cultivated in the Eastern Cape Province is under dry land agriculture in the Eastern part of the province (Hamann & Tuinder, 2012). Cultivation may take place in outfields or in home gardens. Outfields (Figure 2.1) are farm lands situated outside villages or residential sites and generally range from one to five hectares in size. They are often not fenced and typically cultivated with maize and pulses (Bryndum *et al*., 2007). Feynes & Meyer (2003) estimated that 40 to 80% of outfields are cultivated in any given year.

Figure 2.1. Maize cultivated in outfields in Flagstaff in the OR Tambo District Municipality of the Eastern Cape Province

Home gardens (Figure 2.2) on the other hand are small plots of land (0.1-0.5), adjacent to residential dwellings that are fenced (Bryndum *et al*., 2007). About 88.8% of farming households in South Africa cultivate home gardens (Stats SA, 2015a). Fraser *et al.*, (2003) reported that cultivation of home gardens is a strategy to produce some measure of food under conditions where households have access to land but lack implements or resources to purchase inputs to cultivate outfields.

Figure 2.2. Maize cultivation in home gardens in the Mqanduli area of OR Tambo District Municipality of the Eastern Cape Province

Although most maize fields are planted between November and December, (DAFF, 2013a) the main determinant of planting date is rainfall (Schimmelpfennig *et al*., 2013). Most farmers plant their fields after the first rains of the cropping season, planting may thus begin in August if early rain falls (Joubert, 2000). It is estimated that 90% of smallholder farmers plant open-pollinated varieties (OPVs) of maize or recycle seed from OPVs (Gouse *et al*., 2005). Ploughing and planting operations in areas where farmers plant farm saved seeds are generally undertaken using draught animals (Manona, 2005). Van der Walt (2009) has identified high seed cost as a major deterrent to the purchasing of maize seeds by smallholder farmers. In the case of GM maize seed, difficulties associated with the signing of technology agreements that bind farmers to abide by GM maize technology stewardship requirements have also been identified as an additional deterrent (Van der Walt, 2009). In areas where farmers receive GM maize seeds as part of government development initiatives however, ploughing, planting, as well as pest and weed management operations are undertaken using tractors and tractor mounted boom sprayers (Jacobson, 2013; Fischer & Hadju, 2015).

Harvesting of cultivated maize commences from the end of May up to the latter part of August (DAFF, 2013a). Harvested maize may be sent for milling, sold, stored for household consumption or for brewing traditional beer ("Umqombothi") (Manona, 2005; Gouse & Kirsten, 2005). Fresh maize ears may also be harvested as green "mealies" and consumed early in the season or sold to the fresh maize market (Gouse *et al*., 2008). Yields of maize in the province averaged 3.23 tonnes per hectares over a five year period (2006/7-2010/11) (GrainSA, 2012).

Key production constrains faced by smallholder maize farmers in the province include shortage of labour, draught oxen, resources to purchase inputs, limited access to inputs and tractor services, soil erosion and declining soil fertility, high risk of crop damage due to shortage of labour for herding livestock and fencing, as well as the inability to use tractors to plough steep fields on hillsides (Feynes & Meyer, 2003; Fischer & Hadju, 2015**)**. Variable quality of extension contact (DoA, 2008), limited market access and land tenure issues (Andrew *et al*., 2003) as well as limited technology adoption (use of traditional varieties) (Gouse *et al.*, 2006a; Schimmelpfennig *et al*., 2013) have also been reported to contribute to low productivity of smallholder maize production. Other important constraints include stem borer pests, cutworms and weed infestation (Gouse *et al.*, 2006a; Assefa & Van den Berg, 2009; Schimmelpfennig *et al.*, 2013; Jacobson & Myhr, 2012; Kotey *et al*., 2016).

2.4. Pest constraints to smallholder maize cultivation

Maize production by smallholder farmers in the Eastern Cape like other maize growing areas of Sub-Saharan Africa is hampered by a number of factors amongst which infestation by stem borer insect pests is the most important (Van den Berg *et al.*, 1991a; 2001; Kfir *et al.*, 2002). Depending on the agro-ecological zone, pest population density and plant growth stage at infestation, yield loss of between 10 to 50% may occur (Annecke & Moran, 1982; Revington, 1986; Kfir *et al.,* 2002). The main stem borer pests of maize comprise the larvae of the maize stem borer *Busseola fusca* and the spotted stem borer, *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) (Kfir *et al.,* 2002; Kfir, 1988). Both species may occur in single or mixed populations (Van den Berg *et al.,* 1991a).

Smallholder farmers can discern stem borer pests and the effect of stem borer infestation on the yield of their maize crop (De Groote *et al.*, 2003). However owing to lack of resources to purchase insecticides (Smith, 1997), very few farmers apply insecticides on their maize crop to control stem borers in South Africa (Schimmelpfennig *et al*., 2013). The few farmers that do apply insecticides generally do a once-off application of carbaryl (1-naphthyl methylcarbamate) granules in the maize funnel when stem borers are observed (Gouse *et al*., 2008). Owing to the fact that larval and pupal development of stem borers is mostly completed inside the maize stem and lack of proper timing of application, the efficacy of applied insecticides may be compromised (Eizaguirre *et al.,* 2002; Gouse *et al*., 2008).

Weeds are regarded as the most common crop pests, occurring each year on every farm across the world (Gianessi & Williams, 2011). Weeds adversely affect crop yields through competition for sunlight, water and nutrients with crops (Du Plessis, 2003). The main method of weed control on smallholder maize farms in the Eastern Cape is hand weeding involving either pulling or hoeing weeds (Joubert, 2000; Vissoh *et al.*, 2004). Where family sizes are large and labour is locally abundant (Kibwage *et al*., 2004), both methods are efficient and practical and require little capital investment (Joubert, 2000). In rural areas of the Eastern Cape however, labour supply for weeding is constrained by the advanced ages of farmers and high enrollment of children in school (Assefa & Van den Berg, 2009). The use of draft animal power for inter-row weeding has been suggested as a viable alternate that can significantly reduce the high labour requirements faced in hand-hoe-based farming systems and allow farmers to reduce the time spent weeding and increase the area and frequency of weeding (Simalenga & Shetto, 2000). The utility of draft animal power in smallholder systems in the province is however limited by the fact that row planting of maize is not commonly practiced by farmers in the province (Joubert, 2000).

Given the constraints to effective stem borer and weed management, the availability of maize genetically modified to resist stem borer infestation and herbicides potentially provides farmers alternative weed and stem borer control strategies that are effective, safe, economical and convenient to use (Green & Owen, 2011; Carpenter, 2011; Kruger *et al*., 2012a).

2.5. Introduction of GM maize to South Africa

Maize modified with genes from the soil bacterium *Bacillus thuringiensis* Berliner for the control of *B. fusca* and *C. partellus* was first approved for commercial production in South Africa in 1998 (Gouse *et al.,* 2005). Currently, Bt maize provides effective control of *C. partellus* and partial to very good control of *Sesamia calamistis* (Hampson) (Lepidoptera: Noctuidae) and *B. fusca* (Van Rensburg, 1999; Van den Berg & Van Wyk, 2007; Tende *et al*., 2010). The first maize variety approved was Bt yellow maize and about 3,000 hectares of the approved variety was planted during the first cropping season (Gouse *et al*., 2009). Between 1998 and 2006, all Bt maize hybrids approved in South Africa contained Bt Event MON810 which expresses the Cry1Ab protein (Van den Berg *et al.,* 2013). Following the evolution of resistance by *B. fusca* to Event MON810 in the main commercial maize production region of the country, a 'stacked' maize event, MON89034 expressing different Bt proteins (Cry1A.105 and Cry2Ab2) was approved in 2011 in a bid to counteract *B. fusca* resistance (Van den Berg *et al.,* 2013). Cry1A.105 and Cry2Ab2 have different protein structures and bind differently to the mid-guts of target insects (USEPA, 2010). The expression of the two unrelated Bt toxins at a high level is therefore expected to counteract resistance evolution even with small refuge sizes and an initially high resistance allele frequency (Gould *et al*., 2006). The total area planted to Bt maize with single Bt trait and two-stacked Bt traits in 2014 is respectively estimated at 120,000 ha and 480,000 ha (James, 2014a).

Herbicide tolerant roundup ready maize, which allows farmers to spray glyphosate, a non-selective foliar herbicide over the tops of their maize plants up to the eight leaf stage (Monsanto, 2012) was commercially produced in South Africa for the first time during the 2003/04 crop production season (Gouse, 2012a). The area planted to single trait herbicide tolerant maize in South Africa increased from 19,000 ha during the 2004/05 cropping season to 410,000 ha in 2014 (Gouse *et al.,* 2008; James, 2014a). ‘Stacked’ trait maize (with Bt and herbicide tolerance traits in one seed) was first released for commercial production in South Africa during the 2007/08 crop production season (Gouse, 2012a). The area cultivated to ‘stacked’ trait Bt and herbicide tolerance GM maize increased from 83,000 ha during the 2007/08 season to 1.13 million ha in 2014 (Gouse, 2012b; James 2014a). In South Africa, GM maize is mainly cultivated in Mpumalanga, Northern Cape, the North West and Free State Provinces (Gouse *et al.,* 2009; Van den Berg *et al*., 2013)

Smallholder farmers in South Africa undertook the maiden cultivation of GM (Bt) maize during the 2001/02 cropping season, this distinguished South Africa as the first country in the world to produce a subsistence crop using GM seed (Gouse, 2012a). About 3000 smallholder farmers in communal areas of the KwaZulu-Natal, Mpumalanga and Eastern Cape Provinces were the first group of farmers that cultivated GM maize seed (Gouse *et al.,* 2008). Since 2003, many other smallholder farmers in the province have received GM maize seeds for cultivation through a number of private enterprise interventions and government programmes (Fischer *et al*., 2015; Kotey *et al*., 2016). Amongst these initiatives are; Siyakhula/Massive Food Production Programme and the Crop Production Programme (Cropping Programme) (ECDA, 2008; ECRDA, 2013). Currently, smallholder farmers in the province cultivate GM maize under the Cropping Programme of the Department of Rural Development and Agrarian Reform (DRDAR) (Kotey *et al.,* 2016). No accurate records exist on the number of smallholders that purchase GM seed or the area of land cultivated to GM maize seed in smallholder systems (Gouse, 2012a).

Gouse *et al.* (2008) however estimated that approximately 10,500 smallholder maize planted GM maize seed on about 33,000 hectares during the 2007/08 cropping season.

Fischer & Hadju (2015) have observed that although there have been repeated attempts at promoting the use of hybrid GM maize by both Government and non-governmental agencies, the adoption of the technology by smallholders in South Africa has been low.

2.6. Potential challenges to the adoption of GM maize technology by smallholder farmers in South Africa

Several factors, including the high cost of GM maize technology (Manes, 2013) limited GM seed availability and poor market access (Gouse *et al*., 2016), lack of seeds adapted to local conditions (Fischer & Hadju, 2015), age of smallholder farmers (risk aversion) (Mulaudzi & Oyekale, 2015), institutional challenges and inadequate support services (Manona, 2005; Jacobson, 2013; Fischer *et al*., 2015) and the regulatory environment for GM maize in South Africa amongst other factors have been identified as hindering the adoption of GM maize technology by smallholder farmers in South Africa.

2.6.1. Institutional challenges and inadequate support services

Cultivation of GM maize by smallholder farmers in South Africa has largely been through Government support initiatives (Fischer *et al*., 2015; Kotey *et al.*, 2016). Despite repeated efforts, these initiatives have failed to help smallholder farmers successfully transition to cultivating GM maize on their own. Most of these programmes have been top-down (Hart & Aliber, 2012; Jacobson, 2013) and sought to dictate what inputs farmers use, their scale of production and purpose of production (whether for consumption or sale) (PSPPD, 2011). The

MFPP, which was the first initiative to introduce GM maize to smallholders for instance, had a primary focus on maximizing the yield that smallholder farmers obtain, as such the programme sought to promote the cultivation of high yielding but input demanding hybrid maize varieties that did not reflect the conditions, practices and preferences of smallholder farmers (Jacobson, 2013).

In the Eastern Cape, although most households have larger fields (outfields) located some distance from the homestead, maize cultivation is usually undertaken in home gardens. During the 2008 cropping season for instance, 84% of home gardens as opposed to 54% of fields were cultivated with maize (Jacobson & Hadju, 2013). The reason for this is that fields are located far away from homesteads, and are more prone to damage by livestock, they are also impossible to cultivate without access to tractors (Jacobson, 2013). The focus on maximizing yield and the adoption of commercial farming techniques such as large-scale mechanisation of fields however meant that past and current GM maize support programmes prioritize the cultivation fields that can easily be consolidated to aid large-scale mechanisation operations (ECRDA, 2013; Jacobson, 2013; Kotey *et al*., 2016). This largely entails that only fields located some distance from the homestead (outfields) are cultivated with GM maize varieties. The cultivation of these fields, which are not easily accessible by farmers as well as the use of contractors to undertake most farming operations, entails that essentially, farming is done by Government on the lands of project beneficiaries (Manona, 2005). Historically too programme planning for such initiatives are done without the input of farmers (Kotey *et al*., 2016). Programme guidelines regarding mechanisation and planting schedules are also not flexible so as to allow for farmers to undertake operations on their own farms (Jacobson, 2013). The non-participatory nature of these programmes therefore does not provide an opportunity for farmers to build their capacity to effectively transition from the cultivation of OPVs to GM maize hybrids. De Grassi (2013) has stated that participation in decision making and project implementation ensures responsiveness, ownership, effective mobilization and use of resources, and building local capacity.

To enable respond positively to new innovations, they need to be adequately informed about how best to apply these new innovations or practices to their farming activities (Anaeto *et al.,* 2012). Extension plays a critical role in increasing the awareness of farmers about new technologies and helping them to adopt new technologies (Purcell & Anderson, 1997). In South Africa, extension and advisory support tailored to smallholder GM maize farmers has been reported to be inadequate and not well suited to helping farmers efficiently adopt GM maize (Assefa & Van den Berg, 2009; Jacobson & Myhr, 2012; Kotey *et al*., 2016).

2.6.2. Limited infrastructure and poorly functioning input and output markets

Fernando-Cornejo *et al.,* (2001) have stated that the availability of an agricultural technology innovation in input markets is a pre-requisite for its adoption. Majority of smallholder farmers in South Africa operate in rural areas (DAFF, 2012a). These areas are characterized by limited access to good roads. Poor road infrastructure increases the cost of transportation and consequently the delivered price of inputs (Tregurtha, 2009). Limited road infrastructure also makes markets for agricultural inputs and outputs in rural areas absent or unreliable (DAFF, 2012a). Challenges related to poor road infrastructure also decreases competition amongst input suppliers and middlemen and this potentially emboldens such suppliers and middlemen to charge higher prices for inputs and pay lower prices for outputs (Kelsey, 2013). It also restricts the ability of smallholder farmers to reach distant markets and also take advantage of demand and participate in value chains that could raise their incomes (IFAD, 2012). Lack of access to storage infrastructure may also prevent farmers from storing surplus harvest and timing their market entry to coincide with demand so they can gain higher prices (IFAD, 2012). Local markets are thus often flooded with agricultural commodities immediately following harvest, thereby driving down prices (Parvan, 2011). Bailey *et al*. (2014) contends that the adoption of a technology that increases productivity in the context of small fragmented crop markets is not sustainable. The prevalence of high prices for inputs and low prices for output and lack of market access may therefore serve as a barrier to the adoption of GM maize technology (Kelsey, 2013). Gouse *et al.* (2016) for instance reported that the non-availability of GM seeds and absence of a market for selling the extra yield obtained from GM maize was a deterrent to the adoption of the technology by smallholder farmers.

2.6.3. High input costs

Technologies such as GM maize seeds are associated with added costs in the form of technology fees (Shelton & Zhao, 2009). The need to apply complimentary technologies such as herbicides and fertilisers also imposes huge upfront costs on farmers that cultivate GM maize hybrids. In South Africa, owing to the provision of GM maize inputs at subsidized costs, farmers have largely been insulated from the full costs associated with adopting GM maize technology (Fischer *et al.*, 2015). This notwithstanding, reports indicate that without Government support, many smallholder farmers cannot afford GM maize inputs at current cost levels (Manona, 2005; Jacobson, 2013). In a study of GM maize cultivation by smallholders under a Government initiative in the Eastern Region, Manona (2005) estimated that smallholder farmers needed to obtain yields exceeding 11 tons per hectare to cover input costs. The same study indicated that even in cases where farmers managed to reduce input costs, yields of approximately eight tons per hectares were required to enable farmers break even (Manona, 2005). Actual yields obtained by farmers however ranged between two and three tons per hectare (Manona, 2005). Due to the high costs associated with GM maize seed, farmers need to obtain sufficient profits in order to be able to afford GM inputs (Griffin & Weaver, 2014; Fischer *et al*., 2015). The conditions and context of smallholder farmers in South Africa however makes GM maize production at levels necessary for achieving very high yields impossible.

Hybrids are generally high-yielding under optimal agricultural conditions and high fertilization (Fischer & Hadju, 2015). Such conditions may be obtained through irrigation and the application of fertiliser (NCB, 2004). Providing these conditions is however beyond the means of many resource-poor smallholder farmers. It has been reported that due to cost implications, GM maize farmers in South Africa do not apply fertiliser to their maize crops, others too are reported (Gouse, 2012a) to apply fertiliser and herbicides at rates lower than the recommended (Gouse *et al*., 2006a; Gouse, 2012a). The net effect of the inability of smallholder farmers to afford and apply inputs at recommended levels is a poor yield which may not suffice to off-set the higher input costs associated with GM maize.

2.6.4. Lack of varieties suited to smallholder conditions

A key factor identified for the slow adoption of GM maize in South Africa relates to the marketing of varieties not suited to local conditions (Schimmelpfennig *et al*., 2013). Unlike commercially-oriented farmers, smallholder farmers cultivate maize for subsistence purposes

(IFAD, 2012; Jacobson, 2013). In view of this, smallholder farmers have a preference for traits other than high yield, for example storability and yield stability (Jacobson, 2013). Due to a strong focus on increasing yield however, these features preferred by smallholder maize farmers are side-lined in the development of modern maize varieties (Brookes *et al.,* 2009; McCann *et al.,* 2006). GM maize varieties currently cultivated by smallholder farmers are therefore those designed for advanced agricultural markets and commercially oriented large-scale farmers (Bailey *et al.*, 2014; Assefa & Van den Berg, 2009). As a consequence, currently commercialized GM maize varieties in South Africa are based on commercial hybrids that do not necessarily reflect the specific conditions of smallholder farmers (Bailey *et al.*, 2014; NCB, 2004). Ensuring the participation of farmers over the course of technology development including views on preferences regarding traits selected, through to testing and commercialization, enhances the possibility that technologies developed are appropriate and adoptable (Bailey *et al.*, 2014: Nuffield Council on Bioethics (NCB), 2004). The possibility to achieve this is however limited by the fact that the private sector has little incentive to invest in developing technologies for smallholder farmers (Bailey *et al.*, 2014).

2.6.5. Regulatory environment for GM maize

Regulations regarding Bt maize in South Africa potentially obstruct smallholders from fully benefitting. These regulations apply both to the patents for GM crops and the biosafety management practices that come with planting GM crops in the country (Fischer *et al.*, 2015). The Nuffield Council on Bioethics (2004) has observed that ensuring that smallholder farmers have a genuine choice of seeds through the sustenance of funding for research in the public sector can counter high seed costs related to monopolistic seed suppliers. Research and development of GM seeds by the public sector is however restricted by Intellectual Property Rights (IPR) laws (NCB, 2004). In South Africa for instance, the use of GMOs is regulated by patent legislation. This together with other biosafety legislations have been observed to limit the possibility for developing suitable GM maize seeds which farmers can recycle (Fischer *et al.*, 2015) year after year without any appreciable loss in yield (NCB, 2004). Schimmelpfennig *et al*. (2013) have also stated that the possibility for segmenting and applying differential seed pricing for smallholder and commercial farmers is limited by potential costs associated with ensuring that smallholder farmers that receive such seeds comply with GM maize seed regulatory requirements. Most of these regulatory requirements are based on experiences from large-scale commercial settings and are said to be at variance with smallholder maize cultivation practices (Jacobson & Myhr, 2012; Fischer *et al.*, 2015). The regulatory framework surrounding GM maize introduction in South Africa therefore likely limits the opportunity for smallholders to benefit from the technology (Fischer *et al*., 2015). A detailed description of the regulation governing GM maize seed use is provided in section 2.8. Further, section 2.9 discusses the possible constraints smallholder farmers face in adhering to these regulations.

2.6.6. Risk and uncertainty associated with GM maize cultivation

Smallholder agriculture is plagued by a myriad of difficulties including climatic risk, declining soil fertility, pressure to expand food production into more marginal areas owing to population increases, high input costs, extreme poverty, and unavailability of credit systems (Bänziger & Diallo, 2004). These challenges lead many smallholder farmers to pursue livelihood strategies that involve lower-risk and lower-yielding agricultural activities (Bänziger & Diallo, 2004; Fan *et al*., 2013). Although GM maize is reported to be higher yielding, its cultivation is associated with high upfront costs associated with the use of complimentary inputs such as fertilisers, herbicides and pesticides. For instance Bt maize is currently sold at about double the price of popular non-GM hybrids and five times that of the price of popular open pollinated varieties (OPVs). Gouse *et al*. (2006a) have reported that during dry seasons when stalk borer infestations are low, farmers that plant Bt maize are financially slightly worse off than farmers planting less expensive conventional seeds. While large-scale farmers can buffer economic losses in one season with gains in other seasons, smallholders often do not have the economic capacity to do this (Jacobson, 2013). Historically, smallholder maize farmers in South Africa have mitigated the risks of possible crop failure by intercropping maize with other crops. The cultivation of herbicide tolerant GM maize varieties under various support programmes however makes this risk mitigation activity (intercropping) impossible.

According to Parvan (2011) without some level of assurance that access to future benefits is not at risk, farmers have little incentive to invest their time, labour and capital into technology adoption. Gouse *et al*. (2008) reported that during the 2004/05 season, owing to low and untimely rainfall in the eastern part of South Africa, many smallholders farmers made the rational decision not to invest in a risky maize production endeavor. The same study reported that some farmers who previously planted hybrid maize seed and applied fertiliser, planted OPV seed and did not apply any fertiliser for that season (Gouse *et al*., 2008).

Typically, patterns of technology adoption are influenced by individual farmers’ risk preferences and their ability to bear the risk of a new and uncertain endeavor (Parvan, 2011). Most GM maize farmers in South Africa are elderly folk (Assefa & Van Den Berg, 2009; Mandikiana, 2011; Gouse *et al.,* 2016). Studies have shown that older smallholder farmers are risk averse and are the most resistant to new technology adoption (Mulaudzi & Oyekale, 2015).

Adopting GM maize is a risky proposition for poor farmers with little in the way of resources to spend on the technology or fall back on if the technology fails (Bailey *et al.,* 2014). Given this, it is evident that without enhanced market integration and access to financial services and risk mitigation tools (IFAD, 2012) GM maize adoption by smallholder farmers is likely to remain small.

2.7. Potential advantages of GM maize

GM crops are among the most rapidly adopted technologies in the history of agriculture (Tabashnik, 2015). Proponents of the technology contend that insect resistant and herbicide-tolerant GM crops reduce the need for expensive chemical inputs and act as a scale-neutral technology, which holds particular advantages for smallholder farmers (Bailey 2005).

2.7.1. Potential advantages of herbicide tolerant maize cultivation

Weed control is often the most important crop protection activity undertaken on the farm (Hillocks, 1998). For smallholder farmers in rural areas, hoe-weeding is the most cost-effective and practical method of weed control (Mashingaidze, 2004; Joubert, 2000). It is however slow, labour intensive, cumbersome and inefficient (Chivinge, 1990). It is estimated that smallholder farmers spend about 50–70% of their total labour time hoe-weeding (Chikoye *et al*., 2007). Generally, the amount of labour available for farm operations depends on the amount of family labour that a household can mobilize or the amount of labour that can be hired in the local labour market (FAO, 2011). Limited supply of labour during the height of the cropping season entail that smallholder farmers always weed a large proportion of their fields after significant yield damage has been sustained (Chivinge, 1990). Marais (1985) estimated that delayed weeding of maize fields following plant emergence, could result in yield losses of up to 55% in smallholder fields. The adoption of labor-saving technologies such as herbicide tolerant maize is therefore particularly relevant in labour constrained environments such as in the Eastern Cape (Manes, 2013). The use of herbicide tolerant maize technology by smallhoder farmers can potentially reduce labour input for weed control thereby allowing additional resources to be allocated to other crops that may enhance nutrition and food security (Mavudzi *et al.,* 2001). The technology may also afford farmers greater production efficiency and flexibility as well as the facilitation of conservation tillage (Dill, 2005). In South Africa, reduced costs due to less spending on oxen, reduced number of hours spent on land preparation and reduced labor costs per hectare due to no-till planting have been reported as advantages smallholders derive from using herbicide tolerant maize (Gouse *et al.*, 2006b; Regier *et al.,* 2012; Brookes & Barfoot, 2014).

2.7.2. Potential advantages of Bt maize cultivation

According to Kfir *et al.* (2002) cultural control is the most appropriate and economical stem borer control strategy for resource-constrained smallholder farmers. The adoption and implementation of this control strategy by smallholders may however be severely constrained by inadequate extension support (Harris, 1989). The use of transgenic insect resistant varieties of maize may therefore provide smallholder farmers with a practical and economical way to minimize maize yield losses to stem borer pests (Hellmich *et al.*, 2008; Brookes & Barfoot, 2014). Smith (1997) has suggested that when insect resistant maize varieties are planted, insect control is available for little more than the cost of the crop seed, and there is often no need or in many cases, a greatly reduced need to purchase insecticides or the equipment to apply them for pest control. Bt maize technology is available in the seed and is thus completely divisible and can be used in any amount (Gómez-Barbero *et al*., 2008). Current evidence indicates that farm size has not been a factor affecting the ability of farmers to benefit from Bt technology (Brookes & Barfoot, 2014). In South Africa, both large and small farmers have been reported to derive benefits from Bt maize technology (Gouse *et al*., 2005; 2010). Small-scale maize farmers in the country reported higher yields for Bt maize hybrids compared to conventional iso-hybrids (Gouse *et al*., 2010). Although there may not be differences in yield between farmers who plant Bt and those who plant conventional hybrids in seasons with low stem borer pressure (Gouse *et al*., 2006a), the potential of Bt maize to reduce yield variability between seasons is considered an important advantage for smallholder farmers (Hellmich *et al*., 2008).

Stem borer damage to maize ears may predispose maize kernels to attack by fumonisin-producing pathogens which cause *Fusarium* ear or kernel rot (Munkvold & Desjardins, 1997). Munkvold *et al.* (1999) report that Bt maize hybrids that express Cry1A(b) proteins have reduced borer infestation and incidence of *Fusarium* ear rot compared to conventional maize. Esophageal cancer in humans has been linked with the consumption of maize with high concentrations of fumonisins (Munkvold *et al*., 1999). Pray *et al.* (2013) have therefore suggested that consumption of Bt maize kernels could potentially reduce the exposure of smallholder farmers in South Africa to esophageal cancer.

2.8. Potential negative effects of GM maize

The cultivation of GM crops has been suggested as a development that will have dire environmental and social consequences on the world (Brac de la PerriFre & Seuret 2000; GRAIN 2004). The spread of the technology has therefore contributed to concerns related to possible biosafety and biodiversity impacts (Wroblewski & Cullen, 2009). For instance there has been concern regarding the possible risks cross-pollination between GM and non GM crops could pose to agricultural diversity in developing countries (Klepek, 2012). It has been suggested that cross pollination of GM crop varieties with non-GM varieties, may result in loss of biological and genetic diversity (Andow & Zwahlen, 2006). In centres of agricultural diversity this could potentially result in erosion of locally adapted crop varieties that are tolerant to various biotic and abiotic stresses and produce stable yields with a minimum of external inputs in diverse and often marginal growing conditions (Soleri *et al*., 2005; Altieri, 2009). The issue of potential gene transfer from GM crops to wild relatives resulting in the emergence of "superweeds" has also been raised as a key concern. Cross hybridization between GM canola (*Brassica napus*) and a weedy relative (*Brassica rapa*) in Canada is cited as a case in point (Conway, 2013).

With specific reference to the cultivation of Bt maize, it has been suggested that Cry toxins in wind drifted pollen (Pleasants *et al*., 2001; Sears *et al*., 2001) may be deposited on plants within and adjacent maize fields thereby adversely affecting other Lepidoptera living within the agro-ecosystem itself as well as species within natural habitats nearby (Losey *et al*., 2003; Traxler *et al.*, 2005; Hofmann & Schlechtriemen, 2009). Other issues of concern regarding the cultivation of Bt maize include the possibility that Bt crop cultivation would quicken the development of resistance in pests and limit the efficacy of Bt foliar sprays that have been used since the 1930s for control of important pests like the cabbage looper (*Trichoplusia ni* (Hübner) (Lepidoptera: Noctuidae)) (Roush, 1994; Macdonald & Yarrow, 2003). The potential influence of transgenic Bt crops on the occurrence and activities of non-target soil organisms which provide important ecosystem services such as nitrogen cycling, decomposition of wastes and mobilization of nutrients has also been a source of concern (Carpenter, 2011). With regard to herbicide tolerant GM crops, the main issue of contention relates to concern that their use fosters the evolution of herbicide resistant weeds that contribute to increased environmental and food toxicity owing to the increased doses of herbicide required to control such weeds.

GM crop opponents have also stated that the potential for GM crop companies to control the supply of GM crop seeds through patents and biological mechanisms poses dire socio-economic risks (Kuyek, 2002). For instance, worry has been expressed that patenting GM plant varieties will result in high seed prices that will be beyond the means of smallholder farmers, thereby widening the gap between the wealthy and the poor. GM technology has also been cited as favouring input-intensive industrialized production systems (IAASTD, 2009) which is engendering a ‘technological treadmill’ of commercial input reliance that disadvantages smallholder farmers and facilitates a new wave of industrial export expansion (Otero 2008; Binimelis *et al*., 2009). Critics of GM crops therefore advocate that farmers be given the legal space to freely save, use, exchange and sell farm-saved seed (Wynberg *et al*., 2012).

2.8.1. Potential adverse effects of herbicide tolerant maize on weed management

Herbicide tolerant crops particularly, glyphosate resistant crops have transformed weed management (Green & Owen, 2011). The performance of herbicide tolerant crops has been described as remarkable (Dill, 2005). Currently, herbicide tolerant crops are the most widely adopted GM crop technology (James, 2014b). The convenient management of herbicide tolerant crops has resulted in farmers relying solely on herbicides and less on diversified methods of weed control (Green & Owen, 2011). The increased reliance on herbicide sprays to control weeds in herbicide tolerant crop fields may however increase the likelihood for the emergence of populations of plants with resistance to regularly used herbicides (Mannion & Morse, 2013; Brookes & Barfoot, 2016). Resistance may also occur as a result of farmers using higher or lower dose levels than that recommended. To date, biotypes of twelve weed species have been reported to be resistant to herbicides in South Africa (Heap, 2016). Selective pressure on weeds to evolve resistance arises not from the mere cultivation of herbicide tolerant crops but from the application of herbicides to which herbicide tolerant crops are engineered (Green, 2012). Modification of weed control practices including the use of alternate weed control tactics in rotation with herbicides to which herbicide tolerant crops are resistant has been advocated to reduce the likelihood of weeds evolving resistance to herbicides (Carpenter & Gianessi, 2010).

2.8.2. Potential effects of Bt maize on non-target organisms in GM maize agro-ecosystems

Bt maize that express the insecticidal delta (δ)-endotoxin Cry1Ab selectively targets the midgut of target stem boring Lepidoptera (Koziel *et al.*, 1993; Romeis *et al.*, 2009). The possibility however exists that the season-long expression of a high dose of insecticidal proteins may result in unintended effects on the abundance, activity, or diversity (Wolfenbarger & Phifer 2000; Prasifka *et al.*, 2005; Clark *et al*., 2005; Romeis *et al.*, 2009; Lundgren *et al*., 2009) of non-target Lepidoptera and other herbivore species occurring in the Bt maize agro-ecosystem. In agricultural systems, non-target organisms include all species other than those which pest management actions are intended to suppress (Prasifka *et al*., 2005). Non target organisms within maize agro-ecosystems may provide essential ecosystem services such as regulation of arthropod pest populations and nutrient recycling (Comas *et al*., 2014). Unintended effects to non-target organisms in maize agro-ecosystems may occur through ingestion of plant-expressed insecticidal proteins through direct feeding on the leaf, stalk, root, seed, or pollen (Clark *et al*., 2005).

The first report of adverse effects of Bt maize on a non-target species was made by Losey *et al.* (1999) who suggested that pollen from Bt maize harmed larvae of the monarch butterfly, *Danaus plexippus* (L.) (Lepidoptera: Nymphalidae). Subsequent to this, Hellmich *et al*. (2001) showed that when small monarch butterfly larvae were fed high doses of pollen for three to five days there were no observed effects in terms of weight gain or mortality. These findings were further corroborated by the findings of Stanley-Horn *et al.* (2001) who reported no acute effects when they fed monarch larvae on milkweed leaves dusted with levels of pollen from Bt11 and MON810 expected to occur under natural field conditions. Following a review of 20 peer reviewed publications, Lang & Otto (2010) concluded that both Bt11 and MON810 had both lethal and sub-lethal effects on non-target species both in the laboratory and in the field and for pollen or anther densities that can occur under natural conditions. Kramarz *et al*. (2009) also reported that the development of the snail, *Cantareus aspersus* (Müller) (Gastropoda: Helicidae) may be influenced by long-term exposure of at least 47 weeks to Bt maize. In South Africa, Van Wyk *et al.* (2008) reported that maize seedling damage by *A. segetum* was significantly higher on a non-Bt field compared to a Bt field. Similarly, it was observed that the incidence of maize plants damaged by *H. armigera* and *Acantholeucania loreyi* (Duponchel) (Lepidoptera: Noctuidae) in temporal succession studies was lower on Bt maize as compared to non Bt maize (Van Wyk *et al.*, 2008). It has therefore been suggested that Bt toxin ingested through direct feeding on plant tissues may likely have a negative effect on survival of *H. armigera* and *A. loreyi* (Van Wyk *et al.,* 2008). These species are regarded as pest species, adverse effects may therefore seem desirable from the point of view of the farmer. Peacock *et al.* (1998) have however reported that unintended elimination of non-target lepidopteran larvae by Bt proteins can indirectly impact parasitoids specific to a particular non-target lepidoptera or on generalist natural enemies that depend on lepidopteran larvae as primary sources of food (Schuler 2004; Peacock *et al*., 1998).

Peacock *et al.* (1998) have observed that there is a wide intra-generic variability in the susceptibility to Bt toxins among Lepidopteran species and even among developmental stages within one species. Erasmus *et al.* (2010) for example observed that although maize event Bt11 had no effect on survival and mass of fourth-instar larvae of *A. segetum*, it affected percentage pupation over time. The nature of effects may also vary between laboratory and field conditions. For instance, observations of negative effects are less frequent in field than in laboratory studies (Lang & Otto, 2010). Wraight *et al*. (2000) observed that whilst Bt-maize pollen was lethal to black swallowtail (*Papilio polyxenes*) (Fabricius) (Lepidoptera: Papilionidae) larvae in the laboratory, it had no effect on larval mortality under field conditions. According to Lang & Otto (2010) low or reduced effects in field experiments may possibly be due to smaller Bt effects under natural conditions.

Aside direct effects on non-target pest species, the effective control of target pests by Bt maize may result in pests species that are originally considered as minor pests occupying the niche vacated by the controlled target pest and becoming secondary pests on Bt maize (Erasmus, 2010). In the United States, larvae of the western bean cutworm (*Striacosta albicosta*) (Smith) (Lepidoptera: Noctuidae), a pest which was previously of minor importance and only occurred within a narrowly confined area is reported to be increasing in range and importance as a pest of Bt maize (Then, 2010). Then (2010) has attributed this situation to the unintended elimination of the corn earworm (*Helicoverpa zea*) (Boddie) (Lepidoptera: Noctuidae), a naturally occurring competitor of *S. albicosta* by Bt maize.

2.8.3. Resistance evolution in Bt maize target pests in South Africa

The effects of plant resistance to insects are cumulative over time, and the longer resistance is employed and effective, the greater the benefits of its use (Smith, 1997). Since the first deployment of Bt crops therefore, there has been concern with regard to the possible evolution of resistance in target pests (Tabashnik, 1994; Gould, 1998) which could cut short the benefits of insect resistant GM maize technology. Field evolved resistance can be defined as a genetically heritable change in a pest population arising from exposure of the population to the trait in the field that reduces the sensitivity of the population to the trait (IRAC, 2013). The first official report of field resistance to Bt maize in *B. fusca* in South Africa was made in 2006, when it was demonstrated that significant numbers of the first generation of larvae collected on Bt maize in the Christiana area in the Northern Cape Province survived on Bt maize (Van Rensburg, 2007). Increased incidences of *B. fusca* larvae on Bt maize during the post-flowering period was also reported by Van *Wyk et al.* (2007; 2008) in the Highveld region of the country. Currently, resistance in this pest has spread rapidly to new locations in the country (Van den Berg, 2013). The evolution of resistance by *B. fusca* to Bt maize in the country has largely been ascribed to non-compliance to refuge requirements (Kruger *et al*., 2011, 2012a; 2012b). Van den Berg *et al*.

(2013) have also suggested that the possibility of non adherence to the requirement for a high dose expression of Bt toxin and larval feeding and migration behaviour cannot be excluded. The discovery of the dominance of at least one type of resistance of *B. fusca* to Cry1Ab protein in the country (Campagne *et al.*, 2013) has also been suggested as an additional complicating factor (Van den Berg *et al.*, 2013).

2.9. GM maize technology stewardship requirements in South Africa

The use of GM maize in South Africa is regulated by the Genetically Modified Organisms Act, 1997(No. 15 of 1997) and its subsequent amendment act (Act No. 23 of 2006). The Act requires seed companies to sign technical agreements with farmers who purchase GM seeds. These technical agreements provide information about the use of the GM seed through a user guide (Monsanto 2012). Compliance with an insect resistance management (IRM) and weed resistance management (WRM) programmes including surveillance/monitoring of resistance development (both in insects and in weeds) are an essential requirement of technical agreements (Monsanto, 2012). The GMO act also requires GM maize permit holders to document the locations where GM maize is planted, provide education to farmers and monitor farmers to ensure adherence to GM crop management strategies. In addition to the GMO act, patent legislation and laws regulating the plant breeder’s rights act also regulate the use of GM crop seeds (Monsanto, 2012). This together with aspects of the GMO act that requires end users of GM products to avoid adverse impacts on the environment and animal or human health prohibits farmers from saving or sharing GM seeds.

2.9.1. Operational requirements for IRM: Insect refuges

IRM refers to tactics used to delay the evolution of resistance in pest populations to a specific protein or insect management practice (Tabashnik *et al.,* 2014). The principal strategy employed to delay resistance development in Bt crop target pests is the high-dose/refuge strategy (Alstad & Andow, 1995). The refuge strategy is based on three assumptions. Namely, the initial frequency of resistant alleles is low (less than 1 in 10^3); inheritance is recessive (individuals will have a resistant phenotype only if they have two resistance alleles at a genetic locus that determines susceptibility (Tabashnik *et al.,* 2014); and, random mating occurs between resistant and susceptible individuals (Bates *et al.*, 2005). The effectiveness of the refuge strategy to delay resistance evolution is improved with high refuge zone proportion. The larger the relative size of the refuge the more effective it is in delaying resistance (Tyutyunov *et al*., 2008; Gryspeirt & Grégoire, 2012). Current refuge requirement in South Africa involves the compulsory planting of 5% conventional varieties adjacent to Bt fields (within a 400m vicinity of Bt fields) without spraying or a 20% conventional planting as an insect refuge which can be sprayed with any insecticide either than that with Bt as an active ingredient (Gouse *et al.,* 2008; Kruger *et al.,* 2012a; Van den Berg *et al*., 2013).

2.9.2. Operational requirements for IRM: Resistance monitoring

IRM is based on the premise that resistance will develop in an insect population with continuous use of any insecticidal product including Bt maize (IRAC, 2013). Resistance monitoring is therefore an essential component of IRM (Bates *et al*., 2005). The goal of insect resistance monitoring is to detect resistance or significant changes in the susceptibility to a trait before widespread field failure occurs (Shelton & Zhao, 2009). Resistance monitoring for early detection and reporting of incidents of resistance development has been a registration requirement for transgenic Bt crops since 1996 when the first Bt plant was registered (Shelton & Zhao, 2009). Early detection of control failures may enable the deployment of mitigation measures that may help to extend product life (IRAC, 2013). Changes in the susceptibility of a field collection of a pest population of interest can be determined by comparison with previous (baseline) sensitivity data of pest populations prior to or in the early years of commercialization of the trait (IRAC, 2013). A number of monitoring techniques including, grower reports of unexpected damage; systematic field surveys of Bt maize: discriminating concentration assays and the F2 screen have been proposed (Shelton & Zhao, 2009). In Australia, a proactive resistance monitoring programme for Bt resistance in *H. armigera* using the F2 screen was implemented two years before farmers started planting Bt cotton in the country (Tabashnik, 2015). In South Africa however, between the first plantings of Bt maize in the 1998/99 cropping season and the first report of resistance in 2007, no systematic evaluation or monitoring for resistance evolution in *B. fusca* was undertaken (Van den Berg *et al*., 2013). Following the evolution and spread of resistance in *B. fusca to* Bt maize in the country, appropriate monitoring of pest resistance levels subsequent to release of Bt crops, has been advocated (Van den Berg *et al*., 2013).

2.10. Potential challenges to smallholder compliance with GM maize stewardship requirements

Smallholder maize farming is mostly undertaken on small plots of land by farmers with limited technological skills and formal education (DAFF, 2012a; Aheto *et al*., 2013; Van den Berg & Campagne, 2014). Seeds used in such systems are usually that of OPVs which may be recycled directly from harvest (Denning *et al*., 2009). These unique conditions and practices are deemed to be at variance with GM maize technology stewardship requirements developed to suit the conditions of large-scale commercial agriculture (Assefa & Van den Berg, 2009; Jacobson & Myhr, 2012). Thus, although non compliance has been reported elsewhere in the country (Van Rensburg, 2007; Kruger *et al.*, 2009; 2012a), it has been suggested that compliance with, and enforcement of GM maize technology stewardship requirements in smallholder systems will be more challenging (Kruger *et al*., 2012a).

2.10.1. Limited access to information on GM maize stewardship requirements

In a study on the introduction of Bt maize to smallholders in the Eastern Cape, Jacobson & Myhr (2012) reported that local seed retailers who were required to explain the contents and sign technical agreements with smallholder farmers had limited knowledge of GM maize stewardship regulations. The result of this was a low level of smallholder understanding of biosafety measures and compliance to GM maize stewardship requirements (Jacobson & Myhr, 2012). Similarly, Assefa & Van den Berg (2009) reported a low level of understanding of GM maize stewardship requirements amongst smallholder Bt maize farmers. In the main maize production region it has been reported that outreach education programmes coupled with compulsory signing of technical agreements led to a marked improvement in farmer compliance with GM maize stewardship requirements (Kruger *et al.*, 2009). Whilst it may be straightforward to sign technical agreements with large-scale commercial farmers it may be logistically impossible for seed companies to sign technical agreements with every smallholder farmer that purchases GM seed (Jacobson & Myhr, 2012). Gouse *et al*. (2008) have estimated that more than 10,000 smallholder maize farmers planted GM-maize during the 2007/08 season. This large number is further compounded by the fact that GM seeds cultivated by smallholder farmers are obtained through municipalities, agricultural development projects and groups (Gouse *et al*., 2008) which make it difficult to identify particular end users of GM maize seed.

2.10.2. Smallholder seed recycling practices

Smallholder maize cultivation in Africa has traditionally been based on OPV seeds, recycled from year to year (Denning *et al.*, 2009). In many cases, seed recycling may also extend to hybrids (Morris *et al*., 1999; Gouse *et al*., 2005). Recycled seeds may typically be obtained from informal seed systems based on traditional social networks and family relations within the same community (Almekinders, 2000). Seeds sourced from such informal systems tend to be readily available, inexpensive, of known quality, and well adapted to local conditions (Almekinders *et al*., 1994).

The practice of seed recycling plays an important role in areas where farmers lack credit or access to reliable sources of commercial seed. This practice may however make it impossible to identify and document end users of GM maize in the form of technical agreements. Without keeping track of farmer to farmer seed exchange of GM maize, it may be impossible to enforce any type of Bt maize stewardship requirements (Schimmelpfennig *et al.,* 2013). For example, lack of information on end users and locations of GM maize seed can potentially make it difficult to monitor or trace and remove a GM crop in the event of unanticipated environmental or health effects (Jacobson & Myhr, 2012). Seed saving practices may also increase the possibility for the proliferation of Bt transgenes in non GM maize which could expose target pest larvae to Bt maize plants with variable and sometimes reduced levels of Bt toxin and facilitate resistance evolution (Iversen *et al*., 2014).

2.10.3. Heterogeneity of smallholder farming systems

Smallholder farming environments are often very diverse (Dawson *et al*., 2008). A large amount of crop diversity may still be retained in such environments by smallholder farmers (Van de Wouw *et al*., 2010). Such crop diversity may be potentially useful sources of genetic variation, necessary for maintaining the capacity of crops to adapt to change (Bellon, 2009). Due to the fact that maize is a cross-pollinating species, pollen from one plant may fertilize kernels or seeds on the same plant or on nearby plants (Morris *et al*., 1999). The implication of this is that if uncontrolled, all plants in or near a field will differ from the preceding generation and from each other (Jacobson, 2013; Morris *et al*., 1999). To minimise the risk of cross-pollination of transgenic (Bt) and non-transgenic maize, the following practices are recommended by GM maize user guides: temporal isolation of at least three weeks between planting of transgenic and non-transgenic hybrids; spatial isolation of at least 400 m between transgenic and non-transgenic hybrids (Monsanto, 2012).

The agricultural structure in smallholder systems typically consists of a high density of small fields which makes the maintenance of recommended spatial isolation of GM and non-GM maize impossible (Aheto *et al*., 2013). Whilst temporal isolation may be a feasible option, its utility in smallholder systems may be limited by the fact that smallholder agriculture is largely rain-fed (Moeletsi & Walker, 2012). Farmers therefore have a limited planting window. Requiring farmers to plant too early or later may therefore not allow their crop’s water requirements to be met at critical stages of development (Moeletsi *et al*., 2011; Moeletsi & Walker, 2012) prior to the cessation of rains. Reduced ability of the crop canopy to intercept available solar radiation may also cause a progressive reduction in yield of late planted maize (Green *et al*., 1985).

2.11. The role of extension in GM maize technology information dissemination

In order for new technologies to work, farmers need access not only to land, but also to education, and appropriate agricultural extension support (Hart & Aliber, 2012). Purcell & Anderson (1997) have defined agricultural extension as the process of helping farmers to become aware of and adopt improved technology from any source to enhance their production efficiency, income and welfare. Public extension services play a key role in informing farmers of characteristics and benefits of new varieties and connecting farmers to sources of seed (Neate & Guei, 2010). Extension services are therefore important for diffusing technology and good practices (FAO, 2011). Smale *et al*. (2011) have identified extension as a key driving force behind the widespread diffusion of improved maize technologies in many sub-Saharan countries. Ozowa (1997) has suggested that the major function of extension is to get the farmer into a frame of mind and attitude conducive for the acceptance of technological change. To achieve this, there is the need to package information in a meaningful form (Opara, 2010). The extension information needs of farmers may include sources of farming inputs (seeds and fertiliser) and credit facilities, extension education and agricultural technology innovations (farming equipment, sowing dates, pest and weed control) (Ozowa, 1997; Anaeto *et al.*, 2012).

The information conveyed through extension consists of data (information), knowledge (simple skills), training (advanced skills and techniques) and education (where use of information requires critical thinking) (Vignare, 2013). According to Birner *et al*. (2009) the extension approach adopted by extension services may be dictated by factors such as the policy environment within which the service operates, the competence of its personnel, the farming system and market access of its target clients as well as the level of cooperation that exists between the service and the communities within which it operates. In South Africa, although the Department of Agriculture has stated that no single extension approach is suited to all situations (DoA, 2005), the Norms and Standards for extension and advisory services in agriculture recommends the technology transfer, participatory, advisory and project approaches for extension. The final choice of which extension model to use in particular situations may however be dictated by prevailing local conditions (DoA, 2005). Under the Cropping Programme of the Eastern Cape, extension and advisory services are provided by DRDAR, which is the extension service provider in the Eastern Cape. Farmers participating in the programme are largely introduced to GM maize through non-participatory approaches (Kotey *et al.*, 2016).

2.12. Agricultural technology information dissemination, farmer perceptions and the safe and optimal use of GM maize seed

According to Fliegel (1993) the diffusion of a new technology occurs along a path of awareness, interest, evaluation, trial, and adoption. Trial prior to adoption of an agricultural innovation can facilitate the development of skills in the management of the technology (Abadi Ghadim & Pannell, 1999). Smallholder farmers in South Africa cannot really be considered as GM maize technology adopters since they do not make an informed seed purchase decision (Gouse, 2012a) but are rather provided with the seed through various development initiatives. Government support initiatives aimed at supporting smallholder farmers in South Africa are mostly top-down and very prescriptive about what inputs smallholder farmers use (PSPPD, 2011).

Participatory approaches to technology transfer can play an important role in shaping farmers' perceptions of the characteristics and judgement of the value of agricultural technologies which may ultimately influence their adoption decisions and behaviour (Adesina & Zinnah, 1993; Adesina & Baidu-Forson, 1995; Abadi Ghadim & Pannell, 1999; Sinja *et al*., 2004). According to Lim & Heong (1994) the perception of an agricultural innovation improves with better access to information. Previous studies regarding the dissemination of GM maize technology to smallholders in the Eastern Cape indicate that due to limited access to information about the technology, smallholder Bt maize farmers generally have a limited awareness of the fact that Bt maize provides resistance to stem borers (Assefa & Van den Berg, 2009; Jacobson & Myhr, 2012). The perception of Bt maize as being stem borer resistant can play a major role in the reduction of the amount of pesticides applied on insect resistant crops (Mannion & Morse, 2013). Bt maize seed currently costs about twice the price of conventional hybrid seed and five times the price of OPVs commonly cultivated by smallholder farmers (Fischer *et al*., 2015). Cultivating Bt maize is therefore only profitable/advantageous when there is an evident pest pressure and when pesticide application costs can be sufficiently reduced to outweigh the high cost of seed (Kaphengst *et al*., 2010). Poor perception may however cause farmers to continue to apply pesticides at the same level as on conventional maize thereby limiting the possibility of making savings on pest control costs. It has also been reported that perception of alternate weed control strategies as ineffective, coupled with lack of awareness of the ability of weeds to evolve resistance to herbicides is a major hindrance to the adoption of diversified weed management tactics (Johnson *et al*., 2009; Frisvold *et al.*, 2009). Effective information dissemination about Bt maize to smallholder farmers may therefore be essential in reducing insecticide use on Bt maize and to improving profitability and adoption of weed and insect resistance management strategies.

CHAPTER 3: Disseminating genetically modified (GM) maize technology to smallholder farmers in the Eastern Cape Province of South Africa: Extension personnel's awareness of stewardship requirements and dissemination practices

Abstract

Advice and technical information from extension services are critical in promoting new technologies and their adoption by farmers. This study determined extension personnel's awareness of GM maize technology and the associated extension services they provide to smallholder GM maize farmers in the Eastern Cape Province of South Africa. Face-to-face interviews were conducted with extension staff of the Department of Rural Development and Agrarian Reform (DRDAR) in the province. Results indicated that inadequate training of extension personnel on GM maize technology influenced their perceptions of GM maize technology and awareness of its stewardship requirements. Generally, personnel had a low level of awareness of GM maize technology as a pest control strategy. Awareness of GM maize stewardship requirements amongst extension personnel was also low. These extension personnel disseminated GM maize technology, which they generally perceived as a high-yield technology, to smallholder farmers using non-participatory approaches and media sourced from GM seed companies. The findings of this study suggest that ensuring safe and sustainable adoption of GM maize technology on smallholder farms will require a more participatory extension approach that emphasizes smallholder farmers' access to information as well as the training of extension personnel on the stewardship requirements and dissemination practices associated with GM maize cultivation.

Keywords: Dissemination, extension, GM maize technology, smallholders, stewardship

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3.1. Introduction

Smallholder agriculture is the mainstay of agricultural production in sub-Saharan Africa and plays a critical role in improving livelihoods and reducing the susceptibility of poor rural and urban households to food insecurity (Baiphethi & Jacobs, 2009; Yengoh *et al.*, 2009). In view of this, the Provincial Growth and Development Plan (PGDP) of the Eastern Cape government has placed particular emphasis on subsistence agriculture in its efforts to combat food insecurity and poverty (PGDP, 2004; Ndhleve & Obi, 2013). To this effect the PGDP has formulated a number of initiatives aimed at supporting smallholder farmers in the province. The current initiative being implemented under the PGDP is referred to as the 'Cropping Programme' (ECRDA, 2013). The Cropping Programme seeks to increase smallholder food production and access to production support services such as inputs, mechanisation and advisory services (DRDAR, 2014a). Similar to the Massive Food Production Programme (MFPP), which was the first programme implemented under the PGDP (PGDP, 2004), the Cropping Programme focuses on increasing maize yields through the use of GM maize (Tregurtha, 2009; Jacobson, 2013).

GM maize has enhanced genetic traits that are patent-protected by the Plant Breeders' Rights Act, 1976 (Act No. 15 of 1976) and also regulated by the Genetically Modified Organisms Act (Act 15 of 1997). End-users purchasing GM seed [Bt maize, herbicide tolerant maize and stacked gene trait (BR maize), which combines Bt and herbicide tolerance in one hybrid] are therefore required to sign technology licensing agreements with permit holders where they agree to comply with permit conditions (Iversen *et al*., 2014). Amongst others, these regulations prohibit the saving or recycling and sharing of GM seeds and also requires the spatial isolation of GM and non-GM maize plantings as a stewardship measure. To delay resistance evolution by target pests, farmers who plant Bt seed are required to plant refuge areas of non-Bt maize adjacent to Bt maize fields. Assefa & Van den Berg (2009) have stated that these regulations are better suited to the conditions and practices of commercial farming. This is borne out of the fact that in contrast to commercial farmers, inputs used by smallholder farmers are self-generated, being obtained directly from previous harvests or locally-sourced through exchange with friends, neighbours and relatives (Sperling *et al*., 2006). Additionally, the agricultural structure in smallholder systems typically consists of a high density of small fields which makes the maintenance of stipulated legal separation distances impossible (Aheto *et al*., 2013). Cultivation of GM maize by smallholder farmers therefore necessitates adoption of new management practices and changes in farmer behavior, both for the sake of ensuring optimal use (Jacobson, 2013) and compliance with these regulations.

Extension and advisory support plays a key role in engendering attitudinal change and promoting the adoption of new technologies and good agricultural practices by smallholder farmers (Ozowa, 1997; Mafabia & Obi, 2011; Taye, 2013). The relevance of information transferred by extension services to smallholder farmers is an important determinant of its utilization (Opara 2010). Extension personnel may therefore not be able to successfully facilitate the adoption of new management practices by smallholder GM maize farmers unless they are aware of GM maize stewardship requirements and package these requirements in a manner that farmers perceive to be meaningful and appropriate for ensuring the long-term sustainability of GM maize technology. Studies conducted in localized areas of the Eastern Cape and KwaZulu-Natal Provinces has indicated that successful and safe introduction of GM maize to smallholders was hindered by lack of transfer of information (Assefa & Van den Berg, 2009; Jacobson & Myhr

2012). This study therefore determined extension personnel's awareness of GM maize technology stewardship requirements and the associated extension services they provide to smallholder GM maize farmers in the Eastern Cape Province.

3.2. Materials and methods

3.2.1. Questionnaire based survey

Surveys were conducted in five of the six District Municipalities of the Eastern Cape where dry land maize cultivation is undertaken by smallholder farmers. A total of 81 extension personnel from 16 service centres of DRDAR (Figure 3.1) were interviewed between September 2014 and May 2015. All respondents who had GM maize projects in their areas of operation and were present at post at the time of the survey were purposively selected and interviewed. Extension personnel were interviewed individually using a semi-structured questionnaire (Appendix 10.1). Topics covered in interviews included: insect pest constraints to maize cultivation, the strategies adopted for managing stem borer infestation in maize, the level of awareness of GM maize stewardship requirements as well as the perceptions of extension personnel regarding GM crops with insect resistance and herbicide tolerance traits.

3.2.2. Data analyses

Frequency counts and percentages were used to describe the demographic and educational characteristics and the level of awareness of GM maize technology and its stewardship requirements. For all questions asked during interviews, percentages were calculated using the total number of extension personnel who responded to a particular question. In cases where respondents did not answer a particular question, they were excluded from the calculation of percentage values for that question.

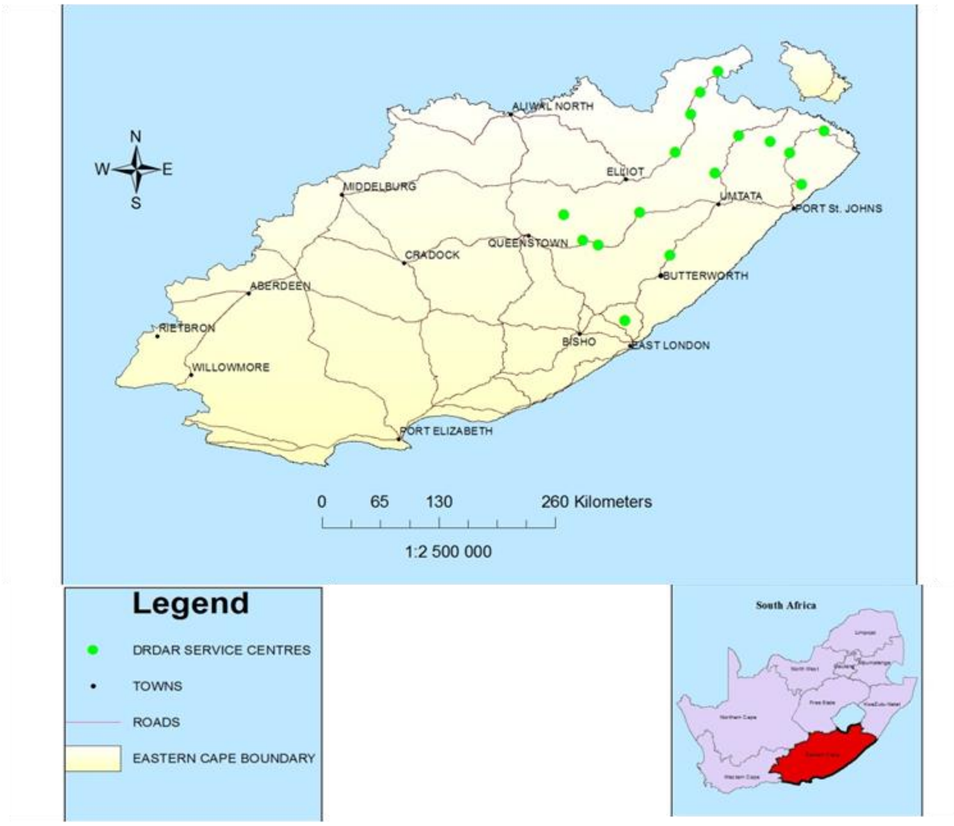

Figure 3.1. Map of the Eastern Cape showing localities at which respondents were interviewed

3.3. Results

3.3.1. Demographic and professional characteristics of extension personnel

The overall ratio of extension personnel to GM maize farmers was 1:101. Results indicated that the majority of extension personnel (64%) who render extension and advisory services to smallholder GM maize farmers are male.

According Figure 3.2 below, majority (77%) of the extension personnel that participated in the survey were below the age of 50 years and only 14% of respondents were above the age of 55.

Most of the respondents had a diploma qualification (35%) in agricultural extension (51%) and 38% had between 5-10 years of experience as extensionists.

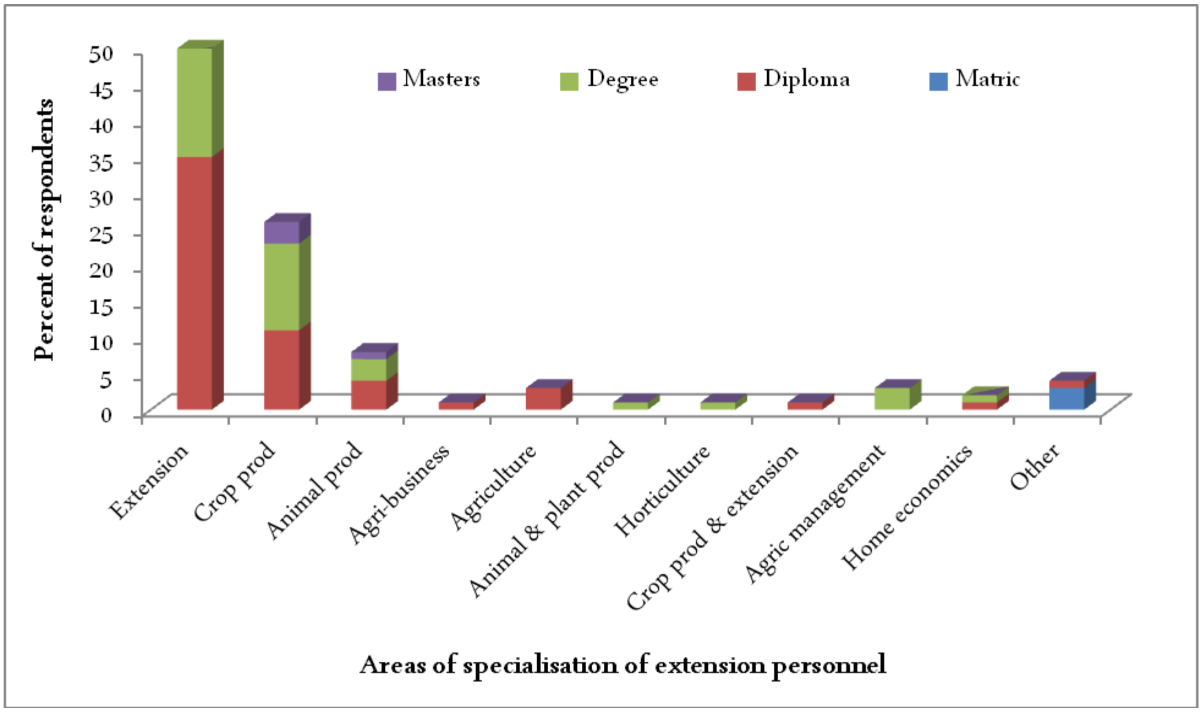

Figure 3.2. Educational and professional profile of extension personnel who render extension and advisory services to smallholder farmers in the Eastern Cape Province

3.3.2. Extension personnel's awareness about GM maize technology and stewardship

A key aim of this chapter was to establish the current status of extension personnel's awareness about GM maize technology and stewardship and identify gaps that justify remedial intervention. The results for this are presented in Table 3.1 which shows extension personnel's level of participation in GM maize technology training and their awareness regarding regulatory and stewardship aspects of GM maize seed use.

Table 3.1. Extension personnel's participation in GM maize technology training programmes and awareness about regulatory and stewardship aspects of GM maize seed use

Training in GM maize technology	**Frequency**	**Percentage**
Yes	32	40
No	49	60
Total	81	100
Awareness of regulations governing GM seed use	**Frequency**	**Percentage**
Yes	19	27
No	52	73
Total	71	100
Specific details of regulations	**Frequency**	**Percentage**
Application of herbicides	1	5.6
Use of co-operatives for GM cultivation	1	5.6
No mixed cropping, re-use of GM seeds	9	50.0
No sharing of GM maize seeds	1	5.6
Don't Know	6	33.3
Total	18	100
Awareness of refuge area planting	**Frequency**	**Percentage**
Yes	4	8
No	47	92
Total	51	100
Bt maize cultivation on smallholder farms poses no potential negative effects for local maize varieties	**Frequency**	**Percentage**
Agree	26	57
Disagree	12	26
Don't know	8	17
Total	46	100

The results indicate that the majority (60%) of respondents did not receive any training on GM maize technology before becoming involved in the dissemination of the technology to smallholder farmers (Table 3.1). The awareness of respondents regarding regulatory aspects and stewardship around GM seed use was generally low. The number of respondents that were aware of stewardship requirements regarding GM maize was low with 50% listing mono-cropping of GM maize (no inter-cropping of GM maize with other plant species) and no re-use of GM seeds as stewardship requirements (Table 3.1). Their lack of knowledge regarding this issue was further illustrated by answers referring to application of herbicides to Bt maize (5.6%), use of cooperatives for GM cultivation (5.6%) and no sharing of GM maize seeds (5.6%). Additionally, only 8% of respondents in whose area Bt maize was cultivated during the 2013/14 season said they were aware of the fact that refugia needed to be planted adjacent to Bt maize fields. All respondents also indicated that neither they nor the farmers in their areas signed any technology agreements before being provided with seeds for cultivation. The level of awareness about the potential effects, through outcrossing of Bt maize on local maize varieties was also low with majority of respondents (57%) indicating that Bt maize cultivation adjacent locally recycled maize seeds or varieties could have no adverse effect. A few (17%) respondents also did not know if Bt maize cultivation could adversely affect local maize varieties or not (Table 3.1).

3.3.3. Extension personnel's awareness on the relative importance of maize pests and GM maize as a pest management technology

The study sought information from extension personnel as to the insect pests that are important constraints to maize cultivation in their areas as well as the strategies adopted for managing these pests. The results are presented in Figures 3.3 and 3.4. Further, Table 3.2 shows extension personnel's perception of the benefits of cultivating GM maize in their areas of operation.

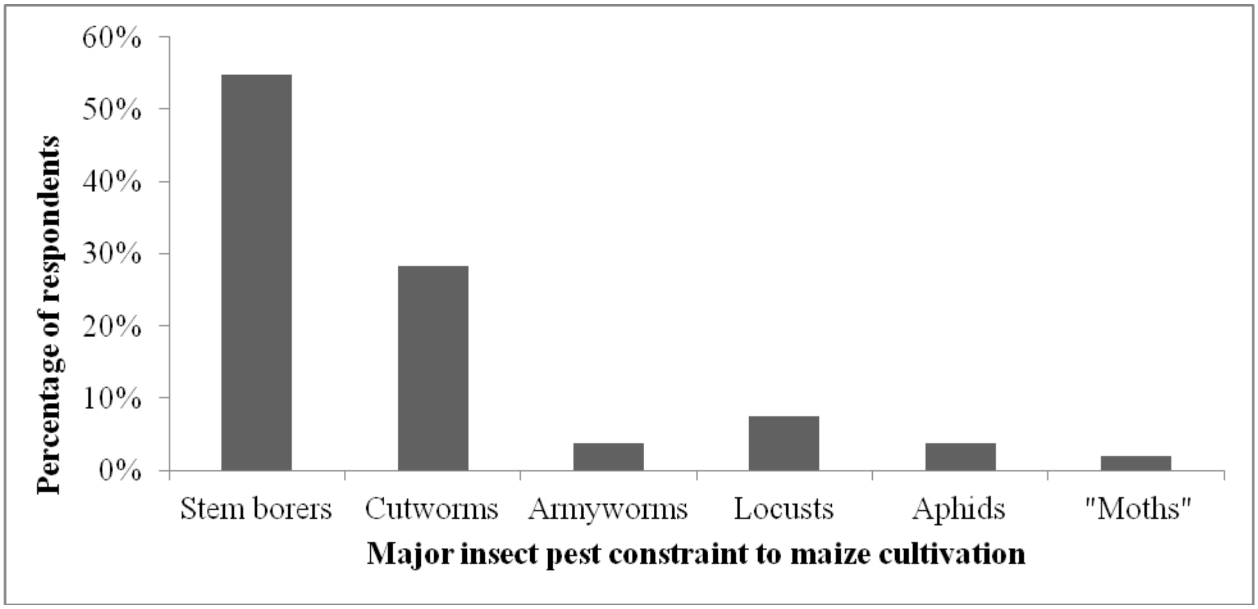

Figure 3.3. Insect pests of maize indicated by extension personnel to be important in the Eastern Cape Province

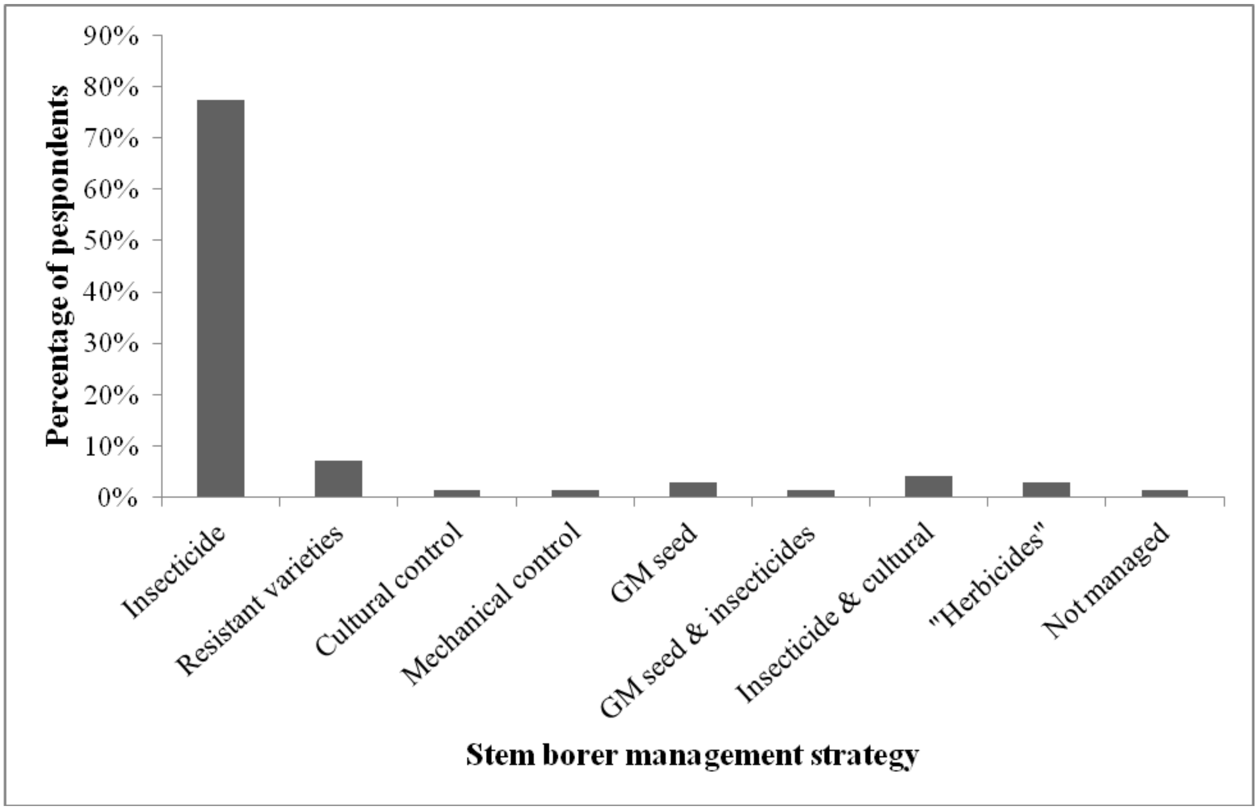

Figure 3.4. Strategies used for the management of stem borers on maize farms of beneficiaries of the Eastern Cape Province's maize Cropping Programme

Stem borers were indicated to be the major insect pests of maize (Figure 3.3) and insecticide application was the most common method of control (Figure 3.4). About 28% of respondents also listed cutworms and locusts as major insect pest constraints to maize cultivation in their areas. The proportion of respondents that recognised the use of Bt maize seed as a stem borer control tactic was generally low. Use of stem borer resistant Bt maize as a sole tactic and in conjunction with insecticide sprays were respectively listed by only 10% and 1% of respondents. A combination of insecticide sprays and adoption of cultural control methods were used in 4% of operational areas. About 3% of respondents mentioned use of herbicides as the stem borer control strategy. Twenty-nine percent of personnel perceived higher yields as the benefit farmers obtain from cultivating GM maize. Lower labour input was cited by 18% of respondents whilst 15% of respondents said farmers in their areas of operation obtained high yields and had a low labour input when they planted Bt maize (Table 3.2).

Table 3.2. Benefits indicated by extension personnel to be associated with planting of Bt maize

Advantage derived from planting GM maize	**Frequency**	**Percentage**
Higher yield	23	29
Lower labour input	14	18
Drought tolerance	3	4
Higher yield, income	1	1
Higher yield and lower labour input	12	15
Lower labour input, resistance to pests	5	6
Seed adaptability, higher yield, resistance	4	5
Higher yield, drought tolerance, food safety	1	1
Higher yield, resistance to pests, diseases	5	6
Higher yield, drought tolerance, lower labour input	1	1
Don’t know	11	14
Total	80	100

3.3.4. Provision of extension and advisory services and GM maize technology information dissemination to smallholder farmers

Table 3.3 shows the level of extension contact and the strategies adopted by extension personnel for disseminating GM maize technology to smallholder farmers in their areas of operation.

Table 3.3. Extension contact and strategies used to disseminate GM maize technology to smallholder farmers in the Eastern Cape Province

Periodicity of contact with GM maize farmers (percentage of personnel's annual extension activities)	**Frequency**	**Percentage of time schedule**
5-10 %	16	20
11-20 %	8	10
21-30 %	11	14
31-40 %	14	18
41-50 %	11	14
>50 %	19	24
Total	79	100
Strategies used for GM maize technology dissemination	**Frequency**	**Percentage**
Information (info) days	7	9.2
Info) days + flyers	1	1.3
Info days + video presentations	14	18.4
Info days + demonstration trials	3	3.9
Info days + flyers + video and training sessions	6	7.9
Workshops & training sessions	6	7.9
Info days + video & demonstration trials	2	2.6
Info days + flyers + video	20	26.3
Info days + flyers + video + Farmer Field Fora	6	7.9
Info days + flyers + video & demonstration trials	7	9.2
None	4	5.3
Total	76	100
Source(s) of media used to disseminate GM maize technology to smallholder farmers	**Frequency**	**Percentage**
DRDAR	7	10.6
GM seed companies	17	25.8
Non-governmental organisations	7	10.6
Dohne Agricultural Development Institute	1	1.5
DRDAR, Non-governmental organisations (NGOs)	3	4.5
GM seed companies & NGOs	11	16.7
DRDAR & GM seed companies	7	10.6
DRDAR, GM seed companies & NGOs	13	19.7
Total	66	100

Twenty four percent of respondents dedicated more than 50% of their annual extension schedules (from commencement of pre-planting operations in October to harvesting in June) to GM maize related activities whilst 20% dedicated between 5-10% of their extension schedule to GM maize related activities. Only 10% of respondents dedicated between 11-20% of their extension schedule to GM maize related activities (Table 3.3). Generally, GM maize technology was disseminated to smallholder farmers through information days (Table 3.3). About 26% of respondents used flyers and video presentations to disseminate GM technology during such days whilst 18% of respondents used only video presentations during information days. Generally, less than 10% of respondents disseminated GM maize technology through workshops, training sessions or through participatory approaches such as farmer field fora and demonstration trials (Table 3.3). The primary source of media used to disseminate information was from GM seed companies (about 26% of respondents) that provided materials for this purpose. Although a sizeable proportion of respondents used media from a range of sources (DRDAR, GM seed company and NGOs) only 2% of respondents indicated that they used media from the Dohne Agriculture Development Institute in the Eastern Cape Province (Table 3.3).

3.4. Discussion

3.4.1. Demographic and professional characteristics of extension personnel

Majority of extension personnel that render advisory services to GM maize farmers were male. This result is similar to the findings of the Department of Agriculture Forestry and Fisheries (DAFF, 2009) which reported that the extension services in seven of the nine provinces of South Africa are dominated by male personnel. The ratio of both male and female extension agents to GM maize farmers were well above the target of one agent to 400 subsistence and household farmers for the country (DoA, 2005). However, increasing the number of qualified female extension personnel may translate into better service provision (Hart & Aliber, 2012) and also boost food security in female-headed households. It has been observed that better information transfer to female farmers is achieved through female-to-female extension as opposed to male-to-female extension (SDC, 1995 cited in Manfre *et al*., 2013). This is particularly important since female farmers constitute more than two-thirds of people involved in smallholder agriculture in South Africa (Hart & Aliber, 2012).

According to the Department of Agriculture (2005), on average, extension personnel in the Government service in South Africa possess a three-year post-matriculation agricultural diploma qualification which does not adequately equip them with the skills and expertise for the attainment of desired outputs. The knowledge and capacity of personnel to effectively perform tasks in a certain field of expertise generally increases with increasing number of years served in that particular field (Mathabatha, 2005). Thus, although the findings of this study indicate that most personnel possess a diploma qualification, the high number of relatively young extension officers in the region provides an opportunity for capacity development related to the new technology such as GM crops that will be an important component of the farming system of the region in future.

3.4.2. Extension personnel's awareness about GM maize technology and stewardship

The awareness of respondents regarding regulatory aspects and stewardship around GM seed use was generally low. In accordance with the provisions of the GMO Act, Act 15 of 1997, the GMO Amendment Act (Act 26 of 2006), the Plant improvement Act, Act 53 of 1976, and the plant breeders rights Act, Act 15 of 1976, GM maize may only be cultivated by a farmer who has signed an agreement with the patent holder (Monsanto, 2012). Consequently, it is illegal to cultivate GM maize without a signed licence agreement or to ignore the conditions set forth in the licence (Monsanto, 2012). All extension personnel interviewed revealed that because beneficiary farmers received their seeds for planting from DRDAR they were not required to sign technology agreements. This situation is however not unique to the Cropping Programme. Jacobson & Myhr (2012) observed that under the MFPP, smallholder farmers did not sign agreements with Monsanto, the permit holder. Results of interviews however indicated that extension personnel may not be aware that planting GM maize without the signing of technical agreements is an infringement of the law. This is particularly so because the specific regulations that respondents said they were aware of did not include the requirement for the signing of agreements (Table 3.1). The awareness of the regulation of mono cropping of GM maize and no re-use of GM seeds may be attributed to the fact that during the workshops that first introduced GM maize to smallholders in the province, farmers were advised not to inter-crop GM maize with other crops species or recycle GM seeds from harvests (Jacobson & Myhr 2012). In most areas of the Eastern Cape, farmers wishing to join the Cropping Programme in an area are required to form a group and elect a committee. The perception that only farmers’ cooperatives can be used for GM maize cultivation may therefore be attributable to this.

The implementation of an insect resistance management (IRM) program is specified by technical agreements. The main IRM strategy used to delay resistance development by Bt maize target pests is the high dose/refuge strategy (Van den Berg *et al*., 2013). This strategy involves the planting of hybrids expressing a high dose of insecticidal proteins and a refuge planting containing hybrids not expressing insecticidal proteins. The target pest is therefore not under selection pressure for resistance evolution in the refuge block and the refuge therefore produces a large number of susceptible insects (Burkness & Hutchison, 2012). The role of GM crops in enhancing environmental sustainability in agriculture is compromised once GM maize target pests develop resistance to the technology (Jacobson & Myhr, 2012). As such, the planting of a refuge area adjacent to Bt maize is a vital component of Bt maize production that ensures long term sustainability of the technology. Awareness of the requirement for the planting of a refuge area next to Bt maize amongst extension personnel was however very limited.

Several authors have observed that the implementation of biosafety regulations including refuge plantings will be problematic on smallholder farms (Assefa & Van den Berg, 2009; Kruger *et al*., 2012a). Reasons assigned for this includes the structure (Aheto *et al.*, 2013) and conditions (Assefa & Van den Berg, 2009) of smallholder agriculture. The current structure of GM cultivation by smallholder farmers under the Cropping Programme mostly consists of several small fields organized into large units to facilitate mechanisation. The consolidation of small farm units into large ones therefore presents an opportunity for the planting of refuge areas adjacent Bt maize on such fields. Mannion & Morse (2013) have stated that the implementation of refugia in smallholder settings depends on increased awareness creation. However, although increasing the awareness of extension personnel in the province may facilitate the implementation of refugia, the implementation strategy of the Cropping Programme as well as short comings of key stakeholders like DAFF/DRDAR and GM seed companies in fulfilling duties stipulated in the GMO Act will have to be addressed. For example, inputs supplied by the District Municipality offices of DRDAR to service centres are usually matched to the area of land to be cultivated in each sub-district. Field visits indicated that seeds of non-GM iso-hybrids for the planting of refuge areas are not supplied along with these inputs. Therefore even if extension personnel at the sub-district level were aware of the requirement for the planting of a refuge area next to Bt maize, they will be constrained to ensure compliance. The practice of supplying GM seed without a conventional near iso-line is contrary to the practice that pertained when Bt maize was first introduced to smallholder farmers in the province. During the initial introduction of Bt maize to smallholder farmers, bags of Bt maize seed and its non-GM iso hybrid were provided to farmers for the planting of refuge areas (Gouse, 2012a).

Under the GMO Act, inspectors within the DAFF are required to monitor for compliance to permit conditions including measuring the effectiveness of risk management strategies and the detection of possible adverse impacts. Similarly, representatives of the GM seed companies from whom farmers obtain their seeds are supposed to advise famers (in this case DRDAR) to ensure on-farm compliance with refuge planting requirements. It therefore follows that if these institutions insisted on compliance it would have heightened the awareness of extension personnel at the sub-district level and facilitated some level of compliance.

Local crop varieties cultivated by smallholders are adapted to different (and often changing) growing conditions and farmer preferences and therefore constitute co-evolving socio-biological systems that conserve genetic diversity under evolution (Tripp & Van der Heide, 1996; Bellon *et al.*, 2015). The genetic diversity of these crops is vital to minimizing the susceptibility of crops to unexpected changes in climate, and to the emergence of new pests and diseases (Esquinas-Alcázar, 2005). Maize is a cross-pollinating crop, as such, unless deliberate measures are undertaken to separate GM and non-GM maize plantings, GM maize transgenes can lead to the erosion of the genetic diversity inherent in local maize varieties. This is particularly important given the fact that GM maize transgenes have recently been reported in non-GM maize in parts of the province (Iversen, *et al.*, 2014). Apart from the effects on the diversity of locally recycled seeds, the presence of transgenes in seed that are perceived to be non-GM may have an effect on pest resistance evolution in the long run. It has been reported by Van den Berg *et al.* (2013) and Iversen *et al.* (2014) that reduced Bt protein expression in open pollinated maize varieties that have Bt gene, may lead to resistance evolution. Increasing the awareness of extension personnel regarding these adverse effects will therefore facilitate the adoption of good GM maize stewardship programs by farmers which will in turn limit the proliferation of GM maize transgenes in locally recycled seeds.

3.4.3. Extension personnel's awareness on the relative importance of maize pests and GM maize as a pest management technology

The listing of stem borers and cutworms as the major insect pest constraints by respondents are consistent with the findings of Schimmelpfennig *et al*. (2013) regarding insect pest constraints on smallholder farms in South Africa. Although the predominant GM seed type (60% of operational areas) used in the operational areas of respondents during the 2013/14 farming season was BR maize (combination of Bt and herbicide tolerance traits in one seed), stem borer infestation on maize in these areas was mostly managed through insecticide application. Very few personnel demonstrated awareness of either the fact that Bt maize was a stem borer management tactic, or that it provided advantages to smallholder farmers. The limited awareness of Bt maize as a stem borer control tactic may be attributable to the low prevalence of personnel with a background in crop protection as well as a lack of on the job training on GM maize technology.

The current model of GM maize dissemination could also be a contributory factor. Interactions with personnel indicated that there was little participation in the selection of GM maize varieties by personnel at the sub-district level. Their role was mostly limited to ascertaining the seed color desired by farmers in their areas. Inputs are also purchased and supplied as a package (fertiliser, herbicides, insecticides and seeds) for a pre-determined area (hectares) to be cultivated. This implied that Bt cultivars were supplied together with insecticides for stem borer control which were subsequently sprayed onto fields including Bt fields. These could have limited the awareness of the personnel about the fact that Bt maize is stem borer resistant. Kruger *et al.* (2012a) also observed preventative application of insecticides on Bt maize on commercial maize farms in the country. The practice however goes contrary to the fact that one of the main advantages of insect pest resistant GM technology is the reduction of insecticide applications (Qaim, 2003; Gouse *et al.*, 2005; Mannion & Morse, 2013). Additionally although the practice may contribute to delaying of resistance evolution by target pests it is far removed from good integrated pest management (IPM) (Van den Berg *et al*., 2013). Hellmich *et al*. (2008) have stated that GM crops expressing insecticidal proteins are an essential component of maize IPM strategies. This is however feasible only if Bt-crops replace the use of broad-spectrum insecticides and not if insecticide sprays are applied without the guidelines of economic thresholds and to GM Bt maize that may not require it. A few personnel indicated that stem borer infestation on maize in their areas was managed with herbicides. As part of the mechanisation of farm operations, herbicides and insecticides are applied simultaneously using boom sprayers. It is therefore likely that these respondents could not distinguish between the two. Damgard-Hansen cited in Tregurtha (2009) previously reported that extension personnel have a limited awareness of agricultural chemicals.

3.4.4. Provision of extension and advisory services and GM maize technology information dissemination to smallholder farmers

Most of the extension personnel interviewed in this study indicated a high level of contact with GM maize farmers. Responses of extension personnel however indicated that GM maize technology was largely disseminated through print media and other non-participatory approaches. Mpofu *et al.* (2012) define extension services as a service of information, knowledge and skills development to enhance the adoption of improved agricultural technologies and facilitation of linkages with other institutional support services (input supply, output marketing and credit). In addition to rendering extension services to farmers, extension personnel in the Eastern Cape act as coordinators of rural development initiatives in their operational areas (DRDAR, 2014b). Services rendered by personnel prior to maize planting include compilation of the lists of farmers who wish to participate in the Cropping Programme during the season. Personnel also assist farmers who cannot afford to pay the ZAR 1,800.00 contribution to obtain credit in order to participate in the program. Other pre-planting services rendered includes soil sampling and testing and plot demarcation. Procurement of production inputs are however undertaken by contractors/service providers appointed by the Eastern Cape Rural Development Agency, the implementing agency of the Cropping Programme. During the actual cultivation season, services provided by extension personnel are limited to supervision of the implementation (ploughing, planting, insecticide and herbicide application) of the programme by service providers and the writing of progress reports on the level of implementation of these services.

Interaction with extension controllers indicated that extension service provision is demand-driven and as such when farmers have problems they notify their extension personnel who diagnose the problem and if they have the solution to the problem they address it. Otherwise they link farmers with the relevant experts for redress. The current standard of service by extension staff in the province is the provision of appropriate technical advice to farmers on request within a stipulated number of working days (DRDAR, 2014b). The current approach to GM maize cultivation, whereby all farming operations are undertaken by contractors, does not build the capacity of farmers in the business of farming or encourage ownership of their fields. Indeed, many extension personnel complained about the apathy of some farmers in their areas. According to personnel, after paying the ZAR 1,800.00 contribution and identifying their fields for ploughing, these farmers will normally only visit fields again during harvesting. Personnel also revealed that in cases when the delivery and application of herbicides are delayed, these farmers leave their fields overgrown with weeds. It is therefore debatable how farmers who do not visit their fields or actively participate in decision making and management of their fields can identify problems and seek solutions from extension personnel. According to Roling (1995) cited in Ssemakula & Mutimba (2011) good farmers produce good extension personnel. An extension approach which empowers farmers is therefore likely to sustain a good and effective extension system. A more participatory approach that builds the capacity of farmers in maize cultivation and encourages ownership will therefore be needed if the goals of the Cropping Programme and in particular the cultivation of GM maize are to be attained.

Provision of information about an agricultural technology to farmers is an essential condition for its subsequent adoption (CIMMYT, 1993). Radio, demonstration trials, village meetings, newspapers, newsletters, magazines, journals, posters, television, video and loud-speakers mounted on cars are important sources from which farmers may receive information about agricultural technologies (Rivera & Qamar, 2003). However, farmers' learning and ability to make good decisions and successfully use agricultural technologies is enhanced if they experiment with a technology prior to adopting it (Abadi Ghadim & Pannell, 1999). Smallholder farmers in the Eastern Cape Province are mostly illiterate and have a low level of awareness of technical matters (Assefa & Van den Berg, 2009; ECDA, 2008). Participatory technology dissemination may therefore be better suited to their circumstances than the use of print media (Obi & Pote, 2012) derived from GM seed companies whose primary clientele are literate commercial farmers. According to Ozowa (1997) the content of such information packages are generally technical, not well understood by farmers and consequently fail to motivate or elicit desired changes in their attitudes.

3.5. Conclusions and recommendations

This study revealed that although smallholder GM maize farmers in the Eastern Cape are relatively well provisioned with extension personnel, most of these personnel lack adequate training to effectively disseminate GM maize technology to smallholder farmers. The awareness of personnel about GM maize technology, its use and stewardship requirements were limited. Inappropriate farm management practices, including the continued application of insecticides on Bt maize varieties were also prevalent in the operational areas of personnel. Additionally, strategies used for disseminating GM maize technology was not participatory and relied mostly on the use of print media from GM seed companies whose primary clientele are literate commercial farmers. Inappropriate GM maize cultivation practices facilitate resistance development by target pests and weeds which ultimately reduces the long term sustainability of GM maize technology. To forestall these undesirable consequences, it is recommended that extension personnel be trained in IPM and aspects of good GM maize technology stewardship and consequences of non-compliance to stewardship programmes. The DRDAR should also facilitate access to the inputs (non-Bt hybrids) necessary for ensuring compliance to GM maize biosafety regulations. Participatory technology dissemination approaches that are better suited to the level of education and understanding of smallholder farmers should be explored and adopted to facilitate attitudinal change of target farmers.

CHAPTER 4: Smallholder farmers' awareness of GM maize technology, management practices and compliance to stewardship requirements in the Eastern Cape Province of South Africa

Abstract

Genetically modified (GM) maize technology adoption is subject to compliance with stewardship requirements that promote the long-term effectiveness of the technology against target pests and weeds. Information transfer and awareness of the value of these requirements can enhance farmer compliance and promote the adoption of improved management practices. A semi-structured questionnaire was used to interview 210 smallholder GM maize farmers in the Eastern Cape to assess farmers' awareness and compliance to GM maize technology stewardship requirements. Field surveys were also conducted to identify the practices adopted for the cultivation of GM maize. Results indicated that although farmers had a high level of contact with extension services their access to information about GM maize and level of awareness of GM maize stewardship requirements were limited. Additionally, although the use of Bt maize resulted in fewer farmers reporting pest incidence on their farms, there was a marked increase in the proportion of farmers that sprayed and relied solely on insecticides for controlling target pests on Bt maize. A high proportion of farmers (71.4%) also relied solely on herbicide sprays (glyphosate) for controlling weeds in their herbicide tolerant maize fields. Field surveys also indicated non-compliance to the requirement for the planting of refuge areas adjacent to Bt maize.

Key words: *Compliance, GM maize, pests, practices smallhoder farmers, weed management*

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4.1. Introduction

Smallholder maize production has traditionally been characterized by low fertiliser use and limited availability of suitable high-yielding varieties (Evenson & Golin, 2003). It has therefore been suggested that input support including provision of improved seeds has the potential to increase the productivity of smallholder agriculture and consequently boost food security (Altman *et al*., 2009; Adesina *et al*., 2011). In recognition of this, the provincial Government of the Eastern Cape has initiated farmer support programmes that seek to increase smallholder maize production and reduce food insecurity and poverty through the provision of inputs and mechanisation services (PGDP, 2004; DRDAR, 2014a; 2014b). A key feature of these support initiatives is the provision of GM maize seed to smallholder farmers (Jacobson, 2013; Fischer & Hadju, 2015; Fischer *et al.*, 2015).

Three types of GM maize hybrids [Bt maize, roundup ready (RR) maize and stacked gene (BR) maize] are currently approved for commercial use in South Africa. Bt maize hybrids contain enhanced traits or genetics that makes them resistant to *C. partellus* and *B. fusca* the main stem boring pests of maize in South Africa whilst RR maize hybrids are modified to be tolerant to glyphosate, a non-selective herbicide. BR maize hybrids combine insect and herbicide tolerance traits in one seed. GM maize seeds have enhanced traits that are patent protected (Monsanto, 2012; Jacobson, 2013; Fischer *et al*., 2015). Additionally, owing to the risk of resistance evolution to these enhanced traits in target insect pests and weeds (Tabashnik, 1994; Green & Owen, 2011), the use of GM maize is subject to compliance with technology stewardship requirements as provided for in the Plant Improvement Act (Act 53 of 1976), the Plant Breeders Rights Act (Act 15 of 1976), the South African Patents Act (Act 57 of 1978) the South African

Trade Marks Act (Act 194 of 1993), the Genetically Modified Organisms (GMO) Act (Act 15 of 1997) and the GMO Amendment Act (Act 26 of 2006) (Monsanto, 2012). Farmers or end users of GM seeds are therefore required to sign stewardship agreements with GM technology licence holders. In these agreements, users accept the conditions and responsibilities regarding the use of GM maize seed and comply with GMO user guidelines including adherence to the requirements regarding the adoption of suitable insect and weed resistance management strategies (Monsanto, 2012; Pannar, 2014). Farmers who plant maize with Bt traits are also required to plant refuge areas adjacent their maize fields so as to delay resistance evolution in Bt maize target pests (Onstad *et al*., 2011; Van den Berg *et al*., 2013). Farmers can comply with this requirement by either planting 20% of their maize area with conventional maize which may be sprayed with any non-Bt (active ingredient) insecticide or by planting a 5% area with conventional maize which is left untreated (Schimmelpfennig *et al*., 2013; Van den Berg *et al*., 2013). To delay selection for weed resistance, it is also recommended that farmers abide by product label rates and directions and proactively implement diversified weed control strategies including the use of multiple herbicides with different mechanisms of action and overlapping weed spectrum with or without tillage operations and/or other cultural practices (Monsanto, 2012).

In contrast to OPVs that are traditionally used by smallholder farmers, GM maize hybrids suffer reduced yields when seeds are recycled. This fact coupled with patent protection of GM maize seeds/traits means that farmers are required to purchase GM maize seed annually. Seed inputs used by smallholder farmers are however most often self-generated, being recycled directly from harvest. This practice has been noted to reduce annual farming expenditure (Fischer & Hadju, 2015). Given that GM maize hybrid seeds are more expensive than OPVs, farmers need to reduce pesticide costs in order to maintain enough profits at the end of every harvest to re-purchase GM seeds and inputs (Kaphengst *et al.*, 2010). However, due to lack of information and awareness of the characteristics and benefits of GM crops, most farmers keep using the same volumes of pesticides and thus do not obtain any benefit from lower pest control costs (Kaphengst *et al*., 2010; Mannion & Morse, 2013). Adoption of new and improved management practices is therefore critical if smallholder farmers are to obtain the full benefits of GM maize and at the same time comply with stewardship requirements (Jacobson & Myhr, 2012) that safeguard GM maize technology.

The majority of smallholders in the Eastern Cape are illiterate and live in rural areas with poor road infrastructure (Assefa & Van den Berg, 2009; DAFF, 2012a), these attributes can generally limit their access to and comprehension of appropriate information necessary for creating awareness and adoption of improved practices (DAFF, 2012a; Jacobson & Myhr, 2012). Additionally, smallholder agriculture is characterized by small land holdings (Aheto *et al*., 2013) and most farmers may be unwilling to set aside parts of their fields for the planting of refuge areas (Morris & Thomson, 2014). All these, coupled with a reluctance to diversify weed management because of the perception that alternative tactics are less cost-effective compared to the use of herbicides can constrain compliance to GM maize stewardship requirements. Information transmission and demonstration of the effectiveness of new technologies can contribute to increased awareness and appropriate use of new technologies and management approaches amongst farmers (Ozowa, 1997; Abadi Ghadim & Parnell, 1999; Cameron, 2007). There is therefore the need to determine the level of farmers' access to information about GM maize and how this contributes to awareness and compliance to GM maize technology stewardship requirements as well as the practices adopted by farmers in its cultivation. Such information can be used to ascertain if alternative strategies are required for smallholder farmers or existing ones need to be better implemented. This will inform policy makers, the seed industry, extensionists and scientists. This study therefore evaluated farmers' perceptions and the practices they adopted for the cultivation of GM maize and its implications to GM maize pest and weed resistance management on smallholder farms.

4.2. Materials and methods

4.2.1. Description of the study area

The study was conducted in five District Municipalities of the Eastern Cape where dry land agriculture is practiced (Figure 4.1). It is estimated that 89.7% of all agricultural operations in the province cultivate maize for grain (Stats SA, 2002). Two different cropping systems can be found in the province, namely, home-gardens and outfields. Home-gardens are small fenced plots of land (0.1-0.5 ha) that are an integral component of rural homesteads. Outfields on the other hand are relatively bigger (1-5 ha) plots of land that are often not fenced and located a distance away from the homestead. Maize is often intercropped with pulses and pumpkins in outfields and with a range of vegetables in home gardens (Jacobson & Myhr, 2012). In view of the dominance of maize in these subsistence agricultural systems, it has been prioritized as the flagship crop of the Cropping Programme, the current government support initiative being implemented in the province. Since 2012, the Eastern Cape Rural Development Agency (ECRDA), a subsidiary of DRDAR, has been implementing the Cropping Programme on behalf of DRDAR (ECRDA, 2013). Participation in the Cropping Programme is conditioned on the ability of farmers to contribute 18% of the total cost of production per hectare. Although the amount contributed by a farmer or area indicates the potential area to be cultivated, the final area cultivated is determined by the availability of funds from Government to cover 82% of the farmers' or areas production costs per hectare. Based on the approved area to be cultivated, each District Municipality draws up a production plan including inputs (seeds, fertiliser and agro-chemicals) and submits this to the ECRDA. The ECRDA appoints contractors/service providers who buy the inputs and also undertake mechanisation services including, ploughing, planting, fertiliser, insecticide and herbicide application (ECRDA, 2013). The objective of this support initiative is to equip farmers with the requisite know-how to successfully undertake the commercial cultivation of maize on their own (after they are weaned off government support).

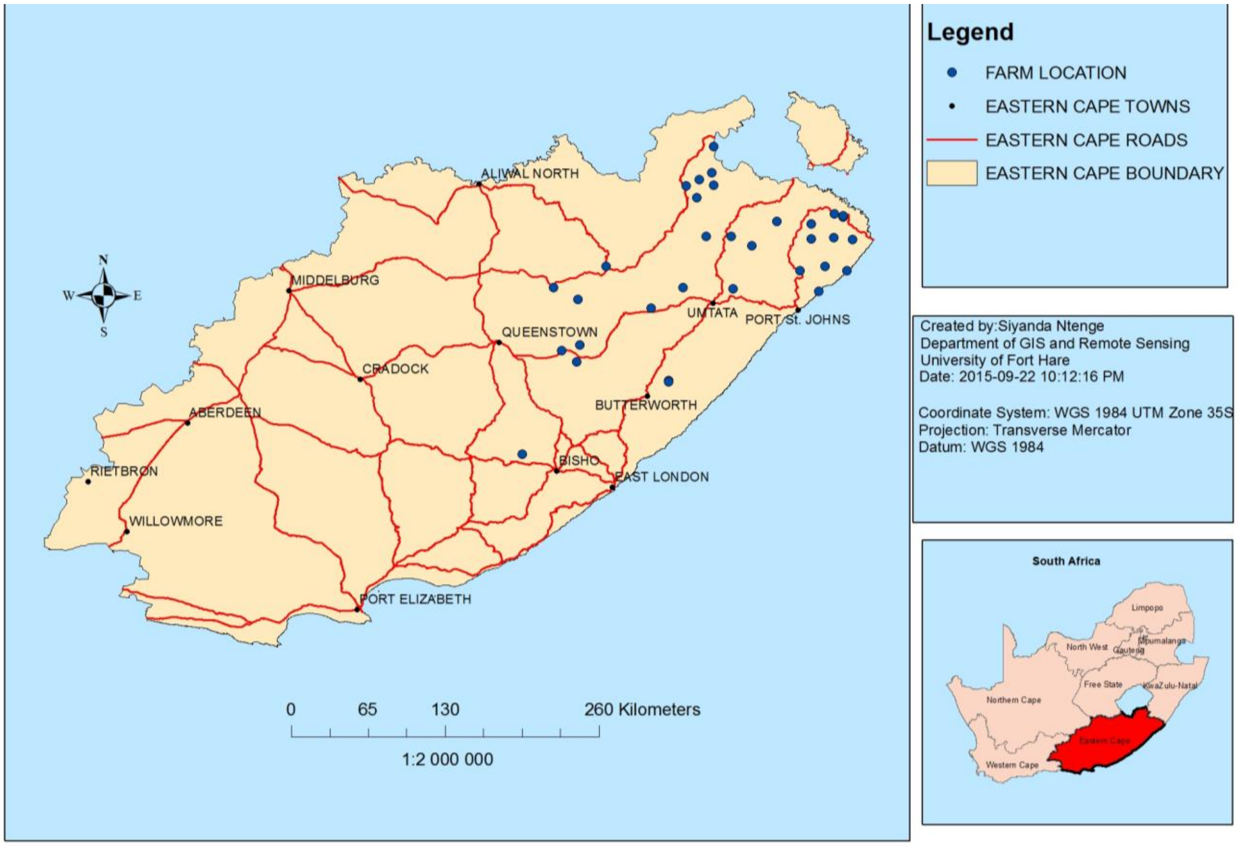

Figure 4.1. Map of the Eastern Cape showing the locations (blue dots) where smallholder GM maize farmers were interviewed

4.2.2. Farmer survey

According to the International Maize and Wheat Improvement Centre (CIMMYT, 1993), when studying different aspects of agricultural technology adoption, a sample size of 60-120 respondents is recommended. A total of 210 farmers were therefore interviewed using a semi-structured questionnaire with closed and open-ended questions (Appendix 10.2). Information about areas where GM maize is cultivated as part of the Cropping Programme was obtained from DRDAR service centres and farmers cultivating GM maize in selected rural areas. Chairpersons of farmers committees in these areas were contacted. Using snowballing sampling technique, other GM maize farmers in these areas were identified. All identified farmers that were willing to participate in the survey in each area were individually interviewed (Figure 4.2). Each interview lasted about 20-45 minutes. Due to constraints of poor road accessibility, surveys were conducted only in rural area within 20 km of the main access roads in each District Municipality (Figure 4.1). The survey questionnaire was divided into four sections namely, personal profile of household head and household size, access to GM maize information and advisory services, awareness and compliance to GM maize technology stewardship requirements and GM maize pest and weed management practices. To obtain first hand information about the GM (Bt/BR) maize cultivation practices, Bt/BR fields in 14 localities (3 fields per locality) were visited and inspected during the 2014/15 maize cropping season. Information regarding the Bt/BR maize variety cultivated in the area, planting dates of Bt and non-Bt maize, the distance between Bt and non-Bt fields, pest and weed management history and the presence or absence of refuge areas were noted and recorded.

Figure 4.2. Interview sessions with smallholder farmers

4.2.3. Data analyses

Answers provided by farmers to questions were coded and analysed using SPSS version 23 (IBM, corporation, USA). Frequency counts and percentages were used to describe the personal and demographic profile of respondents and also summarize responses to questions regarding respondent's awareness of GM maize technology stewardship requirements. Cross-tabulations were used to determine the relationship between categorical variables. For example, the relationship between type of GM maize currently cultivated and farmers' perception of the benefit of cultivating GM maize, the relationship between participation in GM maize training and the number of insecticide sprays made per season. Pearson chi-square test (χ^2) was used to determine if any observed relationships were significant.

4.3. Results

4.3.1. Demographic profile of smallholder GM maize farmers

Most (52.9%) of the farmers interviewed in the survey were male. About 59% of these farmers were between the ages of 51-70 years and had completed seven years of formal education (58.6%) (Table 4.1). Although the majority had been cultivating maize for more than 20 years (71.2%) they had less than four years experience (73.2%) with GM maize which was mostly cultivated on communal land (87.1%). GM maize fields were mostly within the size range of 0.5-1.0 hectares (ha) (49%). Sixty percent of respondent farmers cultivated their fields using labour provided by at least one member of the family (Table 4.1).

The majority of farmers cited encouragement by extension officers (74.8%) as the primary motivation for deciding to grow GM maize. Only 4.8% of respondents cited pest and weed incidence on their conventional maize farms as a motivation for deciding to cultivate GM maize (Figure 4.3). About 53% of interviewed farmers cultivated ‘stacked trait’ (herbicide + insecticide) BR maize, while 41% and 0.5% of farmers cultivated herbicide tolerant and single gene Bt maize. About 5% of respondents could not identify the GM maize type they cultivated.

Table 4.1. Profile of household heads and households

Age of farmer (years)	**Frequency**	**Percentage**
<30	5	2.4
31-40	18	8.6
41-50	33	15.8
51-60	60	28.7
61-70	63	30.1
>70	30	14.4
Total	209	100
Level of education	**Frequency**	**Percentage**
No formal education	21	10
Grade 1-7	123	58.6
Grade 8-12	51	24.3
Tertiary	15	7.1
Total	210	100
Land tenure	**Frequency**	**Percentage**
Permit to occupy	9	4.3
Communal land	183	87.1
Private ownership	18	8.6
Total	210	100
Farmers' experience with GM maize	**Frequency**	**Percentage**
1-3 years	139	73.2
4-6 years	58	26.8
7-10 years	11	6.2
>10 years	2	1.0
Total	209	100
Size of GM maize field	**Frequency**	**Percentage**
0.1-0.5	61	29
0.6-1.0	104	49
1.1-1.5	8	4.4
1.6-2.0	25	11.9
2.1-2.5	3	1.4
>2.5	9	4.3
Total	210	100
Labour obtained from family members	**Frequency**	**Percentage**
0	20	9.5
1	51	24.3
2	43	20.5
3	32	15.2
4	30	14.3
>4	34	16.2
Total	210	100

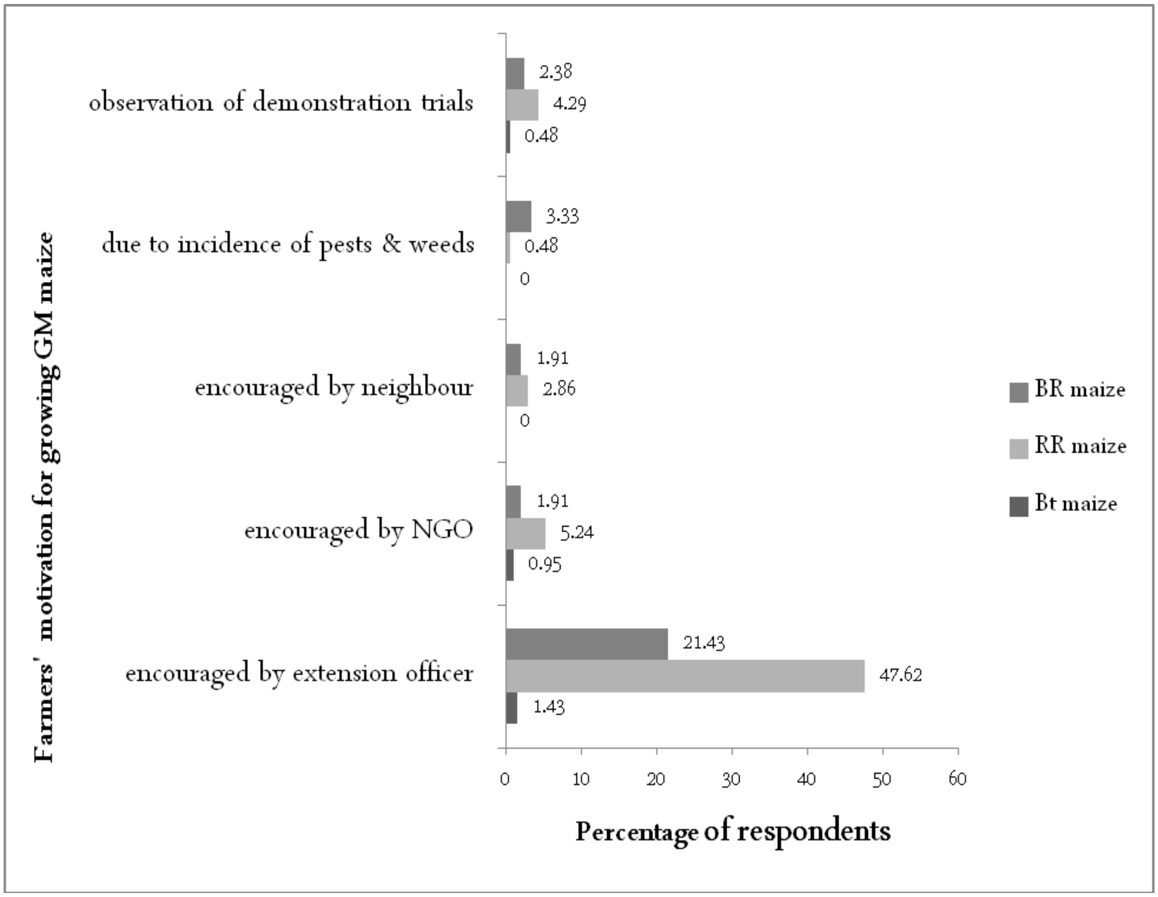

Figure 4.3. Farmers' primary motivations for deciding to cultivate GM maize

4.3.2. Farmers' perceptions of the benefits of GM maize

There was a significant (P = 0.004) relationship between type of GM maize currently cultivated and farmers' perception of the benefit of cultivating GM maize. More farmers cultivating BR maize perceived it as drought tolerant whilst more RR farmers perceived it as early maturing. Majority of farmers who cultivated BR maize (62.8%) and RR maize (61.8%) however cited higher yields as the main benefit obtained from cultivating GM maize (Figure 4.4). Respondents' perception of GM maize as an insect pest and weed management tool was generally low. Only 10.7% of BR maize farmers and (8.1%) of RR maize farmers respectively perceived stem borer resistance or herbicide tolerance (low labour input) as advantages of GM maize cultivation. Furthermore, only 4.9% of BR maize farmers and 34% of RR maize farmers who reported high yield as an advantage of GM maize related this advantage to the stem borer resistance and herbicide tolerance traits of the GM maize varieties they cultivated.

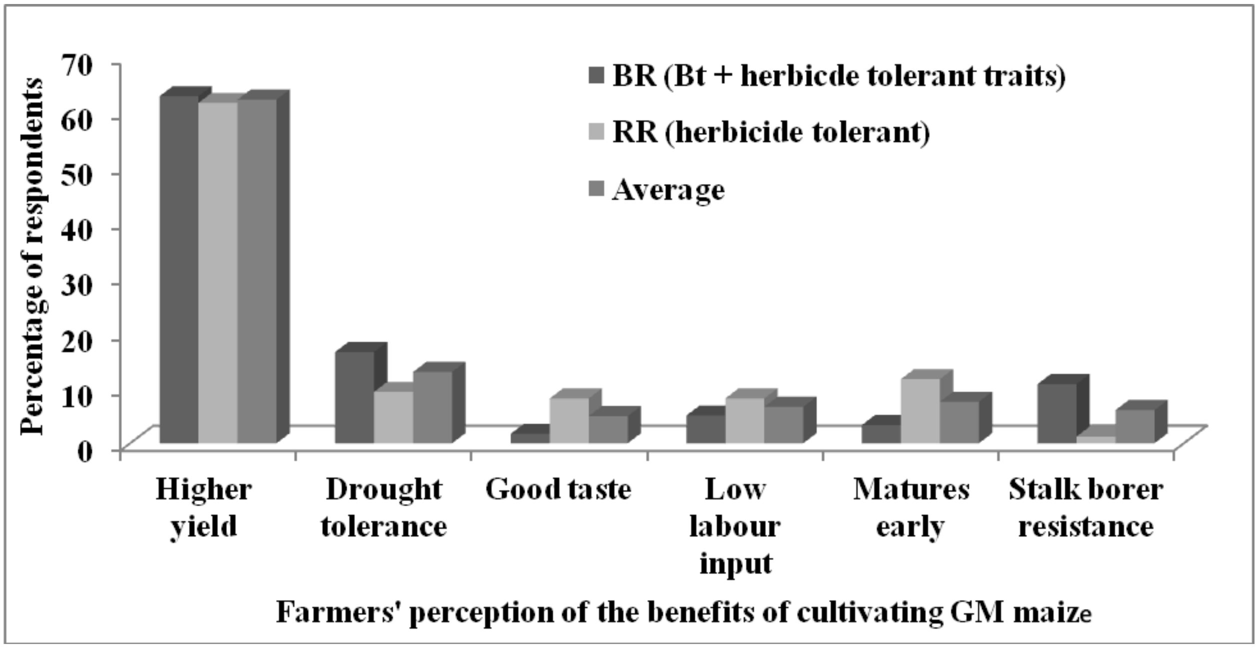

Figure 4.4. Farmers' perceptions of the benefits of GM maize cultivation

4.3.3. Farmers' access to information about GM maize and extension and advisory services

Few farmers (34.9%) reported participating in any training programme on GM maize technology (Table 4.2). Most of the training programmes attended by farmers were organised by DRDAR (85.9%) and discussed single topics like mechanisation of GM maize fields (38.6%) or multiple topics such as mechanisation, pest management and fertiliser application (21.1%). A few respondents could not recollect the subjects discussed (15.8%) at the training workshops they attended. Most of the training programmes were once-off sessions (85.7%) (Table 4.2).

A very high proportion of farmers (77.6%) reported receiving information about GM maize during the last two cropping seasons (Table 4.2). The majority (87.7%) of farmers that reported receiving information obtained it from extension personnel. Farmers' levels of education had no effect ($P > 0.05$) on where they sourced their information from. Most (64%) farmers however indicated that they were not satisfied with the mode of transfer of GM maize information to them. About 51% of interviewed farmers indicated preference for information dissemination through training workshops and seminars whilst 36.3% indicated preference for information transfer using model farms in their villages (Table 4.2).

Table 4.2. Farmers' access to information about GM maize

Does farmer receive information about GM maize	**Frequency**	**Percentage**
Yes	163	77.6
No	47	22.4
Total	210	100
Source of information	**Frequency**	**Percentage**
DRDAR	143	87.7
Colleague farmer	3	1.8
NGO	2	1.2
DRDAR & NGO	1	0.6
GM seed company	4	2.5
NGO & seed company	7	4.3
DRDAR & GM seed company	3	1.8
Total	163	100
Satisfaction with mode of information dissemination	**Frequency**	**Percentage**
Yes	58	36
No	103	64
Total	161	100
Preferred mode of information dissemination	**Frequency**	**Percentage**
Training workshops & seminars	56	50.9
Pictorial guides & manuals	10	9.1
Model farms	40	36.4
Phone call back service	2	1.8
Workshops & model farms	2	1.8
Total	110	100
Has farmer ever participated in any training programme on GM maize?	**Frequency**	**Percentage**
Yes	73	34.9
No	136	65.1
Total	209	100
Organiser of training	**Frequency**	**Percentage**
DRDAR	55	85.7
GrainSA	6	9.4
Unknown NGO	3	4.7
Total	64	100
Subjects covered in training	**Frequency**	**Percentage**
Mechanisation of farm	22	38.6
Pest management	11	19.3
Mechanisation & pest management	1	1.8
Row spacing & pest management	1	1.8
Soil sampling, row spacing & seed rate	1	1.8
Mechanisation, fertiliser application & pest management	12	21.1
Cannot recall	9	15.8
Total	57	100

Comparatively, contact (high contact= more than 5 meetings per season; low= 1-4 meetings per maize growing season) between extension service personnel and farmers increased after farmers were introduced to GM maize. For example, whilst 60.8% of farmers had a high level of contact prior to GM maize use, the percentage increased to 87.1% after introduction to GM maize. Similarly, the percentage of farmers reporting no contact with the extension service decreased from a pre-GM maize use level of 16.3% to 2.4% after introduction to GM maize (Figure 4.5).

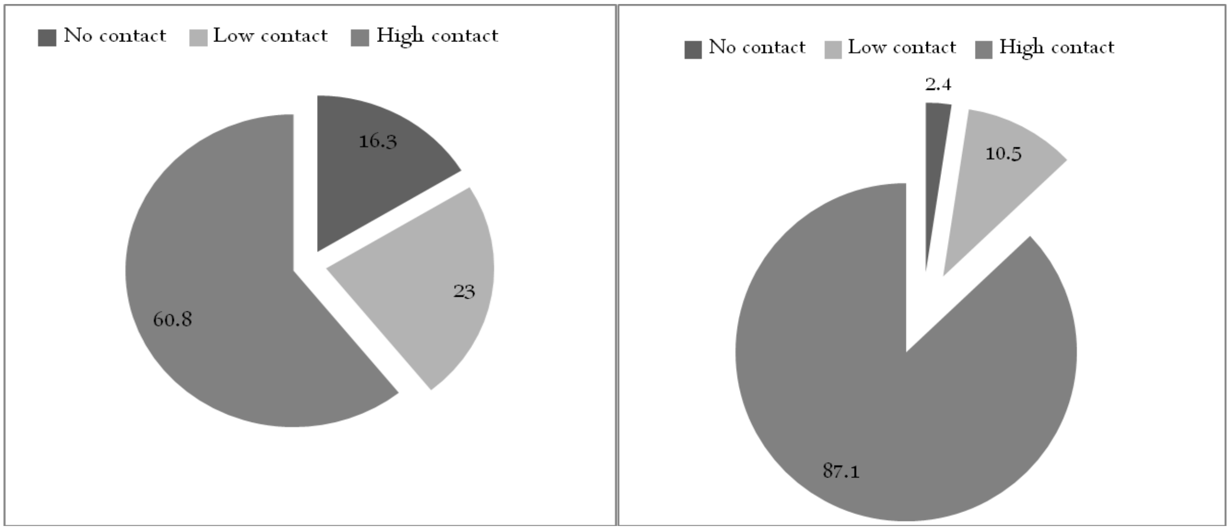

Figure 4.5. Extension contact between farmers and the extension service before and after introduction of GM maize

4.3.4. Farmers' awareness of GM maize technology, its stewardship requirements and compliance

A very high proportion of respondents (96.2%) reported that they had heard of GM maize through extension personnel (79.1%). However only 43.8% of farmers interviewed indicated awareness of rules or regulations to follow when planting GM maize. Farmers' awareness of these rules and regulations were limited to mono cropping of GM maize (83%) and mono cropping and no sharing of GM maize seeds with friends and neighbours (14.8%) (Table 4.3).

When farmers who had cultivated Bt maize during the last two seasons were also asked if they had ever been informed about the requirement for the planting of a refuge area next to their Bt maize fields, all respondents answered in the negative. None of the interviewed farmers reported signing a technology stewardship agreement before being provided with GM maize seeds for cultivation during the 2013/14 season. Approximately, half of interviewed farmers also cultivated OPV maize (47.1%) and conventional maize hybrids (8.8%) obtained from agricultural input shops or recycled from previous harvests in their home gardens. The percentage of farmers who had ever shared GM maize seeds with family members or friends (6.2%) or intercropped (5%) GM maize with other plant species was however very low.

Table 4.3. Farmers' awareness about GM maize technology and stewardship requirements

Has farmer heard of GM maize?	**Frequency**	**Percentage**
Yes	202	96.2
No	8	3.8
Total	210	100
Manner of awareness of GM maize	**Frequency**	**Percentage**
Extension officer	159	79.1
Colleague farmer	10	5.4
Non-Governmental Organisation (NGO)	2	1.0
Program organised by DRDAR & NGO	27	13.4
GM seed company	3	1.5
Total	201	100
Awareness of any rules or regulations to follow when planting GM maize?	**Frequency**	**Percentage**
Yes	92	43.8
No	118	56.2
Total	210	100
What are the recommended rules/regulations	**Frequency**	**Percentage**
Mono-cropping	73	83
Mono-cropping and no seed sharing	13	14.8
Use of personal protective equipment	1	1.1
Mandatory use of herbicides and insecticides	1	1.1
Total	88	100

Results of farm surveys carried out in 14 localities where Bt maize was cultivated during the 2014/15 cropping season indicated that six maize varieties with the stem borer resistant Bt trait were cultivated in the study area. One (Phb 33H52B) contained single gene Bt trait whilst the rest were ‘stacked’ trait (herbicide tolerance + insect resistance) varieties (Figure 4.6). These maize varieties were cultivated in outfields (78.6% of localities visited) with sizes ranging from 0.5 ha to 5 ha and home gardens (21.4% of localities visited) with sizes ranging from 0.1 to 0.5 ha. OPVs and conventional hybrid maize varieties were cultivated less than 400 m adjacent to Bt plants in some of these home gardens. These were generally planted at least one month earlier than the Bt maize hybrids. No structured insect refuges were planted adjacent to any of the Bt maize plantings inspected.

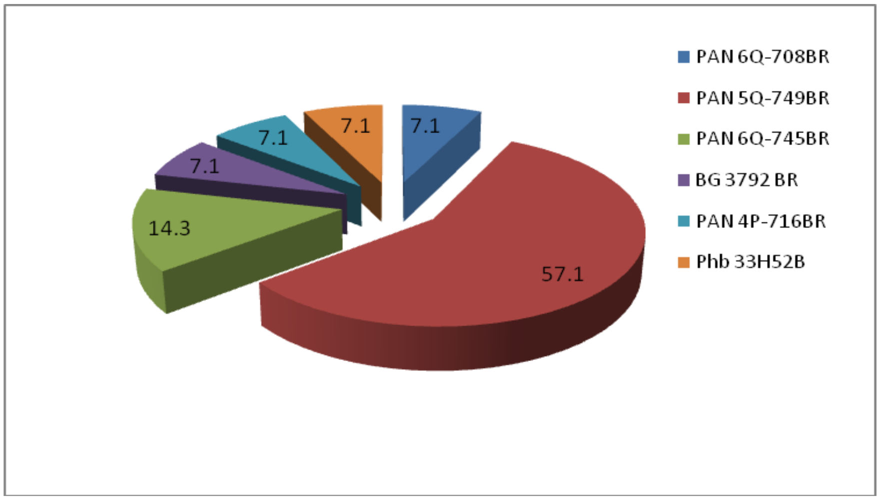

Figure 4.6. Insect resistant GM maize varieties cultivated by farmers during the 2014/15 season

4.3.5. Insect pest and weed management practices of smallholder GM maize farmers

Approximately, 79% of farmers indicated that they had pest problems before they were introduced to GM maize. Important pests cited by farmers included stem borers (48.4%) cutworms (17.9%), stem borers and cutworms (16.8%), stem borers, cutworms and bollworms

(9.5%). Majority of farmers (51.8%) perceived the 'knee height' stage (6-8 WAE) of growth as the most susceptible to stem borer infestation in non-Bt maize (Table 4.4). According to farmers, they managed the pests on their conventional maize farms using a range of strategies, including insecticidal sprays (74%), cultural control (8.3%) and self produced insecticidal dusts (7.3%). A few (10.4%) also reported that they did not apply any pest control measures on their farms (Table 4.4).

Table 4.4 Insect pest constraints faced by smallholder farmers prior to cultivating Bt/BR maize

Pest problem before Bt/BR[1]	**Frequency**	**Percentage**
Yes	96	78.7
No	26	21.3
Total	122	100
Most important pests	**Frequency**	**Percentage**
Stem borer	46	48.4
Cutworms	17	17.9
Bollworm	1	1.1
Stem borers & cutworms	16	16.8
Stem borers, cutworm & bollworm	9	9.5
Unknown pest	6	6.3
Total	95	100
Maize growth stage most susceptible to stem borer infestation	**Frequency**	**Percentage**
Seedling	18	16.4
Vegetative ('Knee height' stage)	57	51.8
Flowering	14	12.7
Vegetative & flowering	1	1
Seedling & flowering	11	10
Seedling & vegetative	9	8.2
Total	110	100
Pest management strategy	**Frequency**	**Percentage**
Insecticide use	71	74
Cultural control	8	8.3
Insecticidal dusts	7	7.3
Unmanaged	10	10.4
Total	96	100

[1] GM maize with both herbicide tolerance and insect resistance traits

About 56.8% of farmers who reported pest incidence on their fields before joining the Cropping Programme cultivated Bt/BR maize during the 2013/14 season. Although fewer (52.5%) farmers reported that there were pests on their Bt/BR maize fields after joining the Cropping Programme (Table 4.5), there was a marked increase in the proportion of farmers (91%) that reported applying of insecticides to control pests on Bt/BR maize. Pests reportedly targeted with these sprays included maize stem borers (60.8%), cutworms (10.8%), cutworms and stem borers (17.6%) (Table 4.5). The primary source (87.4%) of insecticides used by farmers was the extension service (DRDAR). The application frequency ranged from one spray per season (90.1%) to three sprays per season (0.9%). Only 9.2% of Bt/BR maize farmers did not apply insecticides on their crop (Table 4.5). Field survey results indicated that during the 2013/14 farming season, farmers in the study area used two insecticide active ingredients, namely cypermethrin (Kemprin 200EC, Kempton chemicals) and lambda-cyhalothrin [Lamdex 5EC, Makhteshim-Agan SA (Pty) ltd, and Cylam 50EC, Gouws and Scheepers (Pty) ltd] on their maize farms. Participation in GM maize training had no effect ($P > 0.05$) on the number of insecticide sprays made per season. After harvesting, an overwhelming majority of interviewed farmers (85.8%) indicated that they left crop residue on their fields for animal grazing.

Table 4.5. Insect pest management practices adopted by smallholder GM maize farmers

Occurrence of pest on Bt/BR maize last year	**Frequency**	**Percentage**
Yes	64	52.5
No	58	47.5
Insecticide use on Bt/BR last year	**Frequency**	**Percentage**
Yes	101	91
No	10	9
Total	111	100
Pests targeted with insecticide	**Frequency**	**Percentage**
Stem borer	62	60.8
Cutworms	11	10.8
Cutworms & stem borer	18	17.6
Cutworm, stem borer & bollworm	9	8.8
Unknown pest	2	2
Total	**102**	**100**
Number of applications	**Frequency**	**Percentage**
Once per season	100	90.1
Twice per season	10	9.0
Thrice per season	1	0.9
Total	111	100
Source of insecticides	**Frequency**	**Percentage**
DRDAR	89	87.3
Farmers co-op	11	10.8
Local input shop	2	2
Total	102	100
Crop residue management	**Frequency**	**Percentage**
Left on field as compost	16	13.3
Left on the field for grazing	103	85.8
Burnt	1	1
Total	120	100

Many farmers (38.4%) reported the weed presence in their GM maize (BR and RR) fields to be comparatively lower than on their conventional maize fields. Approximately 71.4% of respondents relied solely on herbicides (glyphosate) to control weeds whilst 24.8% of respondents supplemented herbicide sprays with mechanical weed control. A little over 47% of interviewed farmers perceived herbicides to exert a good level of control against weeds whilst 28.4% had the perception that the herbicides they sprayed had a weak level of control (Table 4.6). The weed management strategy adopted by farmers was significantly ($P < 0.001$) related to farm size. Farmers with smaller farm sizes were more likely to use hoe-weeding as a sole control tactic or use it to supplement herbicide application.

Table 4.6. Weed management practices used in GM maize fields of smallholder farmers

Incidence of weeds on farm	**Frequency**	**Percentage**
Yes	151	71.9
No	58	27.6
Don't know	1	0.5
Total	210	100
Assessment of weed incidence	**Frequency**	**Percentage**
Normal	52	34.4
Less weeds	58	38.4
More weeds	41	27.2
Total	151	100
Coping strategy for weeds	**Frequency**	**Percentage**
Hoe-weeding	8	3.8
Herbicide sprays	150	71.4
Hoe-weeding and herbicide sprays	52	24.8
Total	210	100
Rating of control by herbicides	**Frequency**	**Percentage**
Very good	42	20.9
Good	96	47.8
Weak	57	28.4
Don't know	6	3.0
Total	210	100

4.4. Discussion

4.4.1. Demographic profile of smallholder GM maize farmers

The majority of GM maize farmers interviewed in this study were male and aged between 50-70 years. This is similar to the findings of previous studies on GM maize cultivation by smallholders in South Africa (Assefa & Van den Berg, 2009; Mandikiana, 2011; Gouse, 2012a). Access to land has been reported to be a key determinant of the use of external inputs by farmers (Doss & Morris, 2001; FAO, 2011). Thus, although women constitute more than two-thirds of persons involved in smallholder agriculture in South Africa (Hart & Aliber, 2012), their access to land in rural areas of the country is constrained by their gender and social position in the community (Commission for Gender Equality, 2009). This may therefore explain the comparatively higher proportion of male GM maize farmers that participated in this study.

4.4.2. Farmers' perceptions of the benefits of GM maize

Reduced yield losses are most likely the most important benefit of GM maize with respect to improving food security (Schimmelpfennig *et al*., 2013). The majority (62.2%) of farmers interviewed in this study cited high yield as the benefit obtained from cultivating GM maize. In South Africa, maize is attacked by three economically important stem borer species, namely *B. fusca*, *C. partellus* and *S. calamistis* (Krüger *et al*., 2008). Average annual yield losses due to stem borer damage have been estimated at 10% (Bate & Van Rensburg, 1992). Although various methods for managing stem borers exist, Bt maize is the most important in South Africa (Van den Berg *et al*., 2015). Use of Bt maize in the country has resulted in a reduction of the pest status of stem borer pests in maize (Gouse *et al*., 2005; Kruger *et al*., 2012a; Van den Berg *et al*., 2015). Gouse *et al*. (2005) reported increased protection from yield loss due to suppression of target pest species as a benefit obtained by Bt maize adopters in the country. Smallholder farmers for instance reported yields that were 32% higher for Bt maize hybrids compared to conventional isolines (Gouse *et al.*, 2006a). Gómez-Barbero *et al*. (2008) also reported that farmers adopting Bt maize in Spain obtained higher average yields than farmers growing conventional maize. The yield advantage obtained by Bt maize farmers was however related to local pest pressure and damage (Gouse *et al*., 2006a; Gómez-Barbero *et al*., 2008).

All but one of the interviewed farmers cultivated GM maize with the herbicide tolerant trait (RR and BR maize). According to Harper (1983) crops should generally be kept weed-free for 30 - 60 days after planting. It has however been indicated that due to limited supply of labour, smallholder farmers are unable to weed their fields at these optimal times leading to yield losses (Chivinge, 1990; Vissoh *et al*., 2004). Marais (1985) estimated that yield losses of up to 55% could result if weeding is delayed until 40 days after emergence. The use of herbicide tolerant maize which allows farmers to undertake timely and effective weed control as opposed to the practice of hoe-weeding of conventional maize may therefore be a factor for the yield advantage (Green, 2012) reported by interviewed farmers. It is however important to note that smallholder farmers mostly cultivate OPV maize, which is reported to comparatively have a lower yield potential than hybrid maize under optimal growth conditions (Chiduza *et al.*,1994).

Although the use of herbicide tolerant GM varieties may lead to savings on labour for weeding, it requires fertiliser application, and in cases where expected yields increase, more labour may be required for harvesting (Horna *et al*., 2013; Fisher & Kandiwa, 2014). These scenarios may therefore make the labour saving advantage less obvious for farmers who traditionally cultivate low yielding varieties with less use of external inputs (Soleri *et al*., 2006) such as fertiliser.

4.4.3. Farmers' access to information about GM maize and awareness of GM maize technology and its stewardship requirements

The majority of interviewed farmers indicated that they had been introduced to GM maize within the last four years. The rapid increase of farmers being introduced to GM maize during this period may be attributed to the fact that during this period (after 2011), a change in the strategy of implementing the DRDAR Cropping Programme led to more emphasis being placed on supporting more food insecure households to cultivate field crops, this resulted in more hectares being cropped (DRDAR, 2013; 2014b). In view of the fact that the programme is being run by DRDAR, majority of farmers interviewed became aware of GM maize through extension personnel whose encouragement also led to them deciding to cultivate GM maize. As such, very few farmers made a conscious decision to cultivate GM maize because of the reasons for which it was developed (resistance to insect pests and tolerance to herbicides) (Figure 4.3). Under the current structure of the programme, farmers are introduced to particular types of GM maize based on their choice of kernel/seed colour. The extension system in South Africa is noted to pursue top-down non-participatory transfer of technology approaches (De Grassi, 2003; DoA, 2008). With regards to this Cropping Programme, the decision regarding the type of maize varieties to be cultivated by farmers in a given year is taken at the District level. Farming inputs are also purchased in bulk so as to attract discounts from prospective service providers (ECRDA, 2013; DRDAR, 2014c). Thus farmers' role in selecting varieties for cultivation is very limited.

Participatory technology transfer builds on farmers' own capacities by involving them directly in defining, planning and achieving their own development goals in a manner that promotes ownership and empowerment (DoA, 2005). Experimentation prior to adoption of a new technology also equips the adopting farmer with skills for managing the technology and improves decision making regarding the technology (Abadi Ghadim & Pannell, 1999). The limited participation of farmers in decision making about the varieties they cultivate therefore limits their awareness of the traits or characteristics of the varieties they cultivate. Farmers in this study had a low level of awareness of GM maize as a pest or weed management tool probably due to limited dissemination of information about the presence of enhanced traits in the GM maize seeds they cultivate.

Lack of information transfer on what a technology (seed) targets or proper management practices of the technology can increase the risks of resistance evolution by target pests and prevent farmers from obtaining the full benefits of the technology (Assefa & Van den Berg, 2009; Zambrano *et al*., 2013). For smallholder farmers transitioning from the cultivation of OPV maize to GM varieties, information dissemination is particularly critical in enabling them adopt new management practices that are consistent with GM maize technology stewardship requirements. For instance farmers must be made aware of the specific constraints a GM crop technology targets and also the right time to use complementary inputs (Zambrano *et al*., 2013). Limited information dissemination to smallholder GM maize farmers in the Eastern Cape and KwaZulu-Natal Provinces have been reported by other studies (Assefa & Van den Berg, 2009; Jacobson & Myhr, 2012). In this study, the majority of farmers reported that they received information on GM maize and had very good contact with the extension service. This however did not reflect in their level of awareness of GM maize technology stewardship requirements. Most farmers were also not aware of the rules and regulations to follow when planting GM maize. With regards to awareness about the requirement for the planting of a refuge area next to Bt/BR maize, none of the interviewed farmers said they were aware of this requirement. The disparity between the proportion of farmers who reported receiving information about GM maize and the level of awareness of GM maize stewardship requirements can be explained on the basis of the fact that farmers relied almost exclusively on extension personnel for information on GM maize. A recent survey of extension personnel who render extension and advisory services to GM maize farmers in the province revealed that most personnel had limited awareness of GM maize technology and its stewardship requirements (Kotey *et al*., 2016; Chapter 3). Additionally, personnel disseminated GM maize technology information to farmers using non-participatory approaches such as the use of one-way print media produced by GM seed companies (Kotey *et al*., 2016; Chapter 3). As reported by Assefa & Van den Berg (2009) and confirmed by this study, most respondent farmers have less than eight years of formal education and are therefore functionally illiterate (Stats SA, 2011) with limited technological skills (ECDA, 2008). The use of non-participatory approaches to technology dissemination therefore limits the effectiveness and relevance of information transferred to farmers (Ozowa, 1997).

4.4.4. Farmers' compliance to Stewardship requirements

Previous work (Jacobson & Myhr, 2012; Iversen *et al*., 2014) in selected villages in the province reported a high prevalence of the practice of seed sharing with family and colleague farmers. Very few farmers interviewed in this survey however reported sharing seeds with family or colleague farmers. A possible explanation for this may be the fact that during previous initiatives that promoted GM maize to smallholder farmers, local villagers were responsible for choosing and ordering seeds and agrochemical inputs (Jacobson & Myhr, 2012). Under the current initiative, procurement of inputs is done at the district level with little participation by farmers (ECRDA, 2013; DRDAR, 2014c). Additionally, the supply of inputs to a particular locality is strictly matched to the area of land approved for cultivation. Extension personnel also undertake monitoring during planting to ensure that seeds supplied are planted to the approved area. Iversen *et al*. (2014) have reported the presence of GM maize transgenes in non GM maize in smallholder farms and suggested that farmers from whose fields transgenes had been detected, participated in the sharing of seeds. Proliferation of GM maize transgenes can expose target pests to sub-lethal doses of Bt toxin and hence facilitate resistance evolution in target pests (Iversen *et* *al.*, 2014). The low incidence of seed sharing reported in this study is therefore a positive development.

To delay the risk of resistance evolution in GM maize (Tabashnik *et al*., 2013) farmers planting GM maize are required to plant a refuge area next to their Bt/BR maize fields (Monsanto, 2012). The value of refugia for delaying resistance evolution is demonstrated by the fact that non-compliance to this requirement is indicated as a key contributory factor for resistance evolution by *B. fusca* to GM maize on commercial farms in South Africa (Kruger *et al*., 2009; 2011). Refuges are therefore effective in delaying resistance evolution only if farmers comply with the requirement for its planting. Despite this, inspection of Bt/BR fields during the 2014/15 season indicated that no structured refuges were planted adjacent any of the fields inspected. Although non-Bt maize fields adjacent to smallholder Bt/BR fields have been suggested as an option to structured refuges for Bt/BR maize (Fitt *et al*., 2004), their effectiveness can be limited by differences in planting and maturity dates, and differential treatment (insecticide and fertiliser application) (Fitt *et al*., 2004; Van den Berg, *et al*., 2013; Gustafson *et al*., 2006). In the Bt/BR maize cultivating areas visited, non-Bt maize seeds (mainly OPVs), were generally planted at least four weeks prior to the planting of Bt/BR maize fields. Additionally, Bt maize farmers applied inorganic fertiliser in their maize fields whilst non-Bt maize farmers generally did not. According to Muhammad & Underwood (2004) maize may only remain suitable for infestation during a limited time. The differential planting and management of Bt/BR and non-Bt maize therefore increases the likelihood that the emergence of susceptible moths from non-Bt fields and rare resistant moths surviving on Bt/BR crops may not coincide and thus limit the desired mating between individuals of these populations (Fitt *et al*., 2004; Tabashnik, 2008). In commercial farms where *B. fusca* evolved resistance to Bt maize for instance, unstructured refugia were reported to be ineffective in diluting resistant alleles from Bt/BR fields and therefore slowing down resistance evolution (Van den Berg, *et al.*, 2013). The planting of structured refugia by individual Bt maize farmers is therefore essential.

The GMO act (Act 15 of 1997) which regulates the use of GM crops in South Africa, stipulate that GM maize seed companies sign technology agreements with farmers who purchase GM maize seed. Stewardship agreements stipulate the use of GM seed through a user guide which sets strict stewardship requirements, including the planting of refuge areas, subject to which the seed has to be cultivated and planted (Monsanto, 2012). None of the farmers interviewed in the current study however reported signing a technology and stewardship agreement prior to receiving GM seeds for planting. Jacobson & Myhr (2012) also reported that smallholder farmers cultivating GM maize as part of a previous Government initiative in the province did not sign technical agreements. Kruger *et al*. (2012a) reported that although initial compliance to the refuge requirement by commercial maize in the ‘maize triangle’ in the Highveld region of South Africa was low, it increased with increasing number of farmers signing technical agreements for the first time. The signing of technical agreements may therefore contribute to increasing farmers’ awareness and compliance to refuge requirements. With regards to smallholder farmers, it has been reported that due to their vast numbers, GM seed companies previously did not consider it feasible to sign stewardship agreements with each smallholder who purchased GM maize seed (Jacobson & Myhr, 2012). The current strategy of implementation of the DRDAR Cropping Programme may however provide an opportunity for overcoming this challenge. As part of the conditions of participation in the programme, farmers within a given location are required to form a group and elect a committee that assists in the coordination of the programme in the locality. It may therefore be possible to sign technical agreements with these committees and subsequently provide training on refuge area planting to committee members who will then undertake farmer to farmer outreach education within their areas. According to Kiptot *et al*. (2006) farmers who hold leadership positions are effective in spreading information and technologies within their communities. This approach will however require prioritising the training of extension personnel on GM maize technology stewardship requirements as part of the Cropping Programme and collaboration from the GM seed industry and research institutions to develop dissemination approaches that highlights the value of good product stewardship to the long-term sustainability of GM maize.

4.4.5. Stem borer management practices

Most smallholder farmers recognise stem borer damage on their maize (Assefa & Van den Berg, 2009). Although a lower proportion of farmers reported insect pest incidence on their maize fields after being introduced to Bt/BR maize, the proportion of farmers that sprayed insecticides to control pests on their maize crop increased after introduction of farmers to Bt/BR maize. More than 90% of farmers reported spraying insecticides on their Bt/BR fields during the last cropping season. Additionally, the use of diversified pest management strategies decreased following the introduction of farmers to Bt/BR maize. The majority (60.8%) of the insecticide applications on Bt/BR maize was targeted solely at stem borers or pest complexes including stem borers (26.4%). Field inspections during the 2014/15 season indicated that insecticides were generally applied during the vegetative (‘knee high level’) stage of crop development, 6-8 weeks after emergence. Lack of information dissemination about new innovations can result in poor perception of the technology by farmers (Lim & Heong, 1994). Mannion & Morse (2013) have indicated that farmers' perception of Bt crops can play an important role in the reduction (or not) in the volume of pesticides applied on such crops. Most farmers (59%) perceived the vegetative stage of Bt maize to be the most susceptible to pest infestation. Results of field surveys and screening of populations of *B. fusca* from the study area indicate that *B. fusca* is still susceptible to Bt maize (Chapter 6). The insecticide applications reported by farmers may therefore be preventative rather than curative. Kruger *et al*. (2012a) reported that a high proportion of maize farmers in the main maize producing region of the Highveld area of South Africa applied insecticides as preventative sprays on Bt maize irrespective of stem borer infestation levels. With respect to smallholder GM maize farmers, the mode of operation of the Cropping Programme may possibly be a contributory factor for the widespread application of insecticides on Bt maize. Most of the farmers interviewed obtained the insecticides from DRDAR as a component of the inputs subsidized by the programme. Furthermore, the insecticides were applied as a mixture with herbicides by contractors appointed by the implementing agency of the Cropping Programme using boom sprayers. Inputs and mechanisation services are respectively procured and negotiated for based on specified hectares of land to be planted in a given area (ECRDA, 2013). Contractors are also paid after they have finished undertaking the whole range of services, namely discing, ploughing, planting and spraying. The application of insecticides on Bt/BR maize may therefore be based on negotiated terms rather than on an assessment of pest incidence.

Continued use of insecticides on Bt/BR maize may contribute to delaying resistance evolution by reducing the fitness advantage of resistant over susceptible phenotypes through suppression of Bt target pests in Bt/BR fields (Fitt *et al.*, 2004). The practice however imposes significant economic and environmental costs on farmers and insect fauna crucial for the suppression of secondary pest species not targeted by Bt/BR maize (Romeis & Shelton, 2005; Fitt & Wilson, 2005). GM crop seeds are more expensive than traditional OPV seeds, their cultivation is therefore only profitable if pesticide input (and costs) can be reduced sufficiently enough to outweigh the higher seed costs (Kaphengst *et al.*, 2010). Optimal use of Bt/BR maize would therefore include a reduction of insecticide use with maintenance of other traditional IPM practices (Bates *et al.*, 2005).

The basic concept of IPM suggests that insecticide use may be appropriate when other methods cannot adequately suppress pest populations. The decision to apply insecticides should therefore be based on the use of sampling information and economic decision levels (Hellmich *et al.*, 2008). Many aspects of IPM including cultural and biological control play a valuable role in insect resistance management (IRM) (Bates *et al.*, 2005). Crop residue left over after harvest for instance is the most important source of stem borer infestation during a subsequent season (Van den Berg *et al.*, 2015). The destruction of crop residue after harvest can therefore prevent significant numbers of borer larvae from being carried over between seasons (Fitt *et al.*, 2004). An extremely high proportion of Bt/BR maize farmers however retained crop residue on their fields after harvest for animal grazing. Deep ploughing, burning of crop residue, and early cutting and placing of stem on the soil surface have been shown to effectively reduce overwintering populations of stem borers (Kfir *et al.*, 1989). In the study area, although pre-planting operations involved discing and deep ploughing, this was generally done at least a month after famers had planted non-GM maize in their home gardens and fields. This overlap between planting of non-Bt maize and ploughing of Bt/BR fields can therefore provide fresh host plants to which diapausing larvae can migrate to before destruction. Timely crop residue management should therefore be considered a mandatory component (Fitt *et al*., 2004) of Bt maize IRM in smallholder farms. It is however important to access the agronomical benefits derived from maintaining crop residues in the soil, against any other pest management recommendation that is made. Another cultural control strategy that can contribute to IRM is intercropping of maize with leguminous crops. Intercropping of maize with leguminous crops can significantly reduce stem borer densities compared to maize monoculture (Van den Berg *et al*., 1998; Ogol *et al*., 1999; Kfir *et al*., 2002). Although farmers generally intercrop maize with pumpkins and pulses (Joubert, 2000) in their home gardens, the use of broad spectrum herbicides makes this impossible in Bt/BR outfields.

4.4.6. Weed management practices

The majority of farmers perceived the weed incidence on their maize farms to be comparatively less than what use to pertain on their conventional maize farms prior to joining the Cropping Programme. According to Gianessi & Williams (2011) weeds are the most important pest complex in crop production. Weed control is therefore one of the most important crop protection activities undertaken on the farm (Hillocks, 1998). Smallholder farmers have traditionally managed weeds using hoe-weeding (Vissoh, *et al*., 2004). The practice is however slow and labour intensive. Labour availability however depends on the amount of labour that a household can mobilize or hire in local labour markets (FAO, 2011). In the Eastern Cape, labour supply for farming is severely constrained by high incidence of rural-urban migration and a high HIV/AIDS prevalence rate (DEDEAT, 2013; Stats SA, 2015b). Most of the farmers in this study for instance obtained labour for farm activities from only one family member. Herbicide resistant maize will therefore play a critical role in weed management on smallholder farms in the province in the future. It must however be noted that no weed management technology used alone is sustainable since weeds will adapt and become resistant to the tactic (Green, 2012). Thus, although the advanced ages of farmers may be a limitation, farmers should be encouraged to diversify their weed management practices (Powles, 2008) whilst the herbicides to which roundup ready maize is enabled to tolerate are still effective.

4.5. Conclusion

The results reported in this study have indicated the importance of appropriate information transfer to effective use of GM maize technology and complementary inputs. It also highlighted gaps in the implementation of regulations critical to sustaining the long-term efficacy of GM maize technology against target pests and weeds. Although introduction of smallholder farmers to GM maize resulted in increased use of externally sourced inputs, they still perceived GM maize cultivation to be beneficial. This may however not be the case once the Government withdraws the current subsidy that cushions farmers from the full costs of GM technology. It will therefore be essential that going forward, introduction of GM seed and inputs is coupled with farmer training that builds their capacity to utilize diversified pest and weed management strategies that reduces the input of agrochemicals.

CHAPTER 5: Assessment of the effects of Bt maize on selected non-target organisms in smallholder maize fields in the Eastern Cape Province of South Africa

Abstract

Bt maize events currently commercialised in South Africa selectively targets *Busseola fusca* and *Chilo partellus*. Closely related Lepidoptera and other non-target species that feed on Bt maize plant tissue may however be exposed to Bt toxin which may affect their activities and abundance and thereby disrupt species assemblages. Post release monitoring of the effects of Bt toxin on non-target organisms is therefore an essential aspect of Bt maize risk management. Smallholder farmers in the Eastern Cape Province of South Africa have cultivated Bt maize since 2001. There is however no information about the effects of the introduction of Bt maize on non-target organisms associated with the smallholder maize agro-ecosystem in the province. Field experiments were therefore conducted to assess the effects of Bt maize on the incidence and pest status of two lepidopterans, *Helicoverpa armigera* and *Agrotis segetum*, and one gastropod, *Cornu aspersum*. Additionally, the incidence of *C. aspersum* damage, growth and survival on Bt and non-Bt maize plants and the effect of different Bt maize events on survival and weight gain of *A. segetum* were also determined in cage and laboratory experiments. The incidence of *H. armigera* damage was significantly ($P < 0.05$) lower in Bt maize plots compared to non-Bt maize plots. The incidence, growth and survival of *C. aspersum* was not affected by Bt maize. Bt maize event (MON810) had a variable effect on *A. segetum* under laboratory conditions. It is expected that Bt maize of event MON810 that is currently in use by smallholders in Eastern Cape will likely have no adverse effect on *A. segetum*.

Key words: *Bt maize, damage, incidence, non-target organism, survival*

5.1. Introduction

Bt maize has been described as being selective in its mode of action and to generally target pests belonging to a specific order (Clark *et al.*, 2005). Non-target organisms that feed on Bt maize tissues may however be exposed to significant amounts of Bt toxins produced by transgenic maize plants (Marvier *et al.*, 2007). Such exposure to Cry proteins can negatively impact upon non-target organisms (Gatehouse *et al.*, 2011). Potential effects of Bt toxins to non-target organisms are particularly heightened by the fact that transgenic Bt maize plants produce Bt toxins at a high dose in most tissues of the plant during the entire period of growth of the transgenic plant (Gould, 1994; Clark *et al.*, 2005; Lang & Vojtech, 2006; Romeis *et al.*, 2009). Herbivores within Bt maize fields could therefore be exposed to high levels of Bt toxin during their entire larval stage rather than for a few days (Vojtech *et al.*, 2005; Van Wyk *et al.*, 2007) through direct consumption of transgenic plant tissues (Romeis *et al.*, 2009). Soil-dwelling herbivores such as snails may also be adversely affected by residues of Cry proteins present in soil in the form of secretions from the roots of Bt plants (Borisjuk *et al.*, 1999) or decomposition/breakdown of plant stubble remaining on crop fields after harvest (O'Callaghan *et al.*, 2005; Kramarz *et al.*, 2009) or through feeding on young leaves of maize seedlings (Griffiths *et al.*, 2006).

Due to the potential for transgenic Bt maize crops to impact on biodiversity within maize agro-ecosystems, it is essential to undertake post release monitoring of non-target organisms within Bt maize receiving environments. It is however impossible to monitor the whole range of non-target organisms that may be potentially exposed to Bt insecticidal proteins, thus broader categories of non-target organisms are used to monitor for the effects of Bt crops on non-target species

(Prasifka e*t al*., 2008). Species recommended for inclusion in non-target effects monitoring programmes include those commonly occurring in the crop, regardless of geographic location and which are likely to be directly exposed to Bt proteins (Prasifka *et al*., 2008; Yu *et al*, 2014; Carstens *et al*., 2014). In South Africa, Van Wyk *et al.* (2007) have recommended *H. armigera A. loreyi* and *A. segetum* for inclusion in post release monitoring of Bt maize. In the Eastern Cape, field surveys of non-target pest species occurring on smallholder Bt and non Bt maize farms during the 2014/15 maize cropping season indicated *H. armigera* and *A. segetum* as the most important non-target pests on maize cultivated under both dry land and irrigation conditions. The common garden snail, *C. aspersum* has also been observed to occur in significant numbers in maize grown in rotation with vegetables under irrigation in parts of the province (Elove, 2013) where Bt maize has previously been cultivated. Although this species has not been reported as an important pest of maize, its close association with the maize crop in this particular maize farming system could expose it to Bt maize particularly through feeding on Bt maize seedlings.

From a pest management point of view, adverse effects of Bt maize on these non-target species may seem desirable. Kogan & Lattin (1993) however suggest that the conservation of a pest residue is essential for maintaining natural enemy populations. In South Africa, Van Wyk *et al*. (2008) have indicated that adverse effects of Bt maize on non-target lepidoptera could reduce their occurrence and adversely affect populations of natural enemies that rely on these species as food. Depletion of natural enemies of these pests could release them from natural control mechanisms that may change their pest status (Kogan & Lattin, 1993). With regard to *C. aspersum,* adverse effects of Bt maize can reduce their role in nutrient cycling.

Adverse effects of Bt maize on *C. aspersum* has been reported elsewhere (Kramarz *et al*., 2009). Potential risks posed to *H. armigera*,and *A. segetum* by Bt maize in commercial farms in South Africa have also been previously assessed (Van Wyk *et al.*, 2008; Erasmus *et al*., 2010; Erasmus & Van den Berg, 2014). Plant Cry protein concentration/expression in the field may however be affected by many environmental factors. (Clark *et al*., 2005). Potential risks of Bt maize to non-target organisms should therefore be specific to the product (variety) and region, and consider the nature of the trait, crop plant biology, local farming practices, and the local ecological community (Head, 2005). It is in this context that *H. armigera, A. segetum* and *C. aspersum* were selected for ecological risk assessment to Bt maize in smallholder maize agro-ecosystems in the Eastern Cape.

5.2. Materials and methods

5.2.1. Description of the study areas

Studies on the effect of Bt and non Bt maize on *H. armigera* and *A. segetum* in smallholder maize fields were conducted at Zanyokwe, Bhala and Nxanxadi in The Eastern Cape Province of South Africa. The effect of Bt and non Bt maize on *C. aspersum* was undertaken at the Zanyokwe irrigation scheme only.

The Zanyokwe irrigation Scheme (S32.75783˚ E27.05600˚) is located in Keiskammahoek, in the Amathole District Municipality of the Eastern Cape Province. Keiskammahoek is located about 35 km from King Williams Town, the main commercial centre in the area. The area receives a mean annual rainfall of 580 mm which is supplemented with a sprinkler irrigation system for crop cultivation. Bt maize was previously cultivated at the Scheme as part of the Massive Food

Production Programme (MFPP). Farmers at the scheme grow maize in rotation with other cereals and vegetables such as cabbage, butternut, spinach, carrot, onions and potatoes (Monde, 2011; X. Mpengesi, Middledrift, August 2015, personal communication).

The dry land trials were conducted at Nxanxadi (S31.13137˚ E29.63938˚) and Bhala (S30.94832˚ E29.54863˚). These areas fall under the Flagstaff centre of the DRDAR. Flagstaff is located in the Ingquza Hill Local Municipality of the OR Tambo District Municipality and is situated 230 km from Mthatha, the capital of the OR Tambo District Municipality. Flagstaff normally receives about 749 mm of rainfall per year mostly between the months of September and May (SAexplorer, 2014a). Predominant land use in these areas is subsistence agriculture (Qaukeni Local Municipality, 2005) involving the cultivation of maize, the main subsistence food crop. Maize may be intercropped with pulses, pumpkins, sweet potatoes, tomatoes, cabbage, spinach and onions in fenced plots of land adjacent the homestead as a sole crop or in fields located at a distance from the homestead (Department of Water Affairs and Forestry, 2005; Bryndum *et al*., 2007).

5.2.2. Field lay-out and establishment

Field trials to determine the effect of Bt and non Bt maize on the incidence of plant damage by *C. aspersum*, *H. armigera* and *A. segetum* were conducted under irrigation at the Zanyokwe irrigation scheme while at Bhala and Nxanxadi, field trials assessed the effect of Bt and non-Bt maize on *H. armigera* and *A. segetum*. The experiment at Zanyokwe was under irrigation whilst that conducted in Bhala and Nxanxadi were under dry land conditions. Maize varieties used in these studies were PAN-5R-993BR, a ‘stacked’ trait GM (Bt insect resistance + herbicide tolerance) variety that expresses the Cry1Ab protein (Event MON810), PAN-5Q-649R, a herbicide tolerant maize hybrid of similar maturity period as PAN-5R-993BR, PAN 12 a non-GM maize hybrid Okavango, an open pollinated maize variety. At each location, 1.5 ha of farmland was obtained from farmers willing to participate in the study. Each field was tilled using a tractor drawn plough and a heavy disc and demarcated into two 0.75 ha sections using a hand held Garmin GPS device. One section was reserved for a different experiment whilst the other 0.75 ha section was divided into three blocks each measuring 50 m x 40 m. Each block was divided into four 50 x 10 m plots. There were 12 rows of 120 plants per plot. Inter and intra row distances of 0.75 m and 0.33 m was used to achieve a plant population of 40,000 kernels per hectare as is the normal practice in the study areas. Planting was done between late October and December, 2015. All plots in one area were planted on the same day using a tractor drawn planter. Data was collected from the inner 4 rows of each plot, whilst the 4 outer rows on each side of the inner rows were maintained as guard rows. The experimental design was randomised complete block replicated three times per each location. With the exception of insecticide and herbicide application all recommended maize production practices for each specific area were followed. Weeds in each plot were controlled using a hand hoe. Plants in irrigated fields were watered using sprinkler irrigation systems two times a week depending on weather conditions.

5.2.3. Field experiments

5.2.3.1. Experiment 1: Effect of Bt maize on damage of *Cornu aspersum* to maize seedlings cultivated under irrigation: Snail damage to maize plants was assessed from one WAE to four WAE. One hundred maize plants were randomly selected from the four inner rows of each plot (20 m from the edge of each row) and closely inspected for the presence of snail damage symptoms. Plants with snail damage in each plot were counted and expressed as a percentage of the total number of plants inspected. *C. aspersum* damage to maize plants could be distinguished from damage by other pests through the slimy trails left on damaged plants and on the surface of soil around damaged plants.

5.2.3.2. Experiment 2: Effect of Bt maize on damage of *Helicoverpa armigera* under two maize cropping systems: Assessments of the effect of *H. armigera* larval damage to maize were conducted at the seedling, vegetative, flowering and post-flowering stages of plant development in the field. On each sampling date, plant whorls and silk on ears (post-flowering) of 100 randomly selected maize plants (20 m from the end of field) in the four inner rows of each plot were closely examined for damage symptoms, larval frass and the presence of *H. armigera* larvae (Figure 5.1). The number of plants with *H. armigera* damage symptoms were recorded and expressed as a percentage of the total number of plants examined in each plot.

Figure 5.1. ***Helicoverpa armigera*** **damage symptoms on maize whorls and**

5.2.3.3. Experiment 3: Effect of Bt-maize on *Agrotis segetum* damage on maize under two maize cropping systems: Data on the incidence of maize plants damaged by *A. segetum* in the field commenced four DAE and continued till the 12th DAE under irrigation. Due to logistical challenges, data collection in the dry land trials was once-off at two weeks after plant emergence. Data was collected by closely inspecting 100 randomly selected plants in the four inner rows of each plot (20 m from the edge of field) for signs of cutworm damage namely, a neatly chewed round hole in plant stems, severed stems (Figure 5.2) and wilting of central whorl leaf of seedlings (Van den Berg *et al.*, 2015). The number of cutworm damaged plants were recorded and expressed as a percentage of the total number of plants inspected. To collect and identify the species of cutworm present in each plot, a hand trowel was used to turn the soil within a 30 cm radius of cut plants (Figure 5.2).

Figure 5.2. Maize plants damaged by *Agrotis segetum* under field conditions

5.2.4. Laboratory and potted plant experiments

5.2.4.1 Experiment 4: Effect of Bt and non-Bt maize on survival and weight gain of *Agrotis segetum* in the laboratory: Laboratory experiments to determine the effect of non-Bt maize and different Bt maize events on the survival and weight gain of *A. segetum* were conducted at the Entomology laboratory of the Grain Crops Institute (GCI) of the Agricultural Research Council (ARC), Potchefstroom. The Bt maize events used were Bt11, MON810 and MON89034. Bt11 and MON810 express the Cry1Ab protein whilst MON89034 expresses express Cry2Ab2 + Cry1A.105. Labeled 200 ml falcon tubes were filled with dry river sand up to the 10 ml mark. Following which fourth instar larvae of *A. segetum* from a laboratory reared population were then placed on top of the dry river sand held within each falcon tube at one larva per tube. Each larva was pre-starved for 24 hours and its weight determined and recorded using an Ohaus Pioneer balance. Each weighed larva was placed back in the tube with the layer of river sand at the bottom. One freshly germinated maize seedling (one week old seedlings) from either of three different Bt maize events (MON810, MON89034 and Bt11) or a non-Bt maize variety with the top and end of roots cut off was individually placed in a falcon tube containing one *A. segetum* larva at the bottom and stored upright in a test tube holder. The experimental design was completely randomised and there were four treatments. Each treatment was replicated 30 times. Each set of 30 tubes, corresponding to a treatment was held in differently colored plastic tubes labeled with the treatment name. The tubes containing the larvae were placed in a climate controlled room at 27˚C, 50% RH and 14L: 10D photoperiod. Larval survival for each treatment was determined 4, 7, 10, 14 and 17 after infestation whilst larval mass was determined 4, 7 and 10 days after infestation.

5.2.4.2. Experiment 5: Assessment of effect of potted Bt and non-Bt maize on *Cornu aspersum* survival, mass and incidence of damage to maize plants: Potted maize plants of a Bt maize were used to determine the effect of Bt and non-Bt maize on the common garden snail in a cage experiment. Maize varieties used in these studies were PAN-5R-993BR, a ‘stacked’ trait GM (Bt insect resistance + herbicide tolerance) variety that expresses the Cry1Ab protein (Event MON810), PAN-5Q-649R, a herbicide tolerant maize hybrid, PAN 12 a non-GM maize hybrid and Okavango, an open pollinated maize variety. One hundred snail samples were collected from non-GM maize fields in the Zanyokwe irrigation scheme, a known snail infestation hotspot (Elove, 2013) on the 8th of December, 2015. Collected samples were transported to the Entomology laboratory of the Department of Zoology and Entomology, University of Fort Hare, Alice. Collected snails were individually weighed using an Ohaus balance and sorted into three different weight categories (0.4 - 4.5 g; 4.6 – 9.5 g and >9.5 g). Six snails in each of these categories were randomly assigned numbers on their shells using four colour codes (Figure 5.3) each corresponding to a particular maize variety. Snails were individually weighed twice after numbering and the mean weight for each snail was recorded. Numbered snails were used to infest one week old potted maize plants in a 160 cm x 45 cm x 45 cm metal framed shade net (36%) cage divided into four sections. There were three cages and 6 snails per 7 maize plants per variety per cage section. Each section of the cage was secured to prevent cross migration of snails and intrusion by insects and other organisms.

Cages were placed on an elevated concrete platform ringed with grease to prevent infestation of cages by ants and other crawling insects. Snail survival and mass (weekly) on each maize variety was monitored and recorded for 12 weeks. Maize plants were replaced with newly germinated plants every 3-4 weeks depending on severity of damage. Thus, a total of 21 plants were used per variety per cage during the duration of the experiment. Snail damage on plants (Figures 5.3 and 5.4) were evaluated and recorded using a 1-5 damage rating scale (where, 1 = no damage on plant; 2 = 1-25 % of leaves on plant damaged; 3 = 26-50% of leaves on plant damaged; 4 = 51-75% of leaves on plant damaged; 5 = 76-100% of leaves on plant damaged. A 500 ml mist blower was used to spray fine mist on plants in each cage every two hours to prevent aestivation of snails. Average daily temperatures and relative humidity during the experiment ranged from 11˚C (night-time) to 25˚C (daytime) and 50%-60% RH.

Figure 5.3. ***Cornu aspersum*** **feeding on maize whorl tissue**

Figure 5.4. Potted maize seedlings severed by ***Cornu aspersum***

5.2.5. Data analyses

Data on the incidence of pest damaged plants at the pre- and post-flowering plant growth stages for each trial location were analysed separately by way of univariate analysis of variance (ANOVA). Data on larval survival and weight gain of *A. segetum* and the percentage and rating of *C. aspersum* damage on potted maize plants on specific dates were also subjected to univariate ANOVA. The statistical software, SPSS (version 24) (IBM Corporation, USA) was used for all analysis. Treatment (variety) was entered as the fixed factor whilst specific measured variables (for example percent infested plants at flowering) were entered as dependent variable.

5.3. Results

5.3.1. Experiment 1: Effect of Bt maize on damage by *Cornu aspersum* to maize seedlings cultivated under irrigation

There were no significant differences between the number of snails in Bt maize plots and non-Bt maize plots ($P > 0.05$). The general incidence of Bt and non-Bt maize plants with *C. aspersum* damage was low, ranging from 0.1% (PAN-5Q-649R) 1 WAE to 5.2% (PAN 12) 4 WAE (Table 5.1).

Table 5.1. Incidence of Bt and non-Bt maize plants damaged by *Cornu aspersum* under irrigation conditions

Treatments	Mean (±SEM[1]) percentage plants with *C. aspersum* damage symptoms			
	1 WAE	2 WAE	3 WAE	4 WAE
Okavango	0.4 (±0.19)	2.6 (±0.57)	3.3 (±0.68)	4.4 (±0.96)
PAN 12	0.2 (±0.19)	2.9 (±0.57)	3.7 (±0.68)	5.2 (±0.96)
PAN-5Q-649R	0.1 (±0.19)	2.2 (±0.57)	3.4 (±0.68)	5.3 (±0.96)
PAN-5R-993BR	0.3 (±0.19)	2.3 (±0.57)	3.2 (±0.68)	4.2 (±0.96)
P-value	0.648	0.852	0.972	0.803
F-value	0.56	0.26	0.08	0.33

[1] SEM = standard error of mean

5.3.2. Experiment 2: Effect of Bt Maize on damage of *Helicoverpa armigera* under two maize cropping systems

Generally, there was an increase in the percentage of maize plants damaged by *H. armigera* from the seedling to the post flowering stage across all varieties at all locations. The incidence of *H. armigera* damage on Bt maize plants at all plant growth stages under irrigation at Zanyokwe and under dry land at Nxanxadi was significantly (*P* < 0.001) lower than on non-Bt maize plants (Table 5.2). At Bhala, although the percentage of Bt maize (3.0%) plants damaged by *H. armigera* at the vegetative stage was significantly (*P* = 0.020) lower than on plants of PAN-5R-649R (10.1%) and Okavango (8.2%), it was not different (*P* > 0.05) from the percentage of PAN 12 plants (7.2%) damaged by *H. armigera* (Table 5.2).

Table 5.2. Mean percentage of Bt and non-Bt maize plants with *Helicoverpa armigera* damage under irrigation conditions

Treatments	Mean (±SEM[1]) percentage incidence of *Helicoverpa armigera*			
	Seedling	Vegetative	Flowering	Post-flowering
Zanyokwe				
Okavango	4.1 (±0.61)a	9.2 (±1.5)a	17.4 (±1.96)a	37.1 (±2.89)a
PAN 12	4.2 (±0.61)a	10.7 (±1.15)a	18.7 (±1.96)a	33.1 (±2.89)a
PAN-5Q-649R	4.4 (±0.61)a	8.9 (±1.15)a	17.2 (±1.96)a	36.9 (±2.89)a
PAN-5R-993BR	0.2 (±0.61)b	1.0 (±1.15)b	2.2 (±1.96)b	8.4 (±2.89)b
P-value	0.000	0.000	0.000	0.000
F-value	11.1	14.35	15.84	22.67
Bhala				
Okavango	5.4 (±0.95)a	8.8 (±1.24)a	12.6 (±1.47)a	21.1 (±1.54)a
PAN 12	3.8 (±0.95)a	7.2 (±1.24)ab	11.4 (±1.47)a	20.7 (±1.54)a
PAN-5Q-649R	7.1 (±0.95)a	10.1 (±1.24)a	14.0 (±1.47)a	23.2 (±1.54)a
PAN-5R-993BR	2.0 (±0.95)b	3.0 (±1.24)b	4.6 (±1.47)b	10.8 (±1.54)b
P-value	0.004	0.002	0.000	0.000
F-value	5.36	6.24	8.17	12.93
Nxanxadi				
Okavango	3.8 (±0.36)a	8.2 (±0.57)a	13.1 (±0.81)a	20.2 (±1.34)a
PAN 12	3.4 (±0.36)a	7.6 (±0.57)a	12.2 (±0.81)a	19.1 (±1.34)a
PAN-5Q-649R	3.3 (±0.36)a	7.0 (±0.57)a	10.3 (±0.81)a	16.7 (±1.34)a
PAN-5R-993BR	0.7 (±0.36)b	1.9 (±0.57)b	3.2 (±0.81)b	9.2 (±1.34)b
P-value	0.000	0.000	0.000	0.000
F-value	15.77	26.05	30.50	13.62

[1] SEM = standard error of mean

Means within the same column followed by different letter(s) are significantly different at the 0.05 level.

5.3.3. Experiment 3: Effect of Bt maize on *Agrotis segetum* damage on maize under two maize cropping systems

Agrotis segetum damaged plants were observed in plots under irrigation from one to three WAE. There were no significant differences (*P* > 0.05) between the percentage of Bt and non-Bt maize plants damaged under irrigation (Table 5.3) or under dry land conditions (Table 5.4).

Table 5.3. Incidence of Bt and non-Bt maize plants damaged by *Agrotis segetum* under irrigation conditions

Treatments	Mean (±SEM)[1] percentage of maize plants damaged by *Agrotis segetum*		
	1 WAE	2 WAE	3WAE
Okavango	2.9 (±0.91)	3.8 (±1.10)	4.2 (±1.22)
PAN 12	2.8 (±0.91)	4.4 (±1.10)	5.1 (±1.22)
PAN-5Q-649R	3.2 (±0.91)	4.8 (±1.10)	4.9 (±1.22)
PAN-5R-993BR	4.0 (±0.91)	5.0 (±1.10)	5.1 (±1.22)
P-value	0.78	0.87	0.95
F-value	0.37	0.24	0.12

[1] SEM = standard error of mean

Table 5.4. Incidence of Bt and non-Bt maize plants damaged by *Agrotis segetum* under dry land conditions

Treatments	Mean (±SEM[1]) percentage incidence of maize plants damaged by *Agrotis segetum*	
	Nxanxadi	Bhala
Okavango	3.7 (±0.64)	2.6 (±0.48)
PAN 12	4.5 (±0.64)	3.7 (±0.48)
PAN-5Q-649R	4.1 (±0.64)	3.0 (±0.48)
PAN-5R-993BR	4.6 (±0.64)	3.0 (±0.48)
P-value	0.68	0.45
F-value	0.51	0.91

[1] SEM = standard error of mean

5.3.4. Experiment 4: Effect of different Bt maize events on survival and weight gain of *Agrotis segetum* in the laboratory

From the fourth day to the 17th day, survival of fourth instar larvae fed with seedlings of Bt maize reduced rapidly and was lower than survival of larvae fed with non-Bt maize (Figure 5.5). Larval survival on non-Bt maize plants, from the fourth ($F_{(3,116)} = 0.33$; $P = 0.80$) to the seventh ($F_{(3,116)} = 1.13$; $P = 0.341$) day was however not significantly different from the survival of larvae fed with different Bt maize events. Although survival of larvae fed with non-Bt maize was significantly ($F_{(3,116)} = 4.14$; $P = 0.004$) higher than survival of larvae fed with MON89034 on day 10, it was not significantly ($F_{(3,116)} = 4.14$; $P =$) different from the percentage of larvae that survived on Bt11 ($F_{(3,116)} = 4.14$; $P = 1.0$) and MON810 ($F_{(3,116)} = 4.14$; $P = 0.382$) on this day. Larval survival on non-Bt maize was significantly higher than on Bt 11 and MON810 ($F_{(3,116)} = 11.55$; $P = 0.000$) on day 14 and day 17 ($F_{(3,116)} = 3.26$; $P = 0.046$). With regard to MON89034, although survival on this Bt event was significantly ($F_{(3,116)} = 11.55$; $P = 0.000$) lower than on non-Bt maize on day 14, larval survival on this event on day 17 was not significantly ($F_{(3,116)} = 3.26$; $P = 0.405$) different from survival on non-Bt maize. Differences in larval survival between the different Bt maize events did not differ significantly ($P > 0.05$) between any of the days.

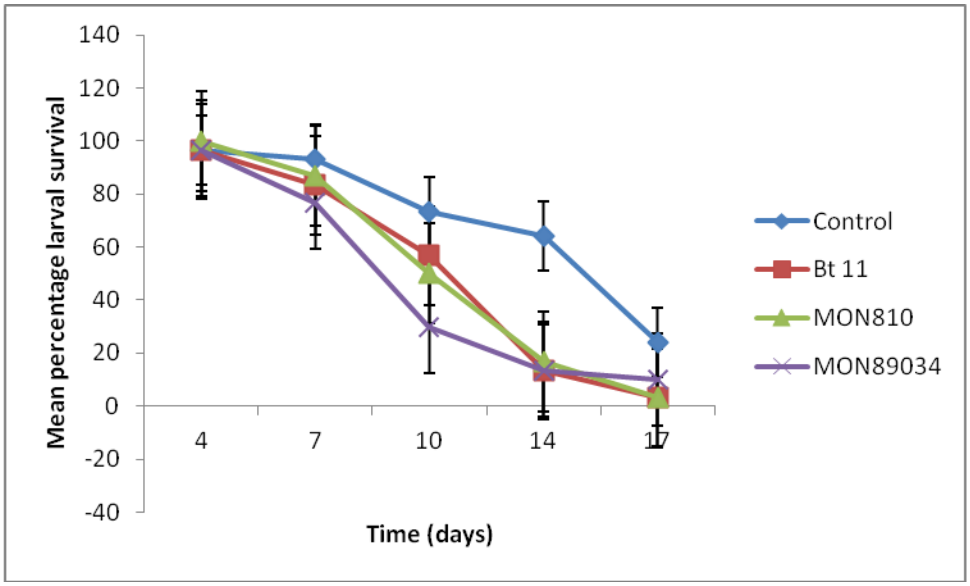

Figure 5.5. Mean survival of fourth instar *Agrotis segetum* larvae fed with non-Bt maize and different Bt maize events over time (bars in diagram are standard error bars)

Compared to larvae fed with non-Bt maize, the weights of larvae fed with different Bt maize events reduced drastically and was generally lower from the fourth to the 10th day (Figure 5.6). Differences between the weights of *A. segetum* larvae fed with non-Bt maize and MON810 plants were not significant on days 4 ($F_{(3,116)}$ =13.09; P =1.0), 7 ($F_{(3,116)}$ =6.34; P =0.999) and 10 ($F_{(3,116)}$ =5.24; P =0.17). The mean weights of larvae maintained on MON89034 on fourth ($F_{(3,116)}$ =13.09; P =0.002), seventh ($F_{(3,116)}$ =6.34; P =0.002) and 10th ($F_{(3,116)}$ =5.24; P =0.001) days were significantly lower than the mean weights of larvae on non-Bt maize plants. Larvae fed with plants of event Bt11 had significantly lower weights than larvae fed with non-Bt maize from the fourth to the seventh day. There were however no significant ($F_{(3,116)}$ =5.24; P =0.092) differences in weights between larvae fed with plants of event Bt11 and larvae fed with non-Bt maize on the 10th day.

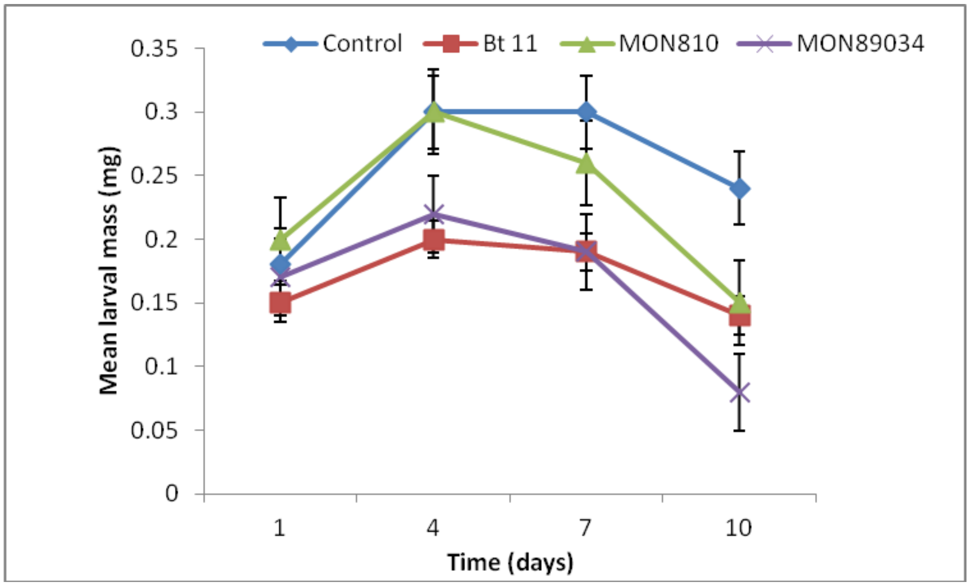

Figure 5.6. Mean mass (mg) of fourth instar *Agrotis segetum* larvae fed with non-Bt maize and different Bt maize events over time (bars in diagram are standard error bars)

5.3.5. Experiment 5: Assessment of effect of potted Bt and non-Bt maize on *Cornu aspersum* survival, mass and incidence of damage to maize plants

Damage to maize plants was first observed seven days after snails were introduced into cages. There were no significant differences between the percentage of Bt plants and non-Bt maize plants damaged by *C. aspersum* during the experiment. The percentage of *C. aspersum* damaged plants ranged from 4.8% (PAN-5Q-649R) to 15.9% (PAN 12) on day 30, 33.3% (PAN-5R-993BR) to 54.0% on day 60 and 65.1% to 88.9% of maize plants on day 90 (Table 5.5). Differences between the mean rating of *C. aspersum* damage to Bt and non-Bt maize plant leaves on days 30 and 60 were not significant ($P > 0.05$). On day 90 however, plants of the Bt maize and OPV maize variety had significantly ($P < 0.001$) higher damage ratings than leaves of PAN 12 and PAN-5R-649R (Table 5.6). Differences between the initial (day 1) and final (day 90) mean weights of individual *C. aspersum* snails maintained on particular maize varieties were not significant ($P > 0.05$) (Table 5.7). No mortality was observed in any treatment during the course of the study.

Table 5.5. Incidence of potted Bt and non-Bt maize plants damaged by *Cornu aspersum* at different time intervals

Treatments	Mean (±SEM[1]) percentage damaged plants		
	Day 30	Day 60	Day 90
Okavango	12.7 (±3.55)	36.5 (±8.25)	76.2 (±8.80)
PAN 12	15.9 (±3.55)	54.0 (±8.25)	88.9 (±8.80)
PAN-5Q-649R	4.8 (±3.55)	36.5 (±8.25)	65.1 (±8.80)
PAN-5R-993BR	14.3 (±3.55)	33.3 (±8.25)	69.8 (±8.80)
P-value	>0.05	>0.05	>0.05
F-value	1.93	1.29	1.37

[1] SEM = standard error of mean

Table 5.6. Mean rating of *Cornu aspersum* damage to leaves of potted Bt and non-Bt maize plants

Treatments	Mean (±SEM[1]) rating of *C. aspersum* damage to maize leaves		
	Day 30	Day 60	Day 90
Okavango	2.6 (±0.34)	3.1 (±0.33)	3.8 (±0.22)a
PAN 12	2.9 (±0.34)	3.1 (±0.33)	3.0 (±0.22)b
PAN-5Q-649R	2.8 (±0.34)	3.1 (±0.33)	2.5 (±0.22)b
PAN-5R-993BR	2.7 (±0.34)	3.0 (±0.33)	4.1 (±0.22)a
P-value	0.96	0.99	<0.001
F-value	0.10	0.05	11.53

[1] SEM = standard error of mean

Means within the same column followed by different letter(s) are significantly different at the 0.05 level.

Table 5.7. Mean weights of *Cornu aspersum* before and after feeding on potted Bt and non-Bt maize plants for 12 weeks

Mean (±SEM[1]) weight (mg)	Maize variety			
	Okavango	PAN 12	PAN5Q-649R	PAN5R-993BR
Day 1	5.2 (±0.78)	4.7 (±0.78)	4.7 (±0.78)	4.9 (±0.78)
Day 90	4.5 (±0.78)	4.7 (±0.78)	4.6 (±0.78)	4.5 (±0.78)
P-value	> 0.05			
F-value	0.10			

[1]SEM = standard error of mean

5.4. Discussion

5.4.1. Effect of Bt and non-Bt maize on mass and survival of *Cornu aspersum*

Results of this study indicated that *C. aspersum* feeds on maize plant whorls during the seedling stage under both field and confined environments (cages). Bt maize had no significant effect on the incidence of *C. aspersum* damage under field conditions or on potted plants. The mass and survival of *C. aspersum* on Bt and non-Bt maize were also not significantly different. These observations confirm the findings of Kramarz *et al*. (2007) and Elove (2013) who reported no adverse effects of Bt maize on *C. aspersum*. De Vaufleury *et al.* (2007) also reported no significant difference in either mortality or mass between snails fed with Bt and non-Bt maize over a 12 week period and concluded that MON810 had no direct or indirect effect on *C. aspersum*. Kramarz *et al.* (2009) however reported *C. aspersum* suffered adverse effects when fed Bt protein in soil and food in chronic exposure tests for periods exceeding 47 weeks. Cry proteins in Bt plants are produced in most plant tissues for the entire season (Bates *et al*., 2005; Romeis *et al*., 2009). Any non-target organism that feeds on a transgenic Bt plant or plant parts may therefore ingest the Bt toxin (Birch *et al*., 2004). *Cornu aspersum,* like other snails feed on decomposing plant materials (Mason, 1970, Kramarz *et al.,* 2009). Thus in addition to possible exposure to Bt-protein from feeding on plant whorls, *C. aspersum* may also likely be exposed to Bt-protein in decomposing plant material within the surrounding soil matrix (Clark *et al*., 2005). According to Saxena & Stotzky (2000), the deposition of Bt-plant residues on soil at harvest can cause an elevation in the concentration of Bt-toxin in soil. Since *C. aspersum* is a long-lived species (Kramarz *et al*., 2009), there is the potential for long term exposure beyond the period of time reported in this study.

The risks associated with the cultivation of transgenic crops are related to the environment in which the crop is grown, and the scale and character of the farming systems in which it is included (Muhammad & Underwood, 2004). *Cornu aspersum* occurs throughout South Africa and is among the most pestiferous introduced snail species in the country (Herbert, 2010). It has however only been reported on maize grown under irrigation at the Zanyokwe irrigation scheme in the Eastern Cape Province of South Africa (Elove, 2013). Maize is cultivated under this system in rotation with vegetables, legumes and other cereal crops, as such maize is only available for a limited time period. This, coupled with the fact that *C. aspersum* has a wide host range which include cereals, potatoes, lettuce, carrots, cabbage, maize and clover (Herbert, 2010; Sallam & El-Wakeil, 2012), makes it unlikely that Bt maize will have any adverse effect of *C. aspersum* in the maize agro-ecosystem in the study area.

5.4.2. Effect of Bt and non-Bt maize on the incidence of plants damaged by *Helicoverpa armigera*

The incidence of *H. armigera* damage during all growth stages was significantly lower in Bt maize plots compared to non-Bt maize plots. These results are similar to that reported by Van Wyk *et al.* (2008). *Helicoverpa armigera* is reported to prefer maize ears to maize leaves

(Erasmus & Van den Berg, 2014). The pest is also reported to be closely associated with maize when cotton is not readily available (Birch *et al*., 2004). Cotton is not cultivated in the Eastern Cape, this could therefore possibly explain the prolonged occurrence and feeding of *H. armigera* on maize leaves from the seedling stage up to the soft dough stage. The prolonged interaction of *H. armigera* and susceptibility to Cry1Ab Bt maize (Fitt *et al.,* 2004) currently cultivated by smallholder farmers in the Eastern Cape may therefore alter the seasonal dynamics and pest status of *H. armigera* (Fitt *et al.*, 2004) and subject this pest to high selective pressure for resistance evolution to Bt maize (Andow & Hillbeck 2004; Van Wyk *et al*., 2008). *Helicoverpa armigera* has a demonstrated ability for resistance development to virtually all insecticidal molecules used against it (Kranthi *et al.*, 2005).

Although the incidence of Bt maize plants damaged by *H. armigera* was significantly lower than the incidence of non-Bt maize plants damaged at the post flowering stages, there was a progressive increase in the incidence of plants damaged by *H. armigera* with plant maturity. *H. armigera* is reported to be susceptible to Cry1Ab protein expressed by Bt maize, albeit to a lower extent than target pests (Fitt *et al*., 2004). The preference of *H. armigera* to feed on maize ears coupled with the fact that the insecticidal activity of Bt toxin in plants declines significantly with plant maturity (Fitt & Wilson 2000) may explain the high incidence of *H. armigera* damaged plants at the post flowering stage. According to Van Wyk *et al*. (2008) *H. armigera* larvae are able to complete larval development under field conditions at the end of crop growth. Survival of *H. armigera* larvae at this plant growth stage has been noted to pose serious risks to the sustainability of Bt technology since it contributes to resistance development in this pest (Erasmus & Van den Berg, 2014). Exposure of *H. armigera* to Cry1Ab in maize ears may subject this pest to selection pressure in a cotton system where Bt cotton that expresses Cry1Ac is included (Fitt *et al.,* 2004). Cry1Ab toxin expressed by Bt maize Event MON810 and the Cry1Ac toxin expressed by Bt cotton currently commercialised for the control of *H. armigera* on cotton in South Africa are similar in their mode of action and are widely reported to confer cross-resistance (Fitt *et al.,* 2004). In Australia, resistant strains of *H. armigera* were reported to complete larval development on cotton in the field when the Cry1Ac concentration reduced at plant maturity (Akhurst *et al.*, 2003; Tabashnik *et al.*, 2003). Although cotton is not cultivated in the Eastern Cape, Bt cotton that expresses the Cry1Ac protein is widely cultivated in the neighboring KwaZulu-Natal Province (Gouse 2012b). It is anticipated that possible resistance development by *H. armigera* to Bt maize will cause it to occupy the vacant niche created by the control of target pests by Bt maize (Erasmus, 2010; Erasmus & Van den Berg, 2014). This may result in increased infestation levels on Bt maize ears which may necessitate the adoption of chemical control measures (Erasmus, 2010). The application of insecticides to control *H. armigera* on Bt maize ears could expose consumers of fresh maize to pesticide residues

5.4.3. Effect of Bt and non-Bt maize on *Agrotis segetum*

Results obtained after exposing *A. segetum* larvae to different Bt maize events under laboratory conditions were not consistent. The weights of larvae fed with plants of MON89034 were significantly lower than larvae fed with non-Bt maize. Conversely, the weights of larvae fed with MON810 were not significantly different from the weights of larvae fed with non-Bt maize. With regard to larval survival, significant effects were only observed for brief periods of not more than three days. Erasmus *et al.* (2010) also observed some adverse effects related to Bt maize events under laboratory conditions, but concluded that Bt maize of events MON810 and

Bt 11 were unlikely to have any effects on *A. segetum* under field conditions. According to Lang & Otto (2010) the effects of Bt on non-target organisms under natural conditions is smaller than under laboratory conditions. Smallholder farmers in the Eastern Cape Province of South Africa cultivate Bt maize with event MON810. Significant differences between larval survival on this event and non-Bt maize was only observed for a brief period of not more than three days. Larval mass across all laboratory treatments declined from the seventh day, possibly indicating the fact that maize alone is not a suitable food source for *A. segetum*. *Agrotis segetum* larvae are reported to prefer feeding on weeds rather than on maize (Van Rensburg, 1994). This fact, coupled with the fact that the pest occurs on maize only during the seedling stage may reduce its exposure to maize (Van Rensburg, 1994) containing Bt toxin of event MON810 under field conditions in the Eastern Cape. This may therefore explain the fact that Bt maize had no significant effect on the incidence of plants damaged by *A. segetum* under field conditions. Pons *et al.* (2005) also observed that Bt maize did not have any effect on the incidence of *A. segetum* in Spain.

5.5. Conclusions

Results of this study showed that Bt maize affects the incidence of maize plants damaged by *H. armigera* under field conditions. With regards to *C. aspersum* and *A. segetum*, results indicate that the Bt maize event (MON810) currently cultivated by smallholder farmers in the province is unlikely to have any effects on these non-target species.

CHAPTER 6: Monitoring resistance to Bt maize in field populations of *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) from smallholder farms in the Eastern Cape Province of South Africa

Abstract

Post-release monitoring of transgenic Bt maize fields for resistant pest populations is an important activity that will contribute to early identification and mitigation of resistance evolution by target pests. An effective Bt maize pest resistance monitoring programme relies on well-established baseline susceptibility data. The target pest of Bt maize in South Africa, *Busseola fusca*, has evolved resistance to Bt maize expressing Cry1Ab proteins, with numerous reports of resistance from the Highveld region of the country. Although Bt maize has been cultivated in the Eastern Cape Province since 2001, no data exist on the resistance status of field populations of *B. fusca* to Bt maize in this region. In view of this, *B. fusca* larvae were collected from fields in two Bt maize cultivating areas and a non-Bt maize cultivating area of the Eastern Cape for laboratory assays to determine the level of susceptibility of *B. fusca* to Bt maize. Rearing colonies of each population were established and neonate larvae from each population were used to infest non-Bt maize plants, and Bt maize plants of events MON810 and MON89034. All larvae maintained on MON89034 died within seven days of infestation. Survival of all *B. fusca* populations maintained on MON810 declined rapidly during the first seven days and was significantly (P <0.001) lower than larval survival on non-Bt maize. Similarly, mass of surviving larvae of all populations on MON810 from the first two weeks to the 21st day was significantly (P <0.001) lower than the mass of larvae on non-Bt maize. These results indicate that field collected populations screened in this study are still susceptible to Bt maize.

Key words: *Busseola fusca*, insect resistance management, refuge planting, resistance evolution, survival

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6.1. Introduction

The African maize stem borer *Busseola fusca* and the spotted stem borer, *Chilo partellus* are the most important stem borer pests of maize in South Africa (Kfir, 1998). These two pest species may occur in single or mixed populations (Van den Berg *et al.*, 1991a). Although *C. partellus* is a highly competitive colonizer, *B. fusca* is considered to be the most destructive lepidopteran pest of maize (Kfir *et al.*, 2002). *Busseola fusca* infestation may lead to a yield reduction of up to 10% or in severe infestations, total yield loss (Van Rensburg & Bate, 1987). The availability of maize genetically modified (GM) to express *Bacillus thuringiensis* (Bt) Cry proteins constitute an important *B. fusca* management tool (Van den Berg *et al*., 2015) since it provides convenient and cost effective options for mitigating yield losses (Hellmich *et al.*, 2008; Brookes & Barfoot, 2014) caused by *B. fusca* in South Africa.

Following the introduction of Bt maize to South Africa during 1998, the pest status of *B. fusca* in the country has diminished (Gouse *et al.*, 2005; Kruger *et al.*, 2012a). Yield advantage of Bt maize hybrids over conventional iso-hybrids of up to 32% has been reported from smallholder Bt maize farms in the country (Gouse *et al*., 2006a). Successful deployment of Bt maize against *B. fusca* has also resulted in a high rate of adoption of this technology in the country (Van den Berg *et al*., 2013). Currently an increasing number of smallholder farmers in many parts of the country, including the Eastern Cape, have been introduced to Bt maize through a number of Government development initiatives (Fischer *et al*., 2015; Kotey *et al.*, 2016). The widespread planting of Bt maize may, however, place intense selective pressure on Bt maize target pest populations to evolve resistance (Tabashnik, 1994; Gassman *et al*., 2014). Insect populations have a demonstrated ability to evolve resistance to insecticides and Cry proteins through selection on novel mutations (Orr & Betancourt, 2001; Tabashnik *et al.,* 2013) and become resistant to previously used highly effective and widely applied pesticides, including Bt sprays (Tabashnik, 1994). This is particularly so in environments where the adoption of Bt maize is not coupled with the implementation of effective insect resistance management (IRM) strategies, as exemplified by resistance evolution of *B. fusca* to Bt maize on commercial farms in South Africa (Van Rensburg, 2007; Kruger *et al*., 2011). The most commonly used IRM strategy involves planting of refuges of non-Bt maize adjacent to the main Bt maize crop (Tabashnik *et al*., 2003). The main assumption of the refuge strategy is that the inheritance of resistance is recessive, that the plants express a high dose of the toxin and that refuges of non-Bt plants are present (Tabashnik *et al*., 2013). Refuges of non-Bt crops are expected to sustain populations of Bt-susceptible target pests which may mate with resistant individuals that survive on the Bt crop (Gould, 1998; Siegfried & Hellmich, 2012). Campagne *et al.* (2013) have recently reported the dominance of at least one type of resistance of *B. fusca* to Cry1Ab protein. The refuge strategy however remains the principal strategy for delaying resistance evolution. In South Africa, resistance development by *B. fusca* has been largely ascribed to non-compliance to the requirement for the planting of refuges (Kruger *et al.,* 2009).

Smallholder maize farming systems in South Africa are characterized by numerous small contiguous fields (Aheto *et al.,* 2013; Van den Berg & Campagne, 2014) and limited access to extension support (Assefa & Van den Berg, 2009; Jacobson & Myhr, 2012; Kotey *et al.,* 2016). All these factors may compromise the management of resistance evolution of lepidopteran stem borers that infest maize (Van den Berg & Campagne, 2014) and possibly facilitate the evolution of resistance of *B. fusca* to Bt maize in smallholder maize systems. In view of this the adoption of post release resistance monitoring programs is vital for sustaining the efficacy of Bt maize. Monitoring and reporting of resistance development is a key tenet of resistance management (Van den Berg *et al*., 2013). An effective monitoring program however requires well-established baseline susceptibility data (Glaser & Matten, 2003). Currently, resistant populations of *B. fusca* are being reported at new locations in the Highveld region of South Africa on a regular basis (Van den Berg *et al.*, 2013). Despite reports of the prevalence of many of the factors implicated in resistance evolution in the Eastern Cape (Assefa & Van den Berg, 2009; Jacobson & Myhr, 2012; Kotey *et al.*, 2016), there has been no study to determine the level of resistance of *B. fusca* larvae from the province to Bt maize. The objective of this study was therefore to evaluate the status of resistance of different populations of *B. fusca* from different maize cultivating areas of the Eastern Cape to Bt maize.

6.2. Materials and methods

6.2.1. Field surveys of Bt and non-Bt maize fields

Localities were identified at which Bt maize had been cultivated continuously for at least two years. In line with this, Bt maize fields in 14 localities (3 fields per locality) (Table 6.1) were visited and inspected for the presence of stem borers during the 2014/15 maize cropping season, prior to collecting stem borer larvae for evaluation of their resistance status in 2016. The number of fields varied from locality to locality, ranging from 10 to as many as 80. To ensure that data collected was representative, stratified sampling procedure was adopted. Fields in each locality were divided into three groups, namely proximal fields, (fields closest to homesteads) median fields (fields in the middle) and distant fields (fields furthest from homesteads). One field was then randomly selected from fields in each of the areas specified. Information regarding the history of Bt maize cultivation and Bt maize variety cultivated in the area were obtained and recorded (Table 6.1).

6.2.2. Collection of *Busseola fusca* larvae

Glaser & Matten (2003) recommended that sampling locations for Bt resistance monitoring should focus on areas where Bt crops are intensively planted since these are the areas where selection pressure is expected to be high**.** Thus, on the basis of the area under Bt maize cultivation, two Bt maize cultivating areas designated as ECBt001 (S30.87372˚ E29.62144˚) and ECBt002 (S31.08722˚ E29.53661˚) were selected for *B. fusca* larvae collection surveys (Table 6.1). A third locality, designated as ECRef001 (S31.08271˚ E29.32504˚) which is a rural area in the Alfred Nzo District Municipality where only open pollinated varieties (OPV) of maize are cultivated (Table 6.1), was also selected for the collection of a reference population of *B. fusca* larvae. Since no stem borer larvae could be found in fields of Bt maize, maize plants from inside 38 home gardens (19 from ECBt001 and 19 from ECBt002) adjacent to farms where Bt maize has been cultivated continuously for at least two cropping seasons were sampled in January 2016. In the non-Bt maize cultivating area, maize plants (OPVs) were sampled from inside 10 home gardens.

Each home garden visited in each area was demarcated into three zones and between 20-100 maize plants (depending on the size of the garden) from within each demarcated zone were randomly selected and closely inspected for signs of borer damage, including scarified or dry leaves and shoots (dead hearts), frass, or holes bored into stems (Moolman *et al*., 2014). The number of infested plants in each home garden was recorded, after which five of the most severely damaged plants in each garden were selected and dissected to collect *B. fusca* larvae (Figure 6.1). Collected larvae were identified *in-situ* and individually placed in perforated, labeled vials containing pieces of tissue from the plant part from which they were collected. The GPS coordinates, number of infested plants and the number of larvae collected from each area were recorded. A total of 145 (ECRef001), 173 (ECBt001) and 210 (ECBt002) third to fourth instar larvae were collected at the different sites.

Figure 6.1. Dissected non-Bt maize stem with *Busseola fusca* larvae inside

6.2.3. Establishment of *Busseola fusca* populations for laboratory screening

Collected larvae were pooled together according to the area from which larvae were collected, after which they were transported to the Entomology laboratory of the Grain Crops Institute (GCI) of the Agricultural Research Council (ARC), Potchefstroom and used to initiate three *B. fusca* populations. For each population, groups of five larvae from each area were placed in a 100 ml plastic cup containing a 4.0 cm piece of non-Bt maize stem and reared until pupation. Larvae were provided with a fresh maize stem piece every five days until pupation. Pupae were removed from containers, sexed and placed in oviposition cages with 30 cm long pieces of maize stems as oviposition substrate and with cut maize whorl tissue as stimulus for oviposition. Cages were maintained at room temperature (23−24 ˚C) and 12:12 hour light:dark photoperiod and 50% relative humidity (RH). Maize stems were checked daily for the presence of eggs. Egg batches were removed from the stem with the aid of a scalpel blade and placed in sterile 100 ml plastic containers with stainless steel mesh lined lids. Eggs from each population were incubated at 60% RH, 25-27 °C and a 14:10 hour light:dark photoperiod until eggs hatched.

6.2.4. The effect of Bt and non-Bt maize on *Busseola fusca* larval survival and mass

The experiment to determine *B. fusca* larval survival and mass on Bt and non-Bt maize consisted of nine treatments (three *B. fusca* populations on each of three maize hybrids) each replicated four times. The experiment was laid out in a completely randomised design. Maize plants of two Bt maize events (MON810 and MON89034) and a non-Bt maize variety (iso-hybrid of the two Bt hybrids) were used. Maize plants of Event MON810 express Cry1Ab protein while those of Event MON89034 express Cry2Ab2 + Cry1A.105. These varieties were: DKC8010 (non-Bt iso-hybrid), DKC8012B (MON810) and DKC8012BGEN (MON89034). The presence of Bt proteins inside Bt maize plants and absence in non-Bt plants was confirmed using Bt test strips (Quickstix Bt test kit, EnviroLogix, Portland USA) (Figure 6.2).

The bottom of the 100 ml plastic cups was lined with five layers of square (4 cm x 4 cm) filter paper to absorb moisture. Four week old maize plants of each of the three maize types were harvested from the field by cutting at the base of the stem. All leaf sheaths were removed from the stems of cut plants by cutting at the base of the leaf with a pair of scissors. Two stem pieces

(4 cm long) were cut from each plant and placed on the paper lining of each cup. Representative samples of neonate larvae (Figure 6.2) from each population were weighed using an Ohaus Pioneer scale. Five neonate larvae were then randomly picked by means of a camel's hair brush and inoculated onto maize whorls in each cup. Each cup was tightly sealed with stainless steel mesh lined lids and placed in a climate controlled room at 27 ˚C, 50% RH and 14L: 10D photoperiod. The number and mass (mg) of the surviving larvae per cup were determined 7, 10, 14, 17 and 21 days after inoculation by carefully inspecting the whorl tissue in each cup. Whorls were replaced with fresh material from the same maize type after each assessment or as and when necessary. Dead larvae were removed during each assessment. The experiment was terminated 21 days after inoculation. Larval survival per cup was recorded and expressed as a percentage of the total number of larvae used per cup. The mean percentage larval survival was then calculated per treatment.

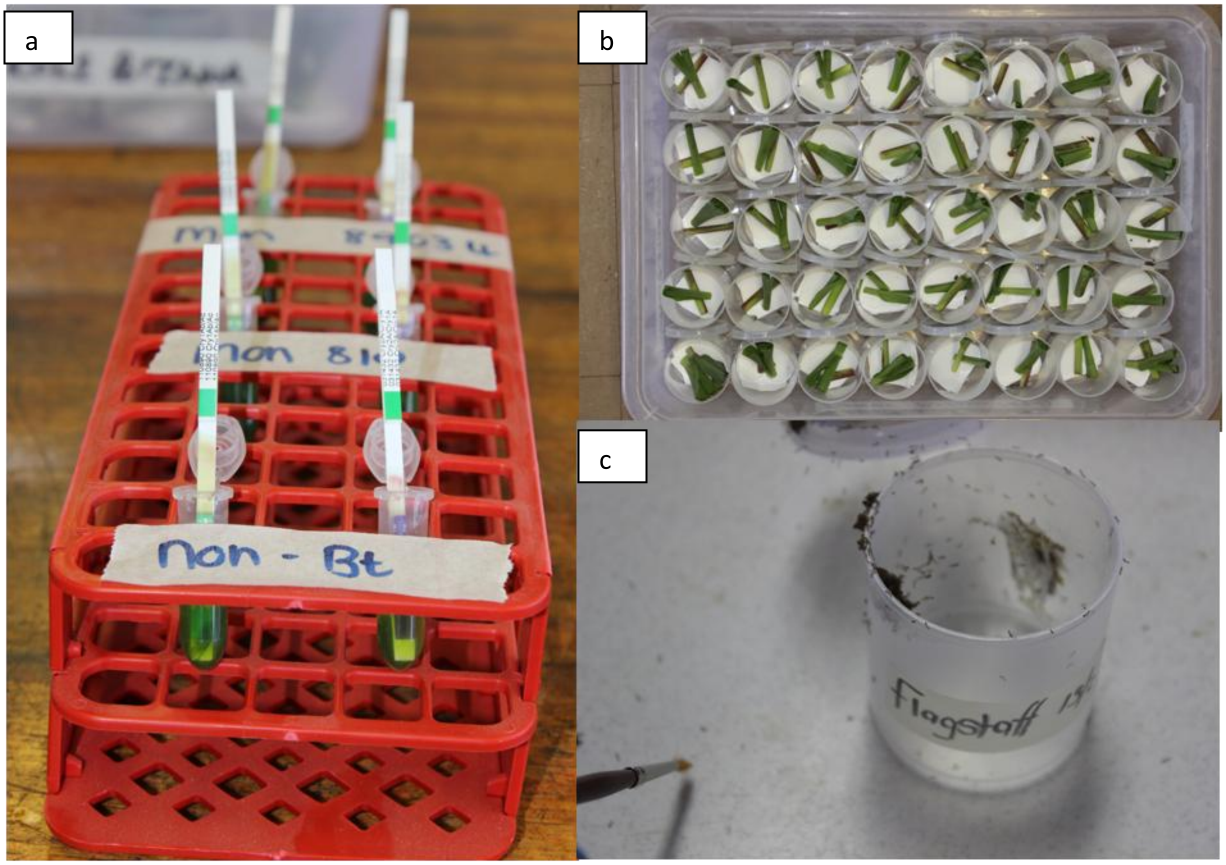

Figure 6.2. Test for presence of Bt toxin by means of strip tests (a) and layout of set up for screening (b) neonate *Busseola fusca* larvae (c)

6.2.5. Data analyses

Data on field incidence, larval survival and mass of *B. fusca* were subjected to analysis of variance (ANOVA) using SPSS (version 24) statistics software (IBM Corporation, USA). Pearson's chi-squared (χ^2) test (SPSS) was used to analyse the sex ratio of *B. fusca* pupae from the different areas.

6.3. Results

Results of field surveys indicated that Bt maize was cultivated in seven sub-districts in the Eastern Cape during the 2014/15 cropping season. Five out of the six varieties cultivated were stacked trait varieties, a combination of insect resistance and herbicide tolerance traits in one variety (Table 6.1). The total estimated area under Bt maize cultivation was 1,235 hectares. Individual Bt maize field sizes ranged from 0.5 to 2.5 hectares. The usual practice was to consolidate these small units into large units of between 10 to 150 hectares to facilitate mechanisation operations. Structured refuge areas were not included in any of the fields visited (data not shown). With the exception of one Bt field in which neonate *B. fusca* larvae were recorded in the central whorl leaves of two maize plants, all 42 Bt maize fields inspected during the 2014/15 cropping season were free of *B. fusca* infestation.

Table 6.1. Bt maize cultivating localities in the Eastern Cape, cultivars planted and stem borer species recorded. (*B.f = Busseola fusca, C.p =Chilo partellus*)

Locality	Geographic coordinate of localities visited	Estimated Bt maize area (ha)	No. of fields visited	GM maize variety in field visited	Borer spp. in nearby non-Bt fields
Bizana	S30.87372˚E29.62144˚	325	9	PAN 5Q-749BR[1]	*B.f, C.p*
Flagstaff	S31.08722˚E29.53661˚	619	7 5	PAN 5Q-749BR PAN 6Q-745BR	*B.f*
Port St. Johns	S31.49170˚E29.49802˚	30	6	PAN 5Q-749BR	*B.f, C.p*
Mount Frere	S31.80815˚E28.75360˚	17	3	BG 3792BR	*B.f*
Maluti	S30.40422˚E28.51627˚	219	6	PAN 4P-716BR	*B.f*
Lady Frere	S31.49633˚E27.36287˚	15	3	PAN 6Q-708BR	*B.f*
Elliot	S31.37500˚E28.00712˚	10	3	Phb 33H52B[2]	*B.f*
	Total	1,235	42		

[1] BR indicates that variety has ‘stacked’ traits (Bt insect resistance + herbicide tolerance) GM maize

[2] B indicates that variety is a single-gene Bt maize event

Mean incidence of *B. fusca* larvae and the number of larvae recovered per non-Bt maize plant in the non-Bt area (ECRef001) was higher than that in the Bt maize cultivating areas. These differences between infestation levels were however not significant ($P > 0.05$), ranging between

39% and 56% (Table 6.2). There were more male than female pupae in populations ECBt001 and ECRef001 as compared to population ECBt002 (Table 6.2).

Table 6.2. Incidence of stem borer infested plants on non-Bt maize in home gardens and sex ratios of populations of *Busseola fusca* collected in the Eastern Cape.

Area	Mean (±SEM) percentage of infested plants/ home garden	Mean (±SEM) number of *B. fusca* larvae/ plant	Sex Ratio (Males : Females)
ECBt001	39.0 (±4.46)	1.7 (±0.26)	1.1 : 1
ECBt002	42.1 (±4.57)	2.2 (±0.25)	0.81 : 1
ECRef001	56.4 (±6.01)	2.6 (±0.32)	1.14 : 1
P-value	0.073	0.090	$\chi^2 = 1.77$
F-value	2.77	2.53	

6.3.1. Larval survival on Bt and non-Bt maize

One hundred percent larval mortality was observed in all three *B. fusca* populations on MON89034 plant tissue within seven days (Table 6.3). Survival on MON810 by larvae from population ECRef001 on the seventh day was significantly higher than that of populations ECBt001 and ECBt002. From the 10th to 21st days, there were no significant (P>0.05) differences in survival between the different populations on MON810 and between populations on MON810 and MON89034. Survival on MON810 on day 21 ranged between 1.0% (ECBt001 and ECBt002) and 1.5% (ECRef001). Compared to non-Bt maize, larval survival on MON810 maize from the seventh to the 21st day was significantly ($P < 0.001$) lower in all populations (Table 6.3). Significantly more larvae from population ECBtRef001, compared to populations ECBt001 and ECBt002 survived on non-Bt maize for the first seven days. Survival on non--Bt maize at the end of the experiment (day 21) ranged between 22.0% (ECBt002) and 53.0% (ECBt001) (Table 6.3).

Table 6.3. Larval survival (%) of different *Busseola fusca* populations maintained on Bt and non-Bt maize.

Treatments	Mean (±SEM) larval survival (%)				
	Day 7	Day 10	Day 14	Day 17	Day 21
ECBt001Control*	88.5 (±2.49)a	83.0 (±2.21)a	75.5 (±2.84)a	70.0 (±2.99)a	53.0 (±3.16)a
ECBt001MON810	6.0 (±2.49)d	3.5 (±2.21)c	3.0 (±2.84)c	2.0 (±2.99)c	1.0 (±3.16)c
ECBt001MON89034	0.0 (0.0)e	0.0 (0.0)c	0.0 (0.0)c	0.0 (0.0)c	0.0 (0.0)c
ECBt002Control	74.0 (±2.49)b	64.0 (±2.21)b	49.0 (±2.84)b	42.0 (±2.98)b	22.0 (±3.16)b
ECBt002MON810	4.0 (±2.49)de	1.5 (±2.21)c	1.0 (±2.84)c	1.0 (±2.98)c	1.0 (±3.16)c
ECBt002MON89034	0.0 (0.0)e	0.0 (0.0)c	0.0 (0.0)c	0.0 (0.0)c	0.0 (0.0)c
ECRef001Control	93.0 (±2.49)a	86.0 (±2.21)a	68.5 (±2.84)a	54.5 (±2.98)b	32.0 (±3.16)b
ECRef001MON810	12.5 (±2.49)c	2.5 (±2.21)c	2.5 (±2.84)c	2.0 (±2.98)c	1.5 (±3.16)c
ECRef001MON89034	0.0 (0.0)e	0.0 (0.0)c	0.0 (0.0)c	0.0 (0.0)c	0.0 (0.0)c
P-value	<0.001	<0.001	<0.001	<0.001	<0.001
F-value	409.59	457.57	195.72	134.04	55.85

-Means within the same column followed by different letter(s) are significantly different at the 0.05 level.

- Figures in brackets are standard error of means.

*ECBt001Control = Population ECBt001 fed with non-Bt maize, ECBt001MON810 = population ECBt001 fed with MON810 maize, ECBt001MON89034 = population ECBt001 fed with MON89034 maize, ECBt002Control = population ECBt002 fed with non-Bt maize, ECBt002MON810 = population ECBt002 fed with MON810 maize, ECBt002MON89034 = population ECBt002 fed with MON89034 maize, ECRef001Control = population ECRef001fed with non-Bt maize, ECRef001MON810 = population ECRef001 fed with MON810 maize, ECRef001MON89034 = population ECRef001 fed with MON89034 maize

6.3.2. Larval mass on Bt and non-Bt maize

Larvae of population ECRef001 maintained on non-Bt maize had significantly ($P < 0.001$) higher mean mass during the first two weeks than larvae from populations ECBt001 and ECBt002 maintained on non-Bt maize. There were however no significant differences in mean larval mass between the three different populations on non-Bt maize between day 17 to day 21. Mean mass of larvae of all *B. fusca* populations maintained on non-Bt maize was however significantly ($P < 0.001$) higher on all days as compared to the mean mass of larval populations on MON810 (Table 6.4). Mean larval mass of populations on non-Bt maize ranged from 66.76

mg (ECBt002) to 73.86 mg (ECBt001) whilst that on MON810 on day 21 ranged from 2.80 mg (ECBt001) to 7.48 mg (ECRef001). There were no significant differences in mean larval mass between the three different populations on MON810 (Table 6.4).

Table 6.4. Mean larval mass of different *Busseola fusca* populations maintained on Bt and non-Bt maize.

Treatments	Mean (±SEM) larval mass (mg)				
	Day 7	Day 10	Day 14	Day 17	Day 21
ECBt001Control*	2.32 (±0.20)b	9.81 (±0.65)b	25.62 (±1.29)a	65.99 (±3.19)a	73.86 (±4.18)a
ECBt001MON810	0.18 (±0.85)b	0.28 (±2.73)b	0.21 (±5.37)c	0.64 (±13.33)b	2.80 (±17.47)b
ECBt001MON89034	-	-	-	-	-
ECBt002Control	1.84 (±0.26)b	7.14 (±0.84)b	22.06 (±1.66)b	53.97 (±4.11)a	66.76 (±5.39)a
ECBt002MON810	0.51 (±0.85)b	0.43 (±2.73)b	0.72 (±5.38)c	2.60 (±13.33)b	4.27 (±17.47)b
ECBt002MON89034	-	-	-	-	-
ECRef001Control	4.21 (±0.24)a	13.86 (±0.76)a	29.61 (±1.49)a	66.09 (±3.70)a	69.56 (±4.84)a
ECRef001MON810	0.04 (±0.65)b	0.66 (±2.32)b	1.68 (±4.39)c	6.02 (±10.88)b	7.48 (±14.26)b
ECRef001MON89034	-	-	-	-	-
P-value	<0.001	<0.001	<0.001	<0.001	<0.001
F-value	17.06	15.82	16.25	14.14	9.30

-Means within the same column followed by different letter(s) are significantly different at the 0.05 level.

- Figures in brackets are standard error of means.

*ECBt001Control = Population ECBt001 fed with non-Bt maize, ECBt001MON810 = population ECBt001 fed with MON810 maize, ECBt001MON89034 = population ECBt001 fed with MON89034 maize, ECBt002Control = population ECBt002 fed with non-Bt maize, ECBt002MON810 = population ECBt002 fed with MON810 maize, ECBt002MON89034 = population ECBt002 fed with MON89034 maize, ECRef001Control = population ECRef001fed with non-Bt maize, ECRef001MON810 = population ECRef001 fed with MON810 maize, ECRef001MON89034 = population ECRef001 fed with MON89034 maize

6.4. Discussion

The total land cultivated to maize in South Africa in 2014 was estimated at 2.5 million hectares (James, 2014a). About 69% (1.73 million hectares) of this area was cultivated with Bt maize (single and stacked Bt traits) and BR (insect resistance + herbicide tolerance trait) (James, 2014a). In the Eastern Cape, the total area planted with maize under the Cropping Programme in 2014 was 18,069 hectares (DRDAR, 2015). Estimates from information obtained during interviews with key stakeholders from the Department of Rural Development and Agrarian Reform (DRDAR) and smallholder maize projects in the Eastern Cape suggest that approximately 1,240 hectares of this area was cultivated with Bt maize. Approximately 99% of the area under Bt maize was cultivated to stacked trait BR maize. This indicates that despite repeated introductions, the area under Bt maize on smallholder farms in the province still remains relatively small. Gouse *et al.* (2010) previously reported that many smallholder farmers in rural areas of South Africa who were initially introduced to Bt maize had a preference for herbicide tolerant maize seed. In settings where labour availability is limited, the adoption of labour-saving technologies such as herbicide tolerant maize is also high (Manes, 2013). Additionally, whilst stem borer pressure on maize is highly variable between cropping seasons (Van Rensburg *et al.*, 1987a) weeds are perennial problems on almost all agricultural fields in Africa (Gianessi & Williams, 2011). The use of BR maize may therefore be an attempt to simultaneously benefit from the labour saving trait and the buffer provided by the Bt trait against possible yield losses caused by target stem borer species (Fernandez-Cornejo & McBride, 2002; Marra *et al*., 2003).

6.4.1. Incidence of *Busseola fusca* larvae on Bt and non-Bt maize

Results indicated *B. fusca* as the dominant stem borer pest of maize in smallholder farms in the province. *Chilo partellus* infestation on maize was observed only in areas close (± 50 km) to the coast or where maize was cultivated under irrigation. Typical *B. fusca* damage was observed on non-Bt plants in all the areas surveyed. However, on Bt maize plants only superficial feeding lesions caused by neonate *B. fusca* larvae were observed on two plants. Generally, the mean density of *B. fusca* larvae per maize field and plant was higher in the non-Bt maize area compared to Bt cultivating areas. Agronomic characteristics of the different varieties planted by farmers were not recorded during the survey but it is known that there are differences in growing season length between these hybrids. Due to the general nature of stem borer infestation patterns and moth flight periods which extend over periods of several weeks, it is not expected that larval infestation levels would be differentially affected by differences in growing season length of the different varieties.

Although *B. fusca* infestation levels may be affected by several factors (Calatayud *et al.*, 2014), the general reduction of the pest status of *B. fusca* in South Africa has been associated with the introduction of Bt maize (Van den Berg *et al.*, 2015). Hutchison *et al*. (2010) have also associated reductions in estimated mean densities of *Ostrinia nubilalis* (Hübner) (Lepidoptera: Pyralidae) in parts of the United States maize belt with the introduction of Bt maize. Similarly, Storer *et al*. (2008) associated reductions in the mean density of this pest on non-Bt maize in other parts of the US to the adoption of Bt maize. The observed variation in the incidence of *B. fusca* in the Bt and non-Bt areas of the Eastern Cape may therefore be associated with the cultivation of Bt maize in these areas.

6.4.2. Larval survival and mass gain on Bt and non-Bt maize

High numbers of *B. fusca* larvae from all populations survived on non-Bt maize. On MON89034, 100% mortality was observed within seven days after introduction of larvae. The high level of mortality of neonate larvae of *B. fusca* on MON89034 is consistent with the findings of Erasmus *et al.* (2016) who reported no survival of this pest on this event. MON89034 is a stacked trait Bt event that was introduced in South Africa in 2011, purposely to counteract *B. fusca* resistance to the single transgene, Cry1Ab (Van den Berg *et al*., 2013). MON89034 combines the transgene Cry2Ab2 with Cry1A.105, a chimeric protein incorporating domains I and II from Cry1Ac and domain III from Cry1Fa (USEPA, 2012). Each of the pyramided transgenes (Cry1A.105 and Cry2Ab2) have a different mode of action and binding characteristic to the mid-gut of target insects, they are therefore highly effective against key lepidopteran pests (Storer *et al.*, 2012). Larval survival on MON810 from day ten onwards was similar to that on MON89034 across all populations. Survival of all three populations of *B. fusca* on MON810 was however significantly lower than on non-Bt maize. Growth of an insect on susceptible or resistant plants is commonly determined by measuring the weight gain of the larvae, and the development of larvae into pupae (Khan, 1997). Although the experiment was terminated before the estimated duration of the larval period of 31 to 50 days (Onyango & Ochieng'-Odero, 1994; Ratnadass *et al.,* 2001; Kruger *et al.*, 2012b) the very low mass of the few surviving larvae makes it likely that none of the individuals would have survived until pupation. Since similar levels of larval survival have been observed between laboratory and field trials conducted with *B. fusca* (Erasmus *et al*., 2016), it is expected that results observed in the laboratory trials during this study, would be similar under field conditions in the Eastern Cape Province.

Bt maize is genetically engineered to express a high dose of Bt toxin (Caprio *et al.,* 2000; Siegfried & Hellmich, 2012) against target pests. It is assumed that for the high dose requirement to be satisfied, the protein concentration in tissues fed on by homozygous susceptible insects should be sufficiently high that nearly all (>99.9%) larvae feeding as neonates fail to complete development, and insects heterozygous for resistance alleles are expected to suffer at least 95% mortality (USEPA, 1998). It is worthy of note that pre-commercialization field data indicate that Cry1Ab proteins (MON810) did not kill 99% of larvae (Van Rensburg, 1999). Given these facts coupled with the fact that the mortality observed in this study falls within the expected range (95-99.9%) it can be concluded that *B. fusca* populations from Bt cultivating areas in the Eastern Cape are still highly susceptible to Bt toxin.

Continuous cultivation of transgenic Bt maize, however, increases selection pressure and consequently increases the risk that insect species directly exposed to Bt toxin may evolve resistance to Bt proteins (Ferré & Van Rie, 2002). The Eastern Cape was amongst the provinces to which Bt maize was first introduced to smallholder farmers during 2001 (Gouse, 2012a). Since then, cultivation has been limited to farmers participating in various Government development initiatives such as the Massive Food Production Programme (2003-09) and DRDAR Cropping Programme (2012 onwards). Adoption of Bt maize outside of Government development initiatives have been very limited. Consequently, Bt maize cultivation in the province has not been continuous and hence, larvae may not be subject to intense selection pressure derived from continuous exposure to Bt toxin. Rice & Pilcher (1998) observed that farmers' perception of transgenic Bt maize technology is an important determinant of its adoption. Previous studies of Bt maize introduction to smallholder farmers in the Eastern Cape indicated limited awareness of the fact that Bt maize provides resistance to stem borers (Assefa & Van den Berg, 2009; Jacobson & Myhr, 2012; Kotey *et al.*, 2016). It is therefore possible that as awareness about the efficacy of the Bt trait against stem borers increases, the area under cultivation may increase. One possible threat posed by this is an increase in the selection of resistant insects to Bt plants, a possibility that could limit the use of Bt technology, if increased use is not accompanied by good stewardship (Gould, 1998).

6.5. Conclusion

Results suggest that *B. fusca* populations in the Eastern Cape remain susceptible to Bt maize. However, as past experience with Bt maize elsewhere in South Africa has shown, adoption of Bt maize without adherence to recommended stewardship requirements, particularly IRM, compromises the long term sustainability of the technology. Continuous monitoring of resistance levels and/or prediction of resistance evolution through the development of diagnostic tools and monitoring of fields for early identification of possible transgenic crop product failure, will be required. Recent studies indicating the dominance of at least one type of resistance of *B. fusca* to Bt maize showed the inherent ability of this species to evolve resistance to cry proteins. This highlights the need to promote Bt maize not as a stand-alone pest control option but as part of a broader integrated pest management strategy.

CHAPTER 7: Evaluation of the cost-effectiveness of GM maize cultivation under prevailing pest and weed constraints on smallholder farms in the Eastern Cape Province of South Africa

Abstract

Over the last decade, various agricultural development programmes in South Africa have sought to improve smallholder maize production by supporting smallholder farmers to obtain farming inputs and technical support. A key aspect of the support to smallholder farmers is the provision of seeds of insect resistant and herbicide tolerant GM maize varieties. Studies of GM maize cultivation by smallholders in South Africa have reported yield and economic gains. The majority of these studies have however been based on farmers' recall of maize production activities and output. Smallholder farmers generally do not keep accurate records of farm activities. A more realistic assessment of GM maize output on smallholder farms may therefore include on-farm trials that reflect the cultivation practices and conditions of smallholders. This will ultimately facilitate evidence-based dissemination of cost-effective technologies. This study therefore determined the cost effectiveness of GM maize cultivation by smallholders in the Eastern Cape. On farm trials were undertaken under irrigation at the Zanyokwe irrigation scheme and under dry land conditions in four farming localities of the province identified as hot-spots of stem borer and weed infestation. Stacked trait herbicide and insect resistant (Bt) maize (PAN-5R-993BR) was evaluated against a non-Bt hybrid (PAN-5Q-649R), a non-GM hybrid (PAN 12) and an open pollinated variety (OPV) (Okavango) in stem borer hot-spots. In the weed hot-spots, PAN-6R-680RR was evaluated against a non-GM hybrid, PAN-6480 and Okavango. Agronomic and pest management practices recommended for each variety in each area were implemented. PAN5R-993BR gave the highest yield and gross margin under irrigation where stem borer pressure was high. Under dry land conditions, PAN 12 yielded higher than PAN-5R-993BR. Yields and gross margins obtained from PAN-6R-680RR cultivated under prevailing smallholder weed management practices in the study locations were lower than those obtained from cultivating PAN-6480. The study revealed that stem borer pressure, growing conditions, input supplies and market access affect the productivity and profitability of GM maize cultivation.

Key words: *Gross margins, hybrid maize, smallholders, stem borers, yield advantage.*

7.1. Introduction

Several studies have emphasized the yield and economic benefits of GM maize to smallholders in South Africa (Gouse *et al*., 2005; 2016; Schimmelpfennig *et al*., 2013; Brookes & Barfoot, 2014). Gouse *et al.* (2005; 2006a) for instance reported that despite higher seed costs, smallholder GM maize farmers, through savings on pest control costs and higher yields, obtained higher income compared to farmers that cultivated conventional maize varieties. Smallholder agriculture is practiced by a highly heterogeneous group of producers (Arias *et al*., 2013; Van den Berg & Campagne, 2014). Owing to this heterogeneity, the output of technologies may vary across locations and seasons (Heatherly *et al*., 2002; Kambhampati *et al*., 2006). A particular variety of crop that produces a high yield under optimum conditions may be sensitive to drought (Kelsey, 2013). This is particularly so for GM maize technology, the profitability of which may depend on several factors including pest pressure that may vary between years (Gouse *et al*., 2006a) and locations (Heatherly *et al.*, 2002).

Many studies (Gouse *et al*., 2006a; 2016; Mandikiana, 2011; Gouse, 2012a; Jacobson & Myhr, 2012; Regier *et al*., 2012; Fischer & Hadju, 2015) have sought to document the socio-economic impact of GM maize introduction to smallholders in South Africa. These studies have however been limited by the fact that they generally relied on farmers' recall of maize production activities and outputs with no attempt made to link survey data with field data that provides information on the incidence and importance of stem borers and weeds to maize cultivation and the management practices adopted by farmers on the profitability of GM maize in smallholder farming systems. Smallholder farmers generally do not keep accurate records of their farm operations and farm output, information obtained through farmer recall may therefore be unreliable (Fermont & Benson, 2011).

Thus, field research under prevailing pest and weed incidence in smallholder systems that takes into account GM maize cultivation practices may provide crucial information that will help to prioritise and disseminate the most cost-effective technologies that will improve smallholder maize production and livelihoods (De Grassi, 2003; De Groote, 2002). This study was therefore conducted to verify previous reports on the yield advantage and economic benefits or losses of GM maize cultivation in smallholder farms under dry land and irrigation conditions in the province.

7.2. Materials and methods

7.2.1. Description of the study areas

The study under irrigation conditions was conducted at the Zanyokwe irrigation Scheme (S32.75783˚ E27.05600˚), located in Keiskammahoek, in the Amathole District Municipality of the Eastern Cape Province of South Africa. Keiskammahoek is located about 35 km from King Williams Town, the main commercial centre in the area. The irrigation scheme was established in 1984 and has a total irrigated area of about 439 ha (Fanadzo *et al*., 2010). There are about 61 farmers with an average land holding of 4.2 ha (Fanadzo *et al*., 2010). The area receives a mean annual rainfall of 580 mm which is supplemented with a sprinkler irrigation system for crop cultivation. The soils in the area are characterised by Arcadia soil (Vertisol) and Shortlands soil forms (Chromic Luvisol) (Soil Classification Working Group, 1991). Bt maize was previously cultivated at the Scheme as part of the Massive Food Production Programme (MFPP). Currently farmers at the scheme cultivate GM maize as part of the Cropping Programme of the Department of Rural Development and Agrarian Reform (DRDAR). Inputs subsidized by the Government under this programme are delivered to farmers at the scheme.

The dry land trials were conducted at Nxanxadi (S31.13137˚ E29.63938˚), Bhala (S30.94832˚ E29.54863˚) (Stem borer hotspots), Goso (S31˚23.254′ E29˚37.959′) and Galatyeni (S31˚15.292′ E29˚29.178′) (weed hot spots). These areas respectively fall under the Flagstaff (Nxanxadi and Bhala) and Lusikisiki (Goso and Galatyeni) service centres of DRDAR. Flagstaff and Lusikisiki are in the Ingquza Hill Local Municipality of the OR Tambo District Municipality. They are situated 230 km (Flagstaff) and 136 km (Lusikisiki) from Mthatha, the capital of the OR Tambo District Municipality. Flagstaff normally receives about 749 mm of rainfall per year while Lusikisiki on the other hand receives about 874 mm of rainfall per year. Most of the rainfall occurs between September and May (SAexplorer, 2014a; 2014b). The underlying geology of the area is composed of hard quartzite rock of the Natal group sandstones and tillite, shale, mudstone and sandstone of the Karoo Sequence (Bezuidenhout & De Kock, 2014). The Natal group Sandstone gives rise to sandy, highly leached and relatively shallow soils which are not suitable for intensive agriculture (Nicolson, 1993). Soils associated with the Karoo supergroup are characterized as being acidic, leached and heavy (Mucina & Rutherford, 2006**)**.

7.2.2. Field surveys

7.2.2.1. Survey of maize fields in Bt maize cultivating areas: Non-Bt maize fields in localities where Bt maize is cultivated were visited (10 maize fields x 13 localities) and inspected for the presence of stem borers during the 2014/15 maize cropping season (Table 7.1). Each field visited in each locality was demarcated into three zones and between 20-100 maize plants (depending on the size of the field) from within each demarcated zone were randomly selected and closely inspected for signs of borer damage, including scarified or dry leaves and shoots (dead hearts), frass or holes bored into stems (Moolman *et al*., 2014). The number of infested plants in each field was recorded and expressed as a percentage of the total number of plants inspected for the field. Five of the most severely damaged plants in each field were selected and dissected to identify the stem borer species present in that field.

7.2.2.2. Survey of weed incidence in herbicide tolerant maize fields: Assessment of the incidence of weeds in herbicide tolerant GM maize fields were carried out in 13 different localities where herbicide tolerant maize is cultivated in the Eastern Cape Province. At each locality, weed incidence in whole maize fields that had previously been sprayed with herbicides (within four weeks of application) were estimated using a 1- 3 visual rating scale (where 1= clean field, 2 = moderately weedy field and 3= very weedy field (Ngoko *et al.*, 2002) (Figure 7.1). The incidence of weeds on individual fields in each locality was used to determine the mean incidence of weeds on fields per locality.

Figure 7.1. Estimates of level of weediness of different maize fields (from top to bottom: clean field, moderately weedy field and weedy field)

7.2.3. Selection of trial locations and varieties

Based on the mean incidence of stem borer infested plants and weeds per locality, Bhala (35.3%) and Nxanxadi (36.2%) were selected as stem borer hot spots for field trials (Table 7.1). The only stem borer species recorded at these localities was *Busseola fusca*. The Zanyokwe irrigation scheme was selected based on farmer reports of high incidence of stem borers on maize (X. Mpengesi, Middledrift, August 2015, personal communication).

Although the highest mean incidence rating for weeds of 2.6 was observed in Maluti, this area was not selected for trials because of a prolonged drought, which made it impossible for any maize to be planted in the area during the 2015/16 cropping season. Goso (2.2) and Galatyeni (2.3) were therefore selected as weed hotspots for field trials (Table 7.2).

Field surveys indicated that most farmers that cultivated GM maize with the Bt trait, cultivated the white maize variety, PAN-5Q-749BR (Figure 4.6 in Chapter 4) whilst for herbicide tolerant maize most farmers cultivated PAN-6R-680R, a yellow maize variety (Table 7.2). White maize is cultivated mostly for human consumption while yellow maize is traditionally cultivated for animal feed (DAFF, 2013a). Fanadzo *et al.* (2009) however reported that smallholder farmers in the Eastern Cape cultivate the yellow OPV, Okavango, for grain maize. Indeed surveys during the 2014/15 cropping season indicated that farmers in some DRDAR service centres cultivated this OPV as part of the Cropping Programme. Based on these observations, the ‘stacked’ trait (Bt insect resistance + herbicide tolerance) variety PAN-5R-993BR was selected for evaluation against a herbicide tolerant maize hybrid of similar maturity period (PAN-5Q-649R), a non-GM hybrid maize variety (PAN 12) and an open pollinated maize variety (Okavango) (Table 7.3) at Zanyokwe, Nxanxadi and Bhala. With regard to the weed hot spots the herbicide tolerant variety, PAN-6R-680R was evaluated against a non-GM hybrid, PAN-6480 and Okavango (Table 7.3) at Goso and Galatyeni.

Table 7.1. Characteristics of maize varieties evaluated in multi location on-farm trials

Variety	Growth class	Characteristics
PAN-5R-993BR	Medium (M)	White maize, GM stem borer and herbicide resistant
PAN-5Q-649R	M	White maize, GM herbicide resistant
PAN-6R-680R	M	Yellow maize, GM herbicide resistant
PAN 12	M	Yellow maize, non-GM, insect, drought and disease tolerant
PAN-6480	M	Yellow maize, non-GM, disease tolerant
Okavango	M to late	Yellow maize, drought tolerant

Three farms were obtained at each location for researcher managed field trials. Each farm had previously been cultivated to maize. The experimental design was randomised complete block replicated three times per each location. There were three blocks of 50 m x 40 m per site. At Zanyokwe, Nxanxadi and Bhala, each block consisted of four 50 m x 10 m plots whilst at Goso and Galatyeni each block consisted of three 50 m x 10 m plots. Planting was done between late October and mid-December, 2015. All fields in one area were planted on the same day using a tractor drawn planter. Inter and intra row distances of 0.75 m and 0.33 m was used to achieve a plant population of 40,000 per hectare as is the normal practice in the study areas. There were 12 rows of 120-130 plants per row. The inner 4 rows were used for data collection whilst the 4 outer rows on each side of the inner rows were maintained as guard rows. Total plant stand per row was determined at the six leaf stage. PAN-5Q-649R was used to plant two rows around the perimeter of each field in the stem borer hotspots. All maize production practices recommended for each variety as per the practice of the Cropping Programme were observed. Basal fertiliser NPK in the ratio of 2:3:4 (30) was applied at the rate of 200 kg/ha at planting whilst limestone ammonium nitrate (LAN 28% N) at the rate of 200 kg/ha was applied at the knee height stage of growth (6-8 WAE). Cypermethrin was applied at the rate of 350 ml/ha on non-Bt maize plants during the vegetative stage (7 WAE) when visual estimation of stem borer damaged plants indicated that more than 10% of plants in each plot were infested. Farmers in the study area control weeds and apply insecticides preventatively at the knee height stage of crop growth. The action threshold for stem borer control in maize is however when 10% of plants (mixed infestations of *B. fusca* and *C. partellus*) in a field show visible symptoms of whorl damage (Van den Berg *et al.*, 2015). Weeding or herbicide application was done as per the usual practice of farmers in each area. Insecticide and herbicide application and manual weeding in each block was undertaken by the same individual or group of individuals (weeding).

The incidence of stem borer infested plants was determined at the seedling (emergence to V3 stage), vegetative (6 WAE), flowering and post-flowering growth stages. During each assessment, 100 maize plants in the four middle rows of each plot were closely inspected for signs of borer damage including scarified or dry leaves and shoots (dead hearts), frass or holes bored in stems (Moolman *et al*., 2014) (Figure 7.2). The number of plants with borer damage in each plot was expressed as the percentage of the total number of plants inspected per plot. During each damage assessment, 10 infested plants from the outer rows in each plot were dissected to identify the stem borer species present in fields.

Data on weed incidence in herbicide and non-herbicide tolerant maize varieties at Goso and Galatyeni were collected 6 WAE (prior to the initiation of weed control at the knee height stage), then four weeks after weed control was initiated and also at the silking stage. A 1 to 3 rating scale was used (Ngoko *et al*., 2002).

Figure 7.2. Stem borer damage symptoms on whorls and stems of non-Bt maize

7.2.4. Harvesting and determination of yield and yield components

Thirty maize plants from the two middle rows of each plot (variety) at each location were randomly selected and tagged 20-24 WAE. The number of ears per tagged plant was determined after which ears were harvested. Each harvested ear was assessed for the presence of stem borer damage. The extent of damage (tunnel length) on each ear was recorded (Figure 7.3). The number of internodes bored in stems of plants from which ears were harvested for each variety was determined and recorded (Figure 7.4). The area from which ears were harvested in each plot was approximately 10 m^2. The harvested ears from each plot were individually weighed using a Sartorius balance (maximum weight=5000 g) and recorded. Weighed ears were threshed and used to calculate yield per plot, which was then expressed in tonnes/ha. Grain moisture content at harvest was determined using an intelligent grain moisture meter and used to calculate grain moisture-standardized yield as follows (Badu-Apraku *et al.*, 2012):

$$Yield\ (at\ 12.5\%\ m.c) = Grain\ yield\ \left(\frac{tonnes}{ha}\right) x \frac{(100 - actual\ grain\ moisture\ \%)}{87.5}$$

Figure 7.3. Stem borer damage to harvested non-Bt maize ears

Figure 7.4. Stem borer (*Busseola fusca*, left and *Chilo partellus*, right) damage to internodes of maize plants

7.2.5. Data analyses: Data on pre- and post-flowering stem borer infestation and grain yield for each trial location were analysed separately by way of univariate analysis of variance (ANOVA), using SPSS (version 24) statistics software (IBM Corporation, USA). Treatment (variety) was entered as the fixed factor whilst specific measured variables (for example percent infested plants at flowering) were entered as dependent variable.

7.2.6. Gross margin analysis

Gross margin analysis was used to determine the profitability of the cultivation of each variety in each locality. A gross margin for a crop is the difference between the revenue obtained from selling the crop and the direct costs incurred in producing the crop (Buckett, 1988). Gross margins can be a quick means through which farmers can determine which crops, among several alternatives, they should cultivate (Karen, 2006). Gross margins for each variety were calculated under two scenarios. Maize farmers in the irrigation scheme sell their harvest to nearby dairies based on the SAFEX (South African Futures Exchange) price of maize. Gross margins for the varieties under irrigation were therefore calculated based on the SAFEX price of white and yellow maize for August 2016 delivery (www.grainsa.co.za/pages/industry-reports/safex-feeds). Owing to challenges faced by smallholders in accessing markets, they are more likely to sell their farm output in local markets (Gouse *et al*., 2016). Following harvest in areas where dry land trials were undertaken, farmers store their maize in household granaries and these are sold periodically to community members at a flat rate of ZAR 200 per 50 kg bag irrespective of maize kernel colour. Gross margins under dry land were therefore calculated based on two scenarios: scenario A, based on SAFEX price of white and yellow maize, and a second scenario (B) based on the price of a 50 kg bag of maize in the areas where the dry land trials were undertaken. Production costs were calculated based on the cost of mechanisation of fields and the cost of labour per man day per hectare per locality as well as the cost of maize inputs associated with the cultivation of each variety per hectare.

7.3. Results

7.3.1. Stem borer and weed incidence in maize fields in different localities surveyed

On-farm surveys of non-Bt maize fields during the 2014/15 cropping season in areas where Bt maize is cultivated indicated low to high levels of stem borer infestation. The lowest incidence of infested plants (8.7%) was recorded at Paballong whilst the highest (36.2%) was recorded in Bhala (Table 7.1). Larvae of *B. fusca* were recovered from 84.6% of the maize fields inspected. Mixed infestations of *B. fusca* and *C. partellus* were observed in 15.4% of maize fields, mostly from fields within 50 km of the coast. About 69.2% of fields had a mean weed incidence rating of between 1-1.5, whilst 23.1% of fields had a rating of between 2.0-2.5 (Table 7.2).

Table 7.2. Mean (of 10 fields) incidence of stem borer infested maize plants at different localities in the Eastern Cape Province of South Africa

DRDAR service Centre	Specific locality	Geographic coordinate of specific locality	Mean percentage damaged plants
Flagstaff	Bhala	S31.00821˚ E29.55080˚	35.3
Flagstaff	Nxanxadi	S31˚05.290"E29˚37.470'	36.2
Flagstaff	Ndukudeni	S31.09646˚ E29.51649˚	32.6
Flagstaff	Maliwa	S31.11759˚ E29.53241˚	10.9
Mount Frere	Ntonjeni	S30˚48.167" E28˚45.094"	25.8
Mount Frere	Cancele	S30˚57.769" E29˚00.530"	27.5
Port St. Johns	Ndayini	S31˚29.292" E29˚29.716"	29.6
Port St. Johns	Lugoqweni	S31˚26.189" E29˚31.784"	19.6
Bizana	Ntlakwe	S30˚54.176" E29˚55.581"	12.9
Bizana	Nzaka	S31˚04.440" E29˚58.080"	15.4
Bizana	Redout Location	S30˚54.643" E29˚55.353"	20.2
Maluti	Paballong	S30˚25.128" E28˚30.603"	8.7
Maluti	Qoboshianga	S30˚24.943" E28˚34.291"	20.5

Table 7.3. Incidence of weeds in maize fields at different localities in the Eastern Cape

DRDAR Service centre	Specific locality	Geographic coordinate of specific locality	Type of RR maize cultivated	Mean incidence (1-3 rating)*
Lusikisiki	Goso	S31˚23.443"E29˚38.196″	PAN-6R-680R	2.2
Lusikisiki	Galatyeni	S31˚15.055"E29˚29.460"	PAN-6R-680R	2.3
Flagstaff	Jaca	S30˚57.858" E29˚33.979"	PAN-6R-664R	1.5
Flagstaff	Maliwa	S31˚07.545"E29˚31.660″	PAN-6R-664R	1.3
Willowvale	Tswelitye	S32˚11.153" E28˚23.764"	PAN-6R-664R	1.3
Mount Frere	Njijini	S30˚49.828"E28˚48.408″	PAN-6R-680R	1.8
Ntabankulu	Ntlamvini	S30 ˚56.437"E29˚17.385"	PAN-6R-680R	1.3
Ntabankulu	Mpisini	S30˚57.675" E29˚20.295'	PAN-6R-680R	1.2
Tsolo	Tsolo Village	S31˚18.385"E28˚44.590"	PAN-6R-680R	1.2
Tsolo	Godzi	S31˚18.453"E28˚42.493'	PAN-6R-680R	1.5
Maclear	Katkop	S30˚53.716" E28˚32.043"	PAN-6Q-508R	1.3
Maclear	Ugie	S31˚16'782" E28˚24'394"	PAN-6Q-508R	1.3
Maluti	Magadla	S30˚22.002" E28˚40.935"	PAN-6R-664R	2.5

*[1–3 scale: 1 = clean field, and 3 = very weedy field (Ngoko *et al*., 2002)]

7.3.2. Stem borer infestation of Bt and non-Bt maize varieties under irrigation and dry land conditions

No stem borer infestation was observed on Bt maize plants from the seedling to the flowering stages in all fields at all trial locations (Table 7.4). On non-Bt maize plants, stem borer infestation was first observed three WAE. The general trend observed was a steady increase in the incidence of stem borer infested plants from the seedling to the post flowering stage. Generally, the incidence of borer infested plants at all plant growth stages was higher for the OPV than for PAN-5Q-649R and PAN 12 (Table 7.4). Differences between the incidences of stem borer infested Bt and non-Bt maize plants at the seedling stage at all locations were not significant ($P > 0.05$). The percentage of plants with stem borer damage was higher under irrigation than under dry land conditions. About 74.9%, 75.0% and 95.4% of borers recovered from maize plants under irrigation at the vegetative, flowering and post flowering stages were *C. partellus*. Differences in incidence of stem borer damaged plants between the non-Bt maize varieties were not significant at the vegetative and flowering stages under irrigation (Table 7. 4). During the post-flowering stage however, significantly ($P < 0.001$) fewer plants of PAN-5Q-649R (47.4%) were infested as compared to the percentage of OPV plants (83.0%) (Table 7.4).

Under dry land conditions only *B. fusca* larvae were recovered from non-Bt maize plants. At Nxanxadi, the incidence of stem borer damaged non-Bt maize plants ranged from 0.2% (PAN-5Q-649R) at the seedling stage to 29.3% (OPV) at the post-flowering stage. The incidence of stem borer damaged plants in PAN 12 (15.1%) at the flowering stage was significantly (P=0.032) lower than the incidence of damaged plants in the OPV (Table 7.4). At Bhala, the incidence of stem borer infested plants ranged from 1.0% (PAN 5Q-649R) to 32.8% (OPV) at the seedling and post flowering stages respectively (Table 7.4).

Table 7.4. Comparative incidence of stem borer damaged plants on Bt and non-Bt maize fields under irrigation and dry land conditions in the Eastern Cape Province

Variety	Mean (± SEM[1]) percentage incidence of borer damage plants			
	Seedling	Vegetative	Flowering	Post-flowering
Zanyokwe irrigation scheme				
Okavango	1.0 (±0.39)	31.1 (±2.58)a	39.1 (±2.97)a	83.0 (±4.51)a
PAN 12	0.8 (±0.39)	29.0 (±2.58)a	36.1 (±2.97)a	67.8 (±4.51)ab
PAN-5Q-649R	0.0 (±0.39)	23.0 (±2.96)a	29.4 (±2.97)a	47.4 (±4.51)b
PAN-5R-993BR	0.0 (±0.39)	0.0 (±2.96)b	0.0 (±2.97)b	0.0 (±4.51)c
P-value	0.168	0.000	0.000	0.000
F-value	1.80	30.70	36.33	64.18
Nxanxadi				
Okavango	0.7 (±0.22)	14.2 (±0.58)a	18.8 (±0.87)a	29.3 (±1.09)a
PAN 12	1.1 (±0.22)	13.2 (±0.58)a	15.1 (±0.87)b	27.3 (±1.09)a
PAN-5Q-649R	0.2 (±0.22)	13.0 (±0.58)a	15.8 (±0.87)ab	26.3 (±1.09)a
PAN-5R-993BR	0.0 (±0.22)	0.0 (±0.58)b	0.0 (±0.87)c	0.0 (±1.09)b
P-value	0.007	0.000	0.000	0.000
F-value	4.84	138.44	94.75	161.51
Bhala				
Okavango	1.7 (±0.51)	15.0 (±0.56)a	18.4 (±0.74)a	32.8 (±1.13)a
PAN 12	1.4 (±0.51)	14.2 (±0.56)a	17.4 (±0.74)a	30.4 (±1.13)a
PAN-5Q-649R	1.0 (±0.51)	14.7 (±0.56)a	17.3 (±0.74)a	30.2 (±1.13)a
PAN-5R-993BR	0.0 (±0.51)	0.0 (±0.56)b	0.0 (±0.74)b	0.0 (±1.13)b
P-value	0.13	0.000	0.000	0.000
F-value	2.06	168.63	145.31	192.26

[1] SEM = standard error of mean; means within the same column followed by different letter(s) are significantly different at the 0.05 level.

Under irrigation, the number of internodes bored per plant of PAN-5Q-649R (0.6) was not significantly ($P > 0.05$) different from that bored per plant of the Bt maize variety (0.0). Significantly ($P < 0.001$) higher numbers of internodes were bored per plant of PAN 12 (3.4) than the other varieties of maize evaluated under this system (Table 7.5). At both dry land trial locations, there were no significant differences between the number of internodes bored per plant of PAN-5Q-649R and the Bt maize variety. At Bhala the number of internodes bored per plant of PAN 12 (0.1) was not also significantly different from that bored per Bt maize plant (0.0) (Table 7.5).

Mean length of tunnels bored in maize plants of PAN-5Q-649R (0.6 cm) under irrigation were significantly shorter than those bored in plants of the OPV (21.5 cm) and PAN 12 (33.2 cm). Mean lengths of tunnels bored in plants in both Nxanxadi and Bhala were not significantly different (Table 7.5).

Table 7.5. Comparative damage of stem borers to Bt and non-Bt maize stems at different locations.

Variety	Location of trial		
	Zanyokwe	Nxanxadi	Bhala
Mean (±SEM[1]) number of internodes damaged			
Okavango	1.0 (±0.20)b	0.5 (±0.89)a	0.2 (±0.49)a
PAN 12	3.4 (±0.20)a	0.6 (±0.89)a	0.1 (±0.49)ab
PAN 5Q-649R	0.6 (±0.20)bc	0.1 (±0.89)b	0.1 (±0.49)ab
PAN 5R-993BR	0.0 (±0.20)c	0.0 (±0.89)b	0.0 (±0.49)b
P-value	<0.001	<0.001	0.034
F-value	51.72	9.64	2.93
Mean (±SEM) length of stem tunnel			
Okavango	21.5 (±4.33)a	17.3 (±3.37)	10.8 (±2.49)
PAN 12	33.2 (±3.28)a	12.5 (±2.81)	14.7 (±3.05)
PAN-5Q-649R	13.6 (±5.45)b	16.2 (±7.54)	12.3 (±3.86)
P-value	<0.005	>0.05	>0.05
F-value	5.52	0.60	0.49

[1] SEM = standard error of mean; means within the same column followed by different letter(s) are significantly different at the 0.05 level.

The mean number of ears harvested from PAN-5R-993BR under irrigation was 1.7 per plant, which was significantly ($P < 0.001$) higher than that from any of the non-Bt maize varieties under irrigation (Table 7.6). There were no significant ($P > 0.05$) differences between the number of ears harvested per plant for any of the varieties under dry land conditions at both Nxanxadi and Bhala. The number of ears harvested per plant of PAN 12 (1.1) was however significantly ($P < 0.001$) lower than that harvested per plant of the other varieties at Nxanxadi (Table 7.6).

No stem borer infestation was observed on all ears harvested from plants of the Bt maize variety under irrigation. The incidence of stem borer damaged ears on non-Bt hybrids and the OPV harvested from irrigated plots ranged between 16.7% (PAN-5Q-649R) and 30.0% (PAN 12) (Table 7.6). No significant differences ($P > 0.05$) were observed between the percentage damaged ears of Bt maize and non-Bt maize under dry land conditions. At Nxanxadi, none of the harvested ears of PAN-5Q-649R and PAN-5R-993BR showed any borer damage. Only 6.7% (OPV) and 10% (PAN 12) of harvested ears were infested at this location. At Bhala, 7.8% of ears harvested from Bt maize had signs of borer infestation. The highest percentage of infested ears at this location (21.1%) was harvested from the OPV (Table 7.6).

Damage to ears was characterized by tunnels and in most cases infection of infested ears (Figure 7.3). A mean tunnel length of 6.2 cm was recorded per ear of PAN 12 under irrigation. Although this was significantly ($P < 0.05$) longer than that on ears of PAN-5Q-649R, it was not different from the tunnel length per ear of the OPV (5.3 cm). Differences in mean tunnel lengths on ears between varieties in both dry land trials at Nxanxadi and Bhala were not significant ($P > 0.05$). Mean tunnel lengths recorded on ears constituted 19.6% (PAN-5Q-649R), 30.5% (OPV) and 31.0% (PAN 12) of the mean length of ears of these varieties under irrigation. With respect to dry land conditions, it constituted 26.2% (OPV) and 34.1% (PAN 12) of the mean length of ears harvested at Nxanxadi and 26.5% (OPV), 29.2% (PAN-5R-993BR), 31.6% (PAN 12) and 32.8% (PAN-5Q-649R) of the length of harvested ears at Bhala.

Table 7.6. Number and length of ears harvested per plant, and proportion and extent of damage to harvested ears

Variety	Location of trial		
	Zanyokwe	Nxanxadi	Bhala
Mean (±SEM[1]) number of ears harvested/plant			
Okavango	1.3 (±0.50)b	1.6 (±0.06)a	1.1 (±0.03)
PAN 12	1.2 (±0.50)b	1.1 (±0.06)b	1.0 (±0.03)
PAN-5Q-649R	1.3 (±0.50)b	1.4 (±0.06)a	1.0 (±0.03)
PAN-5R-993BR	1.7 (±0.50)a	1.4 (±0.06)a	1.3 (±0.32)
P-value	<0.001	<0.001	>0.05
F-value	16.39	9.64	10.94
Mean (±SEM) percentage of harvested ears infested			
Okavango	20.0 (±9.08)a	6.7 (±3.60)	21.1 (±4.84)
PAN 12	30.0 (±9.08)a	10.0 (±3.60)	12.2 (±4.84)
PAN-5Q-649R	16.7 (±9.08)a	0.0 (±3.60)	11.1 (±4.84)
PAN-5R-993BR	0.0 (±9.08)b	0.0 (±3.60)	7.8 (±4.84)
P-value	0.21	>0.05	>0.05
F-value	1.89	1.93	1.38
Mean (±SEM) length of ear			
Okavango	17.4 (±0.25)c	16.5 (±0.54)	13.6 (±0.34)b
PAN 12	20.0 (±0.25)a	17.7 (±0.54)	15.2 (±0.34)a
PAN-5Q-649R	19.0 (±0.25)b	17.6 (±0.54)	14.3 (±0.34)a
PAN-5R-993BR	18.8 (±0.25)b	16.9 (±0.54)	14.4 (±0.34)a
P-value	<0.001	>0.05	>0.05
F-value	17.92	1.14	3.44
Mean (±SEM) length of tunnel on ear (cm)			
Okavango	5.3 (±0.67)ab	4.3 (±0.80)	3.6 (±0.41)
PAN 12	6.2 (±0.54)a	6.0 (±0.64)	4.8 (±0.53)
PAN-5Q-649R	3.7 (±0.73)b	-	4.7 (±0.53)
PAN-5R-993BR	-	-	4.2 (±0.67)
P-value	0.033	>0.05	>0.05
F-value	3.64	2.82	1.36

[1] SEM = standard error of mean; means within the same column followed by different letter(s) are significantly different at the 0.05 level.

7.3.3. Effect of stem borer incidence on Bt and non-Bt maize grain yield

There was significant ($P < 0.05$) negative correlation (r = -0.99) between stem tunnel length and grain yield obtained from PAN 12 cultivated under irrigation. For all other varieties, neither number of internodes bored per plant nor stem tunnel length correlated significantly ($P > 0.05$) with grain yield at any of the locations. The highest yield (8.32 tonnes/ha) under irrigation was obtained from Bt maize. While this was significantly ($P < 0.05$) higher than the yield obtained from the OPV it was not different from the yield obtained from PAN 12 (7.05 tonnes/ha) or PAN-5Q-649R (6.18 tonnes/ha). Differences in yield obtained under dry land conditions at both Nxanxadi and Bhala were not significantly ($P > 0.05$) different. Yield obtained at Nxanxadi ranged from 3.62 tonnes/ha (OPV) to 5.04 tonnes/ha (PAN 12) while at Bhala it ranged from 2.04 tonnes/ha (OPV) to 3.42 tonnes/ha (PAN 12).

7.3.4. Gross margins of GM and non-GM maize cultivation under irrigation and dryland conditions

Considering a scenario (A) where smallholder farmers sell their output based on SAFEX prices for white and yellow maize, Bt maize (PAN-5R-993BR) gave higher gross margins across all locations. The lowest gross margins using both scenarios across all locations were obtained from the OPV. Under irrigation, the gross margins obtained ranged from R 7, 699.90/ha (OPV) to R 27, 135.51/ha (PAN-5R-993BR) (Table 7.7). Using scenario A, Gross margins obtained at Nxanxadi ranged from R 4, 866.05/ha (OPV) to R 10, 436.79/ha (PAN-5R-993BR) (Table 7.8) while at Bhala it ranged from R63.82 (OPV) to R 5, 561.39/ha (PAN-5R-993BR) (Table 7.9). Using scenario B, Gross margins at Nxanxadi ranged from R 7, 855.45 (OPV) to R 12, 567.95/ha (PAN 12) (Table 7.8) while at Bhala it ranged from R 1, 748.45/ha (OPV) to R 6, 304.95/ha (PAN 12) (Table 7.9).

Table 7.7. Total variable costs and gross incomes associated with the cultivation of different maize varieties at the Zanyokwe irrigation scheme

	Cost (ZAR) per hectare			
Item	PAN-5R-993BR	PAN-5Q-649R	PAN 12	Okavango
Income (Gross value of production)	8.32t/ha x R4292[1]	6.18t/ha x R4292	7.05t/ha x R3174.20	4.75t/ha x R3174.20
Gross income (R)	35,709.44	26,524.56	22,378.11	15,077.45
Variable costs				
Pre-harvest costs				
Maize seed	1,475.33	1,275.33	1,111.50	286.00
Herbicide	132.6	132.6	0.00	0.00
Insecticide	0.00	32.55	82.55	82.55
Basal fertiliser	1,416.00	1,416.00	1,416.00	1,416.00
Limestone Ammonium Nitrate (LAN 28%)	968.00	968.00	968.00	968.00
Ploughing	800.00	800.00	800.00	800.00
Disking	600.00	600.00	600.00	600.00
Planting	450.00	450.00	450.00	450.00
Pre-emergence spray application	400.00	400.00	400.00	400.00
LAN application costs	200.00	200.00	200.00	200.00
Post emergence herbicide application	400.00	200.00	0.00	0.00
Irrigation	900.00	900.00	900.00	900.00
Weeding	0.00	0.00	800.00	800.00
Harvest costs	832.00	618.00	705.00	475.00
Total variable costs	8,573.93	7,992.48	8,433.05	7,377.55
Gross margin	27,135.51	18,532.08	13,945.06	7,699.90

[1] www.grainsa.co.za/pages/industry-reports/safex-feeds (accessed 19th August 2016)

Table 7.8. Total variable costs and gross incomes associated with the cultivation of different maize varieties at Nxanxadi

	Cost (ZAR) per hectare			
Item	PAN-5R-993BR	PAN-5Q-649R	PAN 12	Okavango
Income (Gross value of production) (Scenario A)	4.16t/ha x R4292	3.94t/ha x R4292	5.04t/ha x R3174.20	3.62t/ha x R3174.20
Gross income (Scenario A)	17,854.72	16,910.48	15,997.97	11,490.60
Income (Gross value of production) (Scenario B)	4.16t/ha x R4000	3.94t/ha x R400	5.04t/ha x R4000	3.62t/ha x R4000
Gross income (Scenario B)	16,640.00	15,760.00	20,160.00	14,480.00
Variable costs				
Pre-harvest costs				
Maize seed	1,475.33	1,275.33	1,111.50	286.00
Herbicide	132.60	132.60	0.00	0.00
Insecticide	0.00	32.55	82.55	82.55
Basal fertiliser	1,416.00	1,416.00	1,416.00	1,416.00
Limestone Ammonium Nitrate (LAN 28%)	968.00	968.00	968.00	968.00
Input transport cost	10.00	10.00	10.00	10.00
Ploughing	800.00	800.00	800.00	800.00
Disking	700.00	700.00	700.00	700.00
Planting	400.00	400.00	400.00	400.00
LAN application costs	200.00	200.00	200.00	200.00
Post emergence herbicide application	400.00	400.00	400.00	400.00
Weeding	500.00	500.00	1,000.00	1,000.00
Harvest cots	416.00	394.00	504.00	362.00
Total variable cost	7,417.93	7,228.48	7,592.05	6,624.55
Gross margin (Scenario A)	10,436.79	9,682.00	8,405.92	4,866.05
Gross margin (Scenario B)	9,222.07	8,531.52	12,567.95	7,855.45

Table 7.9. Total variable costs and gross incomes associated with the cultivation of different maize varieties at Bhala

	Cost (ZAR) per hectare			
Item	PAN-5R-993BR	PAN-5Q-649R	PAN 12	Okavango
Income (Gross value of production) Scenario A	2.96t/ha x R4292	2.89t/ha x R4292	3.42t/ha x R3174.20	2.04t/ha x R3174.20
Gross income Scenario A	12,704.32	12,403.88	10,855.76	6,475.37
Income (Gross value of production) Scenario B	2.96t/ha x R4000	2.89t/ha x R4000	3.42t/ha x R4000	2.04t/ha x R4000
Gross income Scenario B	11,840.00	11,560.00	13,680	8,160.00
Variable costs				
Pre-harvest costs				
Maize seed	1,475.33	1,275.33	1,111.50	286.00
Herbicide	132.60	132.60	0.00	0.00
Insecticide	0.00	32.55	82.55	82.55
Basal fertiliser	1,416.00	1,416.00	1,416.00	1,416.00
Limestone Ammonium Nitrate (LAN 28%)	968.00	968.00	968.00	968.00
Input transport costs	5.00	5.00	5.00	5.00
Ploughing	1,000.00	1,000.00	1,000.00	1,000.00
Disking	750.00	750.00	750.00	750.00
Planting	500	500	500	500
LAN application costs	200.00	200.00	200.00	200.00
Post emergence herbicide application	400.00	400.00	0.00	0.00
Weeding	0.00	0.00	1,000.00	1,000.00
Harvest costs	296.00	289.00	342.00	204.00
Total variable cost	7,142.93	6,968.48	7,375.05	6,411.55
Gross margin (Scenario A)	5,561.39	5,435.40	3,480.71	63.82
Gross margin (Scenario B)	4,697.07	4,591.52	6,304.95	1,748.45

7.3.5. Effect of weed incidence and weed management practice on GM and non-GM maize grain yield

All fields in Goso had a mean weed incidence rating of 2 at the establishment stage. While at the vegetative stage, mean weed incidences recorded were 3 (PAN-6R-680R) and 2 (PAN 6480 and Okavango). At Galatyeni, the mean weed incidence rating values were 1.3 for all varieties at the establishment stage and 2.3 (PAN-6R-680R) and 1.3 (PAN-6480 and Okavango) at the vegetative stage (Table 7.10). Differences in yield between varieties under different weed management regimes at both Goso and Galatyeni were not significant ($P > 0.05$) and ranged from 1.88 tonnes/ha to 5.46 tonnes/ha at Goso and 2.07 tonnes/ha (Okavango) to 3.59 tonnes/ha (PAN-6480) at Galatyeni.

Table 7.10. Mean weed incidence rating in herbicide tolerant GM and non-GM maize fields at two locations in the Eastern Cape Province, South Africa

Variety	Mean rating* of weed incidence in maize fields			
	Goso		Galatyeni	
	Seedling	Vegetative	Seedling	Vegetative
Okavango	2.0	2.0	1.3	1.3
PAN-6480	2.0	2.0	1.3	2.3
PAN-6R-680R	2.0	3.0	1.3	1.3

*[1–3 scale: 1 = clean field and 3 = very weedy field (Ngoko *et al*., 2002)]

7.3.6. Gross margins of herbicide tolerant GM and non-GM maize cultivation under dry land conditions

Gross margins based on scenario A ranged from R -498.05/ha (OPV) to R 9, 682.08/ha (PAN-6480) at Goso (Table 7.11). At Galatyeni it ranged between R 290.63/ha to 3, 937.61 (Table 7.12). Using scenario B it ranged between R 1, 544.50/ha (OPV) and R 14, 190.95/ha (PAN-6480) at Goso (Table 7.11) and in Galatyeni it ranged between R 2, 000.45/ha and R 6, 902.95/ha (Table 7.12).

Table 7.11. Total variable costs and gross incomes associated with the cultivation of different maize varieties at Goso

Item	Cost (ZAR) per hectare		
	PAN-6R-680R	PAN-6480	Okavango
Income (Gross value of production) Scenario A	3.19t/ha x R3174.20	5.46t/ha x R3174.20	1.88t/ha x R3174.20
Gross income Scenario A	10,125.70	17,331.13	5,967.50
Income (Gross value of production) Scenario A	3.19t/ha x R4000	5.46t/ha x R4000	1.88t/ha x R4000
Gross income Scenario B	12,760.00	21,840.00	7,520.00
Pre-harvest			
Maize seed	1,082.00	1,111.50	286.00
Herbicide	132.60	0.00	0.00
Insecticide	32.55	82.55	82.55
Basal fertiliser	1,416.00	1,416.00	1,416.00
Limestone Ammonium Nitrate (LAN 28%)	968.00	968.00	968.00
Input transport costs	25.00	25.00	25.00
Ploughing	1,000.00	1,000.00	1,000.00
Disking	750.00	750.00	750.00
Planting	550.00	550.00	550.00
Post-emergence spray application	350.00	0.00	0.00
LAN application costs	200.00	200.00	200.00
Weeding	500.00	1,000.00	1,000.00
Harvest	319.00	546.00	188.00
Total variable cost	7,325.15	7,649.05	6,465.55
Gross margin (Scenario A)	2,800.55	9,682.08	-498.05
Gross margin (Scenario B)	5,434.85	14,190.95	1,5445

Table 7.12. Total variable costs and gross incomes associated with the cultivation of different maize varieties at Galatyeni

	Cost (ZAR) per hectare		
Item	PAN-6R-680R	PAN-6480	Okavango
Income (Gross value of production) (Scenario A)	3.12t/ha x R3174.20	3.59t/ha x R3174.20	2.07t/ha x R3174.20
Gross income (Scenario A)	9,902.88	11,394.66	6,570.18
Income (Gross value of production) (Scenario B)	3.12t/ha x R4000	3.59t/ha x R4000	2.07t/ha x R4000
Gross income (Scenario B)	12,480.00	14,360.00	8,280.00
Pre-harvest costs			
Maize seed	1,082.00	1,111.50	286.00
Herbicide	132.60	0.00	0.00
Insecticide	32.55	82.55	82.55
Basal fertiliser	1,416.00	1,416.00	1,416.00
Limestone Ammonium Nitrate (LAN 28%)	968.00	968.00	968.00
Input transport costs	20.00	20.00	20.00
Ploughing	1,000.00	1,000.00	1,000.00
Disking	750.00	750.00	750.00
Planting	550.00	550.00	550.00
Post -emergence spray application	350.00	0.00	0.00
LAN application costs	200.00	200.00	200.00
Weeding	500.00	1,000.00	1,000.00
Harvest	312.00	359.00	207.00
Total variable cost	7,313.15	7,457.05	6,279.55
Gross margin (Scenario A)	2,589.73	3,937.61	290.63
Gross margin (Scenario B)	5,166.85	6,902.95	2,000.45

7.4. Discussion

7.4.1. Stem borer and weed incidence in maize fields at different localities

The Majority of non-Bt maize fields that were inspected were infested by *B. fusca* larvae. Although *C. partellus* is a more competitive species than *B. fusca,* it only occurs in specific agro-ecological zones in South Africa while *B. fusca* on the other hand occurs throughout the country (Van den Berg *et al*., 2015), with a tendency to be more important at higher elevations (Calatayud *et al.*, 2014). In a survey of the incidence of stem borer damage in maize fields in the main maize production region of South Africa, Van Wyk *et al.* (2008) reported infestations ranging between 1.0 and 19.7% on non-Bt maize fields. Van den Berg *et al*. (2013) described these infestation levels as typical of those observed in non-GM maize fields prior to the introduction of Bt maize in South Africa. The mean incidence of plants infested per field in 61.5% of areas surveyed in this study were higher than 21%, which is higher than the levels reported by Van Wyk *et al.* (2008). According to Sithole (1987) stem borer infestation levels on maize in smallholder systems are relatively higher than on maize in commercial farms because of the lack of use of chemical control in smallholder systems. Maize stubble from the previous growing season serves as an important source of new infestation of subsequent plantings (Van den Berg *et al.,* 2015). Destruction of crop stubble after harvest is therefore necessary to prevent significant numbers of borer larvae from being carried over between seasons (Fitt *et al*., 2004). However, this strategy is not always practical under African farming conditions where stubble is an important forage resource (Van den Berg *et al*., 1998). In the study areas for instance, owing to the fact that crop residue serves as an important nutrient supplement for grazing animals, it is usually not destroyed following harvest (Chapter 4). This may also possibly explain the high incidence of stem borer damage observed in the survey areas.

About 23.08% of herbicide tolerant maize fields visited within four weeks of the application of herbicides (glyphosate) had a weed incidence rating above 2 (moderately weedy). This indicates some level of weed control failure (Figure 7.5). The use of chemical weed control methods has the potential to significantly reduce the labor requirements for weed control (Mavudzi *et al*., 2001). It therefore has great potential for smallholders (Gianessi & Williams, 2011) in labour constrained markets (Manes, 2013). The labour saving advantage of herbicide tolerant GM maize is particularly relevant for smallholder systems in South Africa and the Eastern Cape, where labour for farming is severely constrained by a high incidence of rural-urban migration and a high HIV/AIDS prevalence rate (DEDEAT, 2013; Stats SA, 2015b) and the advanced ages of farmers (Assefa & Van den Berg, 2009). The effectiveness of herbicides may however be limited by poor timing of application (Gianessi, 2009). In the study area, although extension personnel indicated that the recommendation is to undertake herbicide application when weeds have on average six leaves, owing to limited budgetary allocation for the purchase and payment of contractors for repeated applications, and limited availability of equipment, herbicides are generally applied only once during the cropping season. This is mostly done during the knee height stage of growth during which time weeds have already established. In the case of *Cyperus esculentus* the most dominant weed species in the survey areas, in most instances spraying is undertaken when the weeds have already flowered (Figure 7.5). The incidents of weed control failure observed may therefore be explained on the basis of poor timing of herbicide application and not resistance evolution in weeds to glyphosate, the most commonly used herbicide.

Figure 7.5. Herbicide tolerant maize field infested with weeds. Photos were taken 3 weeks after herbicide application (left slide) and slashing of weeds to cope with herbicide control failure (right slide)

7.4.2. Stem borer infestation on Bt and non-Bt maize under irrigation and dry land conditions

The on-set of stem borer infestation in maize is characterized by the appearance of small ‘windows’ on the youngest whorl leaves (Van den Berg *et al*., 2015). Whorl damage on young maize plants was observed three WAE. *Busseola fusca* oviposition on maize plants typically happens during these growth stages of plants (Van Rensburg *et al.*, 1987b). Comparatively more maize plants cultivated under irrigation showed symptoms of stem borer damage than maize plants cultivated under dry land conditions. Van Rensburg (2007) has stated that stem borer moths have a preference for high humidity conditions as prevails in irrigated fields. More serious infestations may therefore occur under conditions of high precipitation (Van Rensburg *et al*., 1987a). This could therefore explain the relatively high incidence of damage on maize in this system. Generally, plants of the OPV (Okavango) were more infested than plants of PAN 12 and PAN-5Q-649R at all plant growth stages and locations. In a previous study at the Zanyokwe irrigation scheme, Fanadzo *et al*. (2009) reported that Okavango was observed by farmers and extension officers to have an increased susceptibility to stem borer attack after the vegetative stage. Compared to the other varieties used in this study, Okavango has a relatively longer maturity period (Table 7.3). According to Van Rensburg *et al*. (1988a) under similar growth conditions, maize cultivars with long growing seasons are more susceptible to stem borer damage than cultivars with short growing season. This may therefore explain the relatively high incidence of stem borer damage on Okavango.

The incidence of whorl damaged plants determined through visual observation indicated no infestation of Bt plants at any location prior to harvest. This highlights the fact that Bt maize is effective against *C. partellus* (Van Rensburg, 1999; Van den Berg *et al*., 2015) in South Africa and *B. fusca* in the Eastern Cape (Chapter 6). The only incidence of stem borer damage to Bt maize plants occurred at Bhala where about 7.8% of harvested ears showed signs of borer infestation. This may be ascribed to the ability of *B. fusca* larvae to survive on less toxic plant parts not available during the vegetative stages (Van Rensburg, 2001). Visual estimation of the incidence of stem borer damage indicated that more than 10% of non-Bt maize plants at all locations were infested at the vegetative and post flowering stages. The goal of insect pest management is to maintain economically important insect pest species below threshold densities (Van Wyk *et al*., 2007). In South Africa, the accepted threshold for the initiation of control of *C. partellus* is when 40% of plants exhibit whorl damage (Bate & Van Rensburg, 1992). With regard to mixed infestations of *C. partellus* and *B. fusca*, the accepted threshold level is when 10% of plants exhibit whorl damage (Van Rensburg & Bate, 1987). Visual estimation of the incidence of whorl damage necessarily serves as a measure of expected yield loss in economic threshold models (Van Rensburg & Van den Berg, 1992a). Visual estimation of infestation levels are however reported to lead to underestimation (Schulthess *et al*., 1991) or overestimation (Van Rensburg & Van den Berg, 1992a) of the percentage of infested plants compared to actual infestation levels when plants are dissected. It has therefore been noted that visual estimation of stem borer damage are not always the best predictor of larval infestation levels (Krüger *et al.*, 2008).

In the study areas, majority of farmers make a once-off application of insecticides at the knee height stage (Chapter 4). The rationale for this is that the Cropping Programme budget mostly caters for only one mechanized application (herbicide and insecticide) using a tractor-mounted boom sprayer. Insecticide application is therefore undertaken at this time when it is also expected that weeds will be sufficiently established and of optimum size to warrant chemical control. Following insecticide application, there was a marked reduction in the incidence of new plants infested by stem borers at the flowering stage at all locations. In spite of the application of insecticides at the early vegetative stage however, the incidence of stem borer damaged plants increased over time. According to Van Rensburg *et al.* (1988b) the onset of tasseling causes larval migration from the whorl which exposes plant parts below the tassel and neighboring plants to secondary stem borer attack over a relatively short period of time. The increased incidence of damaged plants over time, likely indicates that migrating larvae were able to re-infest plants at the time the effects of the applied insecticide had abated (Van Rensburg & Van den Berg, 1992b). Due to larval migratory behaviour, late or delayed insecticide application, particularly after tasseling of maize has been reported to provide some control of large larvae originating from early infestations (Van den Berg, 1991; Van Rensburg & Van den Berg, 1992c). The strategy of making once-off application of insecticides at the early vegetative stage may therefore have to be revised.

7.4.3. Effect of stem borer incidence and weed management practice on yield of GM and non-GM maize

Stem borer damage symptoms on maize associated with a reduction in grain yield include: whorl damage, dead hearts, and stem tunneling and exit holes (Mwimali, 2014). Stem tunneling damage has been reported as having a greater effect on grain yield than leaf feeding (Kumar, 1997; Singh *et al*., 2012). The level of damage per plant has also been reported to have a greater impact on ear mass than the number of larvae per plant (Van Rensburg *et al*., 1988b). The relationship between yield loss and visible plant damage may however be distorted by the migratory habits of stem borer larvae which exposes plants to secondary damage (Van Rensburg *et al*., 1988b) and differences in compensatory yield between stem borer damaged and undamaged plants (Van Rensburg & Van den Berg, 1992d). Due to these factors, attempts at correlating stem borer damage with grain yield have been generally inconclusive (Van Rensburg & Van den Berg, 1992a). Van Rensburg *et al*. (1988b) reported that yield in maize was inversely correlated with the level of internal plant damage by *B. fusca* larvae. Van Rensburg & Van Hamburg (1975) also demonstrated a positive correlation between infestation level of *C. partellus* and grain yield. Alghali (1985; 1987) however reported no relationship between grain yield and degree of stem tunneling. Van Rensburg & Van den Berg (1992a; 1992d) also reported no correlation between the levels of stem borer infested plants exhibiting whorl damage, or the incidence of different categories of damage and yield of grain sorghum. Similarly, studies conducted by Ebenebe *et al.* (2000) reported that yield losses in local and commercial hybrid maize varieties were generally not proportionate to the incidences of stem borer damage. With the exception of stem tunnel length of PAN 12 which showed significant negative correlation with grain yield, there were no significant correlations between other damage parameters and grain yield in any of the other varieties at all locations. According to Van den Berg & Van

Rensburg (1991), similar infestation levels in plantings with different yield potentials result in significantly different yield losses. Van den Berg & Van Rensburg (1991) have also stated that, high-yielding varieties likely suffer proportionately more yield loss. The stem borer complex under irrigation was largely dominated by *C. partellus*. *Chilo partellus* is also more injurious to maize plants than *B. fusca* (Van den Berg *et al*. 1991a; 1991b). These factors may therefore explain the significant negative correlation between level of stem tunneling and grain yield of PAN 12 plants observed under irrigation.

Provided the timing and thoroughness of either hand weeding or herbicide application (for weed control) are similar, the use of either strategy to control weeds has little or no impact on maize yields (Muoni *et al*., 2013; Tatenda & Stanford, 2013; Ishaya *et al*., 2008). The results of this study suggest that smallholder farmers in the Eastern Cape will not realize any advantages from the use of herbicides, if these are applied at the wrong time. According to Giannesi (2009) the first one-third to one-half of the life cycle of the maize crop is the critical period of crop-weed competition during which weed growth adversely affects crop yield. Keeping the crop weed-free for the first third of its life cycle will usually assure near maximum productivity (Doll, 2003). In the study area however, due to logistical and resource constraints, the initiation of weed control is delayed until six to eight weeks after emergence. Orr *et al.* (2002) recommended keeping maize weed-free for the first eight weeks after planting. Gianessi (2009) suggested that one week's delay in first weed control may reduce maize yields by one-third, and two week's delay in second weed control may reduce maize yields by one-quarter. The inability to obtain any yield advantage from the use of herbicide tolerant maize may therefore be due to the late initiation of weed control using herbicides.

7.4.4. Gross margins of GM and non-GM maize cultivation under irrigation and dry land conditions

Results indicated lower pesticide and labour costs for Bt maize and herbicide tolerant maize across all locations. Insect and herbicide resistance traits by themselves do not increase crop yield potential, they are rather engineered to facilitate crop management with yield being indirectly affected through reducing the risk of losses resulting from pest or weed infestation (Finger *et al*., 2011). Stem borer pressure observed on maize in this study ranged from moderate (dry land conditions) to severe (irrigation). With respect to Bt maize, it was evident that it provided effective protection against stem borers although a significant yield advantage of Bt over the OPV was only obtained under irrigation where stem borer pressure was high. Under dry land conditions, effective control of stem borers by Bt maize did not translate into any yield advantage, probably due to the moderate stem borer pressure observed during the study. With respect to herbicide tolerant maize results indicate that the herbicide tolerant maize variety gave no yield advantage over the conventional hybrid maize or the OPV. In South Africa, Gouse *et al.* (2005; 2006b) reported high yield advantages from Bt maize for smallholders as well as large commercial farmers. In years and at sites with low stem borer pressure however, the advantage obtained from planting Bt maize was negligible or negative (Gouse *et al*., 2006a).

Although stem borer pressure plays a role in the yield advantage of Bt maize, hybrid maize generally gives higher yields than OPVs under optimal or high input conditions (Fischer & Hadju, 2015). OPVs on the other hand are known to perform better than hybrids in below optimum conditions of low rainfall (Belsitio, 2004). In marginal environments or under low input conditions, therefore, the cultivation of hybrids does not give any yield advantage over OPVs (Pixley & Bänziger, 2004; Chiduza *et al*., 1994). Studies in the Eastern Cape Province, indicate that some OPVs are very stable across different stress-prone environments and seasons, and produced yields that were not significantly different from hybrids (Chimonyo *et al.*, 2014). This may therefore partly explain the significant yield advantage of Bt maize over the OPV under only high input irrigation. The relatively high Gross margin obtained from Bt maize under irrigation can be largely ascribed to increased income associated with increased yields (Gouse, 2012a) under this system.

Aside yield, local pest pressure and the ability to make savings that outweigh seed costs, the profitability of GM maize technology is dependent on the price of the commodity derived from the technology (Shelton & Zhao, 2009). Using two price scenarios under which smallholders may sell harvested maize under dry land conditions gave varying gross margins. Under the scenario where farmers have access to markets and the price of maize is based on the SAFEX price, the cultivation of Bt white maize was most profitable owing to savings on pest control and labour costs and the relatively higher SAFEX price of white maize.

Access to markets is a key factor determining whether smallholders can derive benefits from increased yields (Djurfeldt, 2013; Poulton *et al*., 2010) associated with the adoption of new maize technologies. Obi *et al*. (2012) have reported that in situations where smallholders obtain surplus production, lack of access to markets has constrained their ability to benefit from such surpluses. Fischer & Hadju (2015) cited lack of Government support to enable smallholder maize farmers access markets as a key factor for the failure of the MFPP, the immediate past government support initiative in the Eastern Cape to stimulate agricultural growth through increased maize yields (Fischer & Hadju, 2015). Gouse *et al*. (2016) reported that lack of a market for selling the surplus obtained from GM maize varieties was a major deterrent to the cultivation of GM maize by smallholder farmers. The more probable scenario may therefore be the situation where smallholder farmers sell their maize within their local regions. Under this scenario, conventional non-GM hybrid maize (PAN 12) was most profitable owing to lower seed costs and a higher yield under dry land conditions at both Nxanxadi and Bhala. With respect to herbicide tolerant GM maize (PAN-6R-680R), although its cultivation was associated with reduced labour costs, lower yields obtained relative to that of the conventional hybrid (PAN-6480) at both Goso and Galatyeni meant that it gave lower gross margins than that obtained from PAN-6480. Based on the SAFEX price of maize, the value of the output obtained from the OPV was not high enough to cover the cost of production in Goso.

According to Finger *et al.* (2011), in cases where yield increases and the reduction of pesticide inputs outweigh higher seed costs, farmers receive a higher gross margin by growing GM crops. Gouse *et al.* (2006a) reported that despite higher seed costs, adopters of Bt maize obtained increased income over users of conventional varieties through savings on pesticides and increased yield due to improved pest control. Under dry land conditions results of surveys with farmers and extension personnel indicate that the cultivation of Bt maize under the Cropping Programme leads to a comparative increase in insecticide use. Generally, smallholder farmers apply little or no insecticides on OPV maize (Gouse *et al*., 2008; Schimmelpfennig *et al*., 2013; Van den Berg & Campagne, 2014). Results of field surveys and surveys with extension personnel and farmers in the study areas indicate that farmers make at least one application of insecticides on their Bt maize plants during the mid-vegetative growth stages (knee high stage). This appears to be without basis as Bt maize remains effective against the main stem boring pests of maize in the Eastern Cape (Chapter 6). Potential benefits of cultivating GM maize by smallholders may therefore relate only to the ability of Bt maize to limit yield losses and probably enhance the quality of harvested grains. Although mycotoxin infection and content in maize was not explicitly determined in this study, observation of infested maize ears indicated that majority of them had signs of pathogen infection (Figure 7.3). Transgenic hybrids with kernel expression of Cry1Ab protein are reported to reduce stem borer damage which may predispose maize kernels to infection by fumonisin-producing pathogens (Munkvold & Desjardins, 1997; Munkvold *et al.,* 1999). Esophageal cancer in humans has been associated with consumption of maize with high concentrations of fumonisins (Munkvold *et al*., 1999), particularly in the Eastern Cape region of South Africa (Rheeder *et al*., 1992). The consumption of Bt maize kernels may therefore reduce exposure of farmers to certain carcinogens (Pray *et al.*, 2013).

7.5. Conclusions and recommendation

This study suggests that although Bt maize provides effective control of stem borer pests and increased yield and incomes under high input conditions, this does not necessarily translate into similar advantages under conditions prevailing in smallholder systems in the Eastern Cape. With respect to herbicide tolerant GM maize, although it reduced labour input for farming, its cultivation produced no yield benefits to farmers probably due to inappropriate timing of herbicide application. Most smallholders in the Eastern Cape are resource-poor and do not have the capital to provide an optimal farm environment for the cultivation of GM maize. Additionally, the technology fee associated with GM maize seed and co-technologies may impose huge upfront costs that may unduly burden farmers with debt, particularly in seasons with low pest and weed pressure and low amounts of rainfall. In view of these, evidence-based policy making based on the evaluation of the value of existing maize varieties and their profitability under pest and weed management and agronomic conditions prevailing in smallholder systems may enhance the ability of governments, donors, and non-governmental organisations to provide the interventions needed to help farmers access and benefit from cost-effective agricultural technologies. This will allow smallholders to sustainably benefit from promising technologies that are less variable in outcome.

CHAPTER 8: Synthesis and conclusions

8.1. GM adoption challenges in smallholder maize systems in the Eastern Cape Province

This PhD study provides information on the GM maize cultivation experiences of smallhoder farmers participating in the Cropping Programme of DRDAR and possible effects of exposure to Bt maize on the life histories and activities of target and non-target pests of Bt maize. The study also sought to identify potential challenges that may hinder the ability of farmers to obtain full benefits from GM maize technology. Challenges that may obstruct the successful adoption of GM maize technology by smallholder farmers in the Eastern Cape Province are discussed below.

8.1.1. Limited access to information on GM maize technology

The majority of GM maize farmers interviewed in this study obtained maize seed through the public extension system of the Eastern Cape Province (Chapter 4). Most of these farmers generally depended on extension personnel for information on GM maize and its management practices. Interviews with extension personnel however indicated that extension personnel had a low level of awareness about GM maize and its stewardship requirements (Chapter 3). Rabbinge & Löffler (2011) have observed that for farmers to obtain benefits from supposedly good technologies, they must have access to the right information. Mpofu *et al.* (2012) have described extension as a service of information, knowledge and skills development. Extension was reported to have played a crucial role in the diffusion of improved maize technologies to smallholder farmers in all countries where these technologies were widely adopted (Smale *et al.*, 2011). Extension personnel were also observed to rely on one-way print media from GM maize seed companies for the dissemination of GM maize technology to smallholder farmers (Chapter 3).

This was in spite of the fact that the majority of farmers interviewed in this survey had less than seven years of formal education (Chapter 4). In South Africa, farmers with less than seven years of formal education are considered to be functionally illiterate (Stats SA, 2011). The mode of dissemination of information is noted to be as important as the content of the information being disseminated (Kelsey, 2013). Farmers with limited literacy skills may be greatly disadvantaged if information is disseminated through the use of printed media (Ozowa, 1997). The availability of institutions that can provide reliable and timely information to farmers enhances the beneficial adoption and sustainable cultivation of GM crops (Gouse *et al.*, 2005; Smale *et al.,* 2009; Tripp, 2009). The lack of awareness about GM maize technology by extension personnel and the use of one-way dissemination media may therefore adversely affect the potential for smallholder farmers to successful transition from cultivating low yielding varieties to GM maize.

8.1.2. Top-down dissemination of technologies and lack of awareness of alternatives

Most of the farmers interviewed in this study indicated encouragement by extension personnel as the main reason why they decided to cultivate GM maize (Chapter 4). Interviews with extension personnel indicated that only 28% of extension personnel used participatory methods of technology dissemination (Chapter 3). Fischer *et al.* (2015) recently reported an ongoing process to introduce GM maize to smallholder farmers in the Limpopo Province of South Africa without information dissemination. Jacobson & Myhr (2012) and Assefa and Van den Berg (2009) also noted a similar situation in the Eastern Cape. The extension system of South Africa has been reported to dictate the types of inputs that smallholder farmers use (PSPPD, 2011). In this study farmers reported that their participation in the selection of maize varieties was limited to the choice of kernel colour (that is white or yellow maize) (Chapter 4). A participatory approach to technology dissemination enhances farmers' awareness about technologies and builds their capacity to manage such technologies (Abadi Ghadim & Pannell, 1999). Adesina *et al.* (2011) reported that experimentation and use of incremental quantities of inputs such as seeds provide farmers the opportunity to choose technologies based on their assessments of abiotic factors such as rainfall. The opportunity for farmers to utilize agricultural technologies under changing conditions may also result in agricultural skilling (Stone, 2011). Results of on-farm trials conducted during this study in two maize cropping systems indicate that the cultivation of insect resistant and herbicide tolerant GM maize may not be cost-effective under all conditions (Chapter 7). Smallholder maize cultivation is based on the use of OPVs. Although OPVs are reported to yield less than hybrids, unlike GM maize hybrids, they most often produce stable yields (Altieri, 2009; Chimonyo *et al.*, 2014) with low or no use of external inputs (Chiduza *et al.*, 1994). Smallholder agriculture is plagued by a myriad of difficulties including climatic risk, declining soil fertility, pressure to expand food production into more marginal areas owing to population increases, high input costs, extreme poverty, and unavailability of credit systems (Bänziger & Diallo, 2004). Due to these challenges there is a requirement for low cost/risks/input technologies for smallholder farmers (Bänziger & Diallo, 2004). Results of this study suggest that there may be alternative technologies that are less costly and variable in outcome than the GM maize technology that is available to smallholder farmers under the Cropping Programme (Chapter 7). Although such varieties may exist and may be beneficial to farmers, lack of awareness of the value of such varieties may be a major hindrance to their use (Langyintuo *et al.*, 2008). The use of participatory dissemination approaches may therefore afford smallholder farmers the opportunity to select appropriate technologies from a range of available options.

8.1.3. Achieving reductions in pest control costs through increased awareness on non-target pests of Bt maize

Information obtained from farmers during surveys indicated that the adoption of Bt maize generally resulted in a decrease in the use of diversified pest control strategies and an increase in the application of insecticides on maize (Chapter 4). Most of the insecticide applications were reportedly targeted at maize stemborers, cutworms or bollworms and applied to maize plants at the knee height stage. Results of the susceptibility bioassays indicated that Bt maize is highly effective against *B. fusca*, the main stem borer pest of maize in the Eastern Cape Province (Chapter 6). Although data from field trials indicated that the incidence of cutworm damage was not affected by Bt maize, it was observed that cutworms infested maize only during the first four weeks of growth (Chapter 5). With regard to bollworm (*H. armigera*), it was observed that although the incidence of damage was particularly high following flowering, Bt maize significantly reduced the incidence of bollworm damage during all plant growth stages. These observations indicated that the insecticides reportedly applied by farmers at the early vegetative stages (6-8 WAE) were preventative rather than curative (Chapter 4). Hellmich *et al.* (2008) suggested that reduction of insecticide use alongside the maintenance of other traditional IPM tactics represent the best use of Bt maize. The preventative use of insecticides is however at variance with the basic tenets of IPM which suggests that insecticide use may be appropriate when pest populations cannot be suppressed by other strategies. The evaluation of the cost-effectiveness of Bt maize under different cropping systems indicate that the cultivation of Bt maize provides no significant yield advantage compared to the cultivation of OPV maize under dry land conditions (Chapter 7). The ability of smallholder farmers to benefit from the cultivation of Bt maize therefore depend on their ability to make savings on pest control costs. Generally, the cost of Bt maize is about four times that of OPV maize. Additionally, the cultivation of Bt maize comes with relatively higher upfront costs associated with the purchasing of inorganic fertiliser and associated inputs. The main benefits of Bt maize cultivation by smallholders under dry land conditions will therefore depend on the ability of Bt maize farmers to save on pest control input costs. Lack of knowledge of the characteristics of Bt maize and the types of pests it targets can however cause farmers to continue applying insecticides on Bt maize. Increasing the awareness of farmers about pests not targeted by Bt maize and equipping them with the tools to monitor and selectively control such pests when economic threshold levels are reached will greatly enhance the ability of farmers to benefit from Bt maize technology. Acquisition of baseline data on the incidence of these pests will also facilitate the ability to detect changes in the pest status of these non-target species resulting from the effective control of Bt maize target pests.

8.1.4. Refuge compliance

The majority of extension personnel interviewed in this study were not aware of Bt maize stewardship requirements, including the planting of refugia (Chapter 3). None of the farmers interviewed in this study indicated awareness of the requirement for the planting of refuge areas next to Bt maize (Chapter 4). Further, results from surveys in Bt maize cultivating areas indicated that no structured refuge areas were planted alongside Bt maize in any of the areas visited (Chapter 3). The implementation of refuge area planting is a legal requirement that must be satisfied by all farmers that cultivate transgenic Bt maize in South Africa (Monsanto, 2012). The sizes of maize fields in this study ranged from 0.1 ha to 5.0 ha (Chapter 3). Kruger *et al*. (2009) reported that commercial farmers in South Africa ascribed non-compliance to refuge requirements to the small size of their farming units (25-50 ha). Non-compliance to refuge requirements in smallholder Bt maize farms in the Eastern Cape may however be due to lack of awareness of the requirement for the planting of refuges next to Bt maize Kelsey (2013) noted that lack of access to information was particularly detrimental to the efficient use of technologies that are technically complicated and require precise implementation. Cameron (2007) also observed that demonstrations of the value of new technologies can change farmers' attitudes and facilitate their implementation.

8.1.5. Adopting farm practices that enhance *Busseola fusca* IRM in the absence of structured refugia

Populations of *B. fusca*, the main stem borer pest of maize in the Eastern Cape, was found to be highly susceptible to Bt maize (MON810), compared to populations of this pest in other parts of South Africa. The ability to evolve resistance to Bt toxin is a common phenomenon among the Lepidoptera (Tabashnik, 1994). This is particularly so for *B. fusca*, which is reported to be more tolerant to Bt maize events expressing Cry1Ab proteins (Van Rensburg, 1999; Andow *et al.* 2004; Tende *et al.* 2010; Mugo *et al.* 2011), as well as pyramids of Cry proteins (Mugo *et al*. 2005). Meihls *et al.* (2008) reported that resistance to Bt toxin evolved quickly without refuges and slower or not at all with refuges. Resistance evolution of *B. fusca* to Bt maize in South Africa has been partly blamed on non-planting of structured refuge areas which highlights the importance of refugia to transgenic Bt maize IRM (Kruger *et al*. 2011; 2012a). Non-Bt maize fields adjacent to Bt fields have been suggested as an option to structured refuges for Bt maize (Fitt *et al.* 2004; Van den Berg & Campagne, 2014). It has been observed however, that unstructured refuges are an inadequate replacement for structured refuges (Siegfried & Hellmich, 2012). Van Rensburg (2007) reported that prior to Bt maize resistance evolution in *B. fusca*, some farmers in the main maize producing regions of South Africa did not include refugia inside irrigated fields, but considered adjacent non-Bt fields planted under rain fed conditions as sufficient. Kruger *et al.* (2011) later reported that although there was an abundance of unstructured refuges in this region they were ineffective in diluting resistant alleles and delaying the rate of resistance evolution in *B. fusca*.

Smallholder farmers who mostly cultivate seeds of OPV of maize in home gardens in rural areas of the Eastern Cape, generally plant their seeds at least four weeks prior to the planting of Bt maize fields. Bt maize farmers also apply inorganic fertiliser on their maize fields whilst non-Bt maize farmers generally do not (Chapter 4). These differences in planting dates and fertilization of Bt and non-Bt maize may result in differential emergence of moths from Bt maize hybrids and non-Bt refuge varieties at different times, leading to assortative (non-random) mating between resistance and susceptible individuals, consequently weakening the efficacy of non-Bt fields as refuges (Fitt *et al*., 2004; Gustafson *et al.,* 2006; Siegfried & Hellmich, 2012; Van den Berg *et al.* 2013). Several Bt fields visited in this study were also more than 1 km away from home garden in which non-Bt maize, which could potentially serve as sources of susceptible insects, were cultivated. It has been suggested that the influence of the refuge as a source of susceptible insects which can randomly mate with potentially resistant moths from Bt maize fields declines with distance from the main Bt maize field (Tyutyunov *et al.*, 2008; Siegfried & Hellmich, 2012). Due to a low diversity of wild host plants (Le Ru *et al*., 2006a, 2006b; Ong'amo *et al*., 2006; Moolman *et al*., 2014), *B. fusca* has a strong association and reliance on maize (Van Wyk *et al*., 2008). Thus, in areas where adoption rates of Bt maize is high and large non-Bt maize fields are not available within the stipulated distance range, there is the potential for these systems to place strong selection pressure on *B. fusca* for evolution of resistance (Van den Berg *et al*., 2013). In view of this, the planting of maize hybrids of equivalent maturity as Bt hybrids under similar conditions of fertilization, weed and pest management (Hunt *et al*., 2007; Monsanto, 2012) to minimize selection pressures and prevent or at least delay resistance evolution in *B. fusca* should be a high priority (Siegfried & Hellmich, 2012; Van den Berg *et al.*, 2013) in smallholder Bt maize farming systems in the Eastern Cape.

8.1.6. Ensuring the signing of technical agreements

Results of interviews with extension personnel and farmers indicated that neither farmers nor extension personnel signed any technical agreement prior to receiving Bt maize seeds for planting (Chapter 3 and 4). Additionally, farmers were not supplied with seeds of non-Bt maize for the planting of refuges. Furthermore, there was no indication of the enforcement of GM maize technology stewardship requirements in any of the study areas. The successful deployment of a technology can be constrained or facilitated by institutions that support the technology (Horna *et al*., 2013). Kruger *et al.* (2009) reported that the level of compliance by commercial farmers was increased through the institution of stewardship programmes involving farmer education programmes and the signing of technical agreements between seed companies and farmers coupled with on-farm inspections. It has previously been reported that the signing of technical agreements between GM maize seed companies and smallhoder farmers may be constrained by the signing of technical agreements (Jacobson & Myhr, 2012). Smallholder farmers participating in the Cropping Programme receive their seeds from DRDAR, it should therefore be possible for arrangements to be made for the signing of technical agreements. This may however occur with increased enforcement of GM maize technology stewardship requirements in smallholder maize systems of the province.

8.1.7. Diversification of weed control tactics and timely application of herbicides

The majority of farmers relied on herbicide (glyphosate) sprays to control weeds in their fields (Chapter 4). Few farmers supplemented hand weeding with herbicide application for weed control. During surveys, some farmers reported that herbicides had a poor effect on the weeds they wanted to control (Chapter 4). Smallholder farming systems in South Africa are generally labour constrained (Assefa & Van den Berg, 2009; Manes, 2013; Gouse, 2013). The use of labour saving technologies such as herbicide tolerant maize may therefore be beneficial (Regier *et al*., 2012). The use of glyphosate as a sole method of weed control is however not sustainable since it can exert a high selective pressure for the evolution of weed populations dominated by resistant individuals (Brookes & Barfoot, 2016). The potential for weeds to evolve resistance to glyphosate may however not be recognised by farmers until resistant weed biotypes appear in their fields (Johnson *et al.*, 2009). Monitoring of farmers' fields to identify inappropriate herbicide use practices and the initiation of weed resistance management programmes in smallholder settings in the province will be essential in this regard.

It is also important to note that effective use of herbicides requires good timing of applications (Zambrano *et al.* 2013). Thus although herbicide use is reported to be cost-effective and yield higher returns than conventional methods (Muthamia *et al*., 2001), the use of crop stage rather than the incidence of weeds as an indicator for the initiation of weed control (Chapter 7) may limit benefits from the use of the technology.

8.2. Conclusions

Results of this study indicates that the low level of awareness of GM maize technology by extension personnel and the use of non-participatory dissemination approaches may not adequately equip smallholder GM maize farmers with the knowledge to effectively use GM maize technology and also guarantee its long-term sustainability through compliance with stewardship requirements. Inappropriate use practices of GM maize technology can result in adverse environmental effects, notably resistance evolution of target pests and weed species, and adverse effects on non-target organisms. In the present study it was observed that although there was a low level of compliance to Bt maize stewardship requirements, *B. fusca*, the major pest of maize in the Eastern Cape Province still remains susceptible to Bt maize. Similarly, although glyphosate was used as a sole weed control tactic, most farmers reported that it still gave a good level of control over weeds in their fields. With regard to non-target pests, aside effects on *H. armigera,* a species previously reported to be susceptible to Bt toxin, Bt maize had no effect on the pest status of *C. aspersum* and *A. segetum* on maize.

This study also suggests that technologies such as Bt maize may provide higher yields than OPVs under high input conditions. Smallholder farmers in the Eastern Cape are generally characterized as resource poor, they may therefore not have the resources to provide these conditions. Additionally, this study indicated that smallholder farmers' ability to obtain benefits from such technologies may be constrained by their level of education and lack of relevant information or advisory support. Given these challenges and the projected increase in climate variability in the Eastern Cape and South Africa as a whole, more attention will have to be focused on finding low-cost technologies that are better suited to the practices and conditions of smallholder systems and minimizes the risks of smallholder maize cultivation. The evaluation of GM maize technology alongside alternative technologies in participatory trials under farmers' conditions may therefore promote the selective introduction of the technology to smallholder farmers. This, coupled with concerted action that build the capacity of the public extension system and enforces GM maize technology stewardship requirements in smallholder systems in the Eastern Cape, may contribute to the environmental and economic sustainability of the technology.

8.3. Recommendations for future research

This study provided baseline information about the level of awareness of extension personnel and farmers about GM maize technology and the effect of GM maize introduction into the smallholder maize agro-ecosystem on target and non-target pests. A proactive resistance management and non-target risk assessment programme will require continuous research on the effect of Bt maize on target and non-target pests within smallholder systems. Future research should focus on developing IRM strategies that are specific to the conditions and practices of smallholder agriculture. Given the small farm sizes of smallholder farmers, the refuge in a bag concept (Bt and non Bt maize seed mixtures) should be researched as a possible alternative to structured refuges in smallholder systems to address the anticipated problems regarding compliance to current IRM strategies. Weed management in smallholder maize fields will also be greatly enhanced by research into the effect of timing of herbicide application on the management of the dominant weed biotypes in smallholder farming systems in the Eastern Cape. Finally, the identification and up-scaling of indigenous stem borer management technologies that complements currently recommended GM maize target pest resistance management strategies should be prioritized for future research.

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10.0 APPENDICES

Appendix 10.1: Extension personnel's awareness of stewardship requirements and dissemination practices

A. Personal details of Extension personnel

1. Gender? i. Male [ ] ii. Female [ ] 2. Age?......................

3. Level of education?..............................4. Field of specialization?..

5. How long have you been working as an extension personnel ?

i. < 5 years	[ ]
ii. 6-10 years	[ ]
iii. 11-15 years	[ ]
iv. >15 years	[ ]

B. Details of operational area

1. Can you estimate the number of farmers in your area of operation?...

2. How many of these farmers do you oversee in your area of operation?.......................................

3. How many of the farmers you oversee cultivate maize?..

4. What is the average maize farm size?

i. 0 - 0.5 ha [ ]	ii. 0.6 - 1.0 ha [ ]
iii. 1.1 - 1.5 ha [ ]	iv. 1.6 - 2.0 ha [ ]
v. 2.1 – 2.5 ha [ ]	vi. > 2.5 ha [ ]

5a. Are insect pests a major constraint to maize cultivation in this area? i. Yes [ ] ii. No [ ]

5b. If yes please list these pests in order of importance…………….………………………………..

6a. How many GM maize growing farmers ………and conventional maize farmers……….do you oversee?

6.b Do farmers plant both GM and non-GM seed on same [ ] or on separate [ ] fields?

7. How is stem borer infestation on 'project' maize managed in your area?...................................

8. Can you please indicate when …………how……………………and which………………GM maize variety was introduced in this area?

9a. Why do farmers plant GM maize (what is their motivation)……………………………………………………………………….……………

9b. Which of the following do you rate as the most important consideration for GM maize adoption by farmers in your area? Please rank

i. Cost [ ]
ii. Ease of use [ ]
iii. Efficacy [ ]
iv. Availability [ ]
v. Reduction of labour use [ ]
vi. Environmental and food safety concerns [ ]
vii. Yield potential [ ]
viii. Recommendation by extension agent [ ]
ix. Recommendation by GM seed company [ ]
x. Other (please specify) [ ]

10. What advantages do farmers in this area derive from GM maize (Bt [ ] RR [ ] BR [ ]) cultivation? ……………………………………………………………………………………

C. GM maize technology dissemination

1a. Did you receive any GM maize technology training before becoming involved in GM maize technology dissemination? i. Yes [ ] ii. No [ ]

1b. If yes, did the training continue after you got involved in GM maize technology dissemination? i. Yes [ ] ii. No [ ]

1c. If yes (1b) how often do you update your knowledge on GM maize technology?........................

2. Do you think the knowledge obtained is sufficient to enable you disseminate GM maize technology effectively to farmers in your area? i. Yes [ ] ii. No [ ]

3. On the average, what percentage of your annual extension schedule is devoted to GM maize technology dissemination?

i. 5 – 10 % [ ]
ii. 11 – 20 % [ ]
iii. 21 – 30 % [ ]
iv. 31 – 40 % [ ]
v. 401– 50 % [ ]
vi. > 50 % [ ]

4a. Who is responsible for GM-maize seed distribution in your area?...

4.b Where do farmers buy their GM maize seed?...

4c. Is any agreement signed before GM seeds are received by farmers in your area?
i. Yes [ ] ii. No [ ]

5. Which seed types do farmers in your area of operation currently grow?

i. Bt-maize [ ] ii. Round Up Ready maize [ ] iii. Stacked trait GM maize (BR) [ ] iv. OPVs [ ]

6. Why do farmers in this area grow this GM maize type?

i. My recommendation [ ]
ii. GM seed Company's recommendation [ ]
iii. Easy to obtain [ ]
iv Other reasons [ ]

7. Is GM maize seed available for planting on time? i. Yes [ ] ii. No [ ]

8a. What mediums do you use to disseminate GM maize technology? Please tick as many as possible

i. Pamphlets/manuals [ ] ii. Video [ ]
iii. Demonstration plots [ ] iv. Other (specify)…………………..

8b. Who produces these dissemination mediums?

i. DAFF [ ] ii. GM seed company [ ]
iii. NGOs [ ] iv. Other (specify)…………………

9a. Is the cultivation of GM maize in your area done in accordance with any legal regulations?

i. Yes [ ] ii. No [ ]

9b. If yes please provide specific details of these regulations…………………………………..….

10a. Do you know of any specific requirements that farmers must adhere to if they plant Bt maize? i. Yes [ ] ii. No [ ]

10.b Do you know about the planting of a refuge area next to Bt maize?

i. Yes [ ] ii. No [ ]

11a. Do you receive any GM-maize related complaints from farmers?

i. Yes [ ] ii. No [ ]

11b. If yes, please provide details…………………………………………………………………

12a. Are you aware of any farmers who have stopped growing GM maize?

i Yes [ ] ii. No [ ]

12b. If yes what were the main reasons they assigned for discontinuing with GM maize cultivation?

i. Costs	[ ]
ii. Restrictions on seed recycling	[ ]
iii. Erratic rainfall	[ ]
iv. Limited supply of seeds	[ ]
v. Low incidence of pests	[ ]
vi. Resistance development	[ ]

vii. Other (Please specify……………………………………………………………………….

D. GM maize technology perceptions and attitudes

1 Maize stem borer infestation influences farmers' decision to adopt Bt/BR maize in this area
i. I agree [ ]　ii. I disagree [ ]　iii. I do not know [ ]

2. GM-maize technology extension in this area can be enhanced by additional training of extension agents.
i. I agree [ ]　ii. I disagree [ ]　iii. I do not know [ ]

3. Bt/BR maize technology in this area has eliminated stem borer problems on adopting farmers' fields　i. I agree [ ]　ii. I disagree [ ]　iii. I don't know [ ]

4. Bt/BR maize cultivation on smallholder farms poses no potential negative effects to local maize varieties in this area
i. I agree [ ]　ii. I disagree [ ]　iii. I don't know [ ]

5. More smallholder farmers should be encouraged to adopt and cultivate GM-maize.
i. I agree [ ]　ii. I disagree [ ]　iii. I don't know [ ]

Thank you!

Appendix 10.2: Smallholder farmers' awareness of GM maize technology, management practices and compliance to stewardship requirements in the Eastern Cape Province of South Africa

A. House hold information

1. Gender? a. Male[ ] b. Female [ ]

2. Age in years? …………………………………………………………………………………..

3. Highest level of education?
a. Grade 1-4 [ ] b. Grade 5-8 [ ] c. Grade 9-12 [ ]
d. Tertiary [ ] e. Other, specify……………………………..….

4. Please indicate your language abilities

i. English:	speak [ ]	read [ ]	write [ ]
ii. Xhosa:	speak [ ]	read [ ]	write [ ]
iii. Other (specify).	speak [ ]	read [ ]	write [ ]

5. How many family members do you have? a. 1-3 [ ] b. 4-6 [ ] c. >6 [ ]

6. How many assist you in your farming? a. 1 [ ] b. 2 [ ] c. 3 [ ]
d. 4 [ ] e. >4 [ ] f. None [ ]

7. Could you please indicate the type of land you have for farming?
a. Permit to occupy [ ] b. Private ownership [ ] c. Rented land [ ]
d. Other (specify)…………………………………………………………………………...

8. What is the total size of your farm?...

9. How much of your farm is under maize cultivation?..

10. For how long have you been cultivating maize?...

B. GM maize *(**Round-up Ready Bt and BR maize**)* knowledge and adoption practices

1. Have you ever heard of GM maize? a. Yes [ ] b. No [ ]

2. If yes, how did you get to know about GM maize? ……………………………………………..

a. Extension services (DAFF) [ ] b. Neighbour [ ] c. NGOs [ ]
d. Colleague farmer [ ] e. Other (specify)….........................

3a. When (year) was the first time you cultivated GM maize?..

3b. Was it Bt maize [ ] b. Roundup Ready (RR) maize [ ] c. Stacked gene BR maize [ ]

4. What size of your farm is currently allocated to GM maize production?.................hectares

5. Why did you decide to grow GM maize? (Please rank in order of importance)
    a. Observation of their performance on demonstration trials on other farmers' field [ ]
    b. Motivation by (Project) extension service [ ]
    c. Motivation by NGOs [ ]
    d. Influence by neighbours [ ]
    e. Other, please specify..

6. What are the advantages of the GM maize types (Bt [ ] BR [ ] RR [ ]) you currently grow?...

7a. Where do you obtain you GM maize seeds from?..

7b. Is the seed bag labelled with accompanying specific documentation indicating that it is GM maize seed? a. Yes [ ] b. No [ ]

8. Did you sign any agreement before receiving the seeds? a. Yes [ ] b. No [ ]

9. Did you share the seed with family members or neighbours during the last 2 seasons?
a. Yes [ ] b. No [ ]

10. What other varieties of maize did you grow last season? ....

11. Did you plant GM maize and the other maize varieties on the same field last year?
a. Yes [ ] b. No [ ]

12a. Do you obtain information about GM maize? a. Yes [ ] b. No [ ]

12b. If yes, from which source?...

13a. Are you satisfied with the information you receive? a. Yes [ ] b. No [ ]

13b. What is your preferred mode of GM maize information delivery..

14a. Have you ever received any training on how to cultivate GM maize?
a. Yes [ ] b. No [ ]

14b. If Yes, who organized the training…………………………………………………………

15. How frequent was it?..................and what was the subject of the training...

16a. Are you aware of any rules or regulations to follow when planting GM maize?
a. Yes [ ] b. No [ ]

16b. if yes, what are the recommended regulations?..

17.a Do you follow any of these rules and regulations you have stated above (16b)?
a. Yes [ ] b. No [ ]

17b. If no, please indicate if any of the following has an effect on you not following these rules/regulations

a. Shortage of labour	[ ]	b. Shortage of land	[ ]
c. Lack of education/knowledge	[ ]	d. Lack of perceived benefits	[ ]
e. Lack of funds	[ ]	f. Other (specify)……………………………	

C. Extension contact

1. What level of contact do you have with the extension service at the moment?
a. High [ ] b. Low [ ] c. No contact [ ]

2. What was the level of extension contact before you adopted GM maize?
a. High [ ] b. Low [ ] c. No contact [ ]

D. Pest and weed management practices

1a. Did you have any pest management problems on your maize field before you adopted GM maize? a. Yes [ ] b. No [ ]

1b. If yes, what were the most important pests?...

2a. What crop growth stage was most affected?...

2b. How were you managing these pests...

3. Did you experience any pest problems on your maize field last season? a. Yes [ ] b. No [ ]

4. Did you plant Bt/BR maize varieties on your field last season? a. Yes [ ] b. No [ ]

5a. Did you make use of any insecticide sprays on your BR/Bt field last season?
a. Yes [ ] b. No [ ]

5b. If yes, against which pests...

6. Where did you obtain your insecticides from?..

7. How often did you have to spray to control these pests?...

8. Which crop stage was most affected……………………………………………………………..

9a. Have you noticed any new pest problem that was not there before the coming of Bt/BR maize? a. Yes [ ] b. No [ ]

9b. If yes, please specify…………………………………………………………………………

10. After harvesting, how do you dispose off your crop residue?
a. Left on the field to rot [ ]
b. Fed to livestock [ ]
c. Used as fuel wood [ ] other, please specify...............................

11a. Did you experience any weed problems on your maize farm last season?
a. Yes [ ] b. No [ ]

11b. If yes, what is your overall assessment of the weed incidence in your GM maize field compared to your conventional maize fields
a. Normal [ ] b. High weed incidence [ ] c. Low weed incidence [ ]

11c. How did you cope with these weed problems...

12. Did you spray herbicides to control any weeds on your field last season?
a. Yes [ ] b. No [ ]

13a. Did you plant Roundup Ready (RR) maize cultivars on your field last season?
a. Yes [ ] b. No [ ]

13b. Have you ever sprayed herbicides on these fields where you planted Roundup-Ready maize? a. Yes [ ] b. No [ ]

14. How would you rate the level of weed control by herbicides on your field last season?
a. Very good [ ] b. Good [ ] c. Weak [ ] d. Don't know [ ]

15a. Has there been any change in the amount of labour you use for pest/weed management since you adopted GM maize? a. Yes [ ] b. No [ ]

15b. If 'yes' what kind of change has it been?
a. Increase in the amount of labour [ ] b. Decrease in the amount of labour [ ]

16. Please give the reason(s) for this change?...