The effect of water volume and dosage rate on the efficacy of Break-Thru S240 for stem borer control

O. Slabbert

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Study leader: Prof. J van den Berg

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ABSTRACT

Title: The effect of water volume and dosage rate on the efficacy of Break-Thru S240 for stem borer control.

The two most prominent stem borer species responsible for damage to maize in South Africa are the African maize stem borer, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) and spotted stem borer, *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae). Chemical control of stem borers is particularly important because these pests may cause yield losses of up to 80 % on individual fields. Cryptic feeding, overlapping of generations and recurrence of infestation of the same planting at later crop growth stages are some of the factors hampering effective chemical control of these pests. In some situations *C. partellus* and *B. fusca* may occur as mixed populations in the same planting which complicates chemical control. Water volume and the correct insecticide dosage rate are two crucial aspects of chemical control. The addition of organo-silicones to insecticide spray applications may increase the efficacy of such sprays applied for stem borer control. The aim of this study was to determine the effect that the tank-mix organosilicone Break-Thru S240 has on the efficacy of insecticides applied for control of stem borers in maize and to evaluate the effect of this adjuvant on movement of spray applications into whorls of maize plants. Field trials were conducted between January 2007 and May 2008. Maize plants that were used were in the whorl stage approximately five weeks after emergence. All applications were done by means of a CO_2-presurised knapsack sprayer and were directed into the whorls of plants. Prior to this study the feeding site of stem borer larvae inside plant whorls was described as "deep inside" the whorl or in the "yellow-green" area of whorl leaves. The position of larval feeding damage caused by *B. fusca* and *C. partellus* in whorl leaves was similar. Leaves 3 and 4 made up the largest proportion of damaged leaves and any application that moves further than the 80 and 70 % distances on leaves 3 and 4 respectively, can be considered to be successful. Break-Thru S240 and Agral was superior to other tank-mix adjuvants that were tested. The addition of Break-Thru S240 to different insecticides applied against *C. partellus* resulted in an increase in efficacy, measured in terms of larval mortality, of between 14 and 58 % for the insecticides. However, Break-Thru S240 did not result in increased efficacy of systemic insecticides, measured over the 14-day period. The efficacy of insecticides applied against *B. fusca* decreased from 98 % on day 2 to 30 % on day 14. The effect of Break-Thru S240 on the distance of movement of spray applications down into whorl leaves were determined by applying different dosages of the organo-silicone at a single water volume as well as applying the organo-silicone at a single dosage with different water volumes. This resulted in increased movement of 9 and 12 % compared to the control treatment respectively when Break-Thru S240 was applied at the registered dosages of 100 and 200 ml ha^{-1}. The addition of Break-Thru S240 to water volumes of 100 and 200 l ha^{-1} resulted in an increase in the distance of movement down whorl leaves of 12.5 % compared to 50 l ha^{-1}. This study provided data on the effect of Break-Thru S240 on spray applications that will be used for product registration purposes.

Keywords: *Busseola fusca*, *Chilo partellus*, chemical control, organo-silicones

OPSOMMING

Titel: Die effek van watervolume en dosis op die effektiwiteit van Break-Thru S240 vir stamboorderbeheer.

Die twee belangrikste stamboorderspesies wat mielies in Suid-Afrika aanval is die mielie-stamboorder *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) en die Chilo-boorder *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae). Chemiese beheer van hierdie twee stamboorderspesies is besonder belangrik omrede hierdie plae opbrengsverliese van tot 80 % op individuele mielielande kan veroorsaak. Die verskuilde voedingswyse, oorvleuelende generasies en die herbesmetting van dieselfde aanplanting op latere groeistadiums is slegs 'n paar faktore wat die effektiewe chemiese beheer van stamboorders bemoeilik. In sekere gevalle kan *C. partellus* en *B. fusca* as gemengde populasies in dieselfde aanplantings voorkom en dit bemoeilik chemiese beheer nog verder. Watervolume en die korrekte dosis insekdoder is twee van die mees kritieke aspekte van chemiese stamboorderbeheer. Die byvoeging van organo-silikone tot insekdodertoedienings kan bydra tot verhoogde effektiwiteit van hierdie middels wanneer dit vir stamboorderbeheer toegedien word. Die doel van hierdie studie was om te bepaal wat die effek van die organo-silikoon, Break-Thru S240, is op die effektiwiteit van insekdoders wanneer dit toegedien word teen stamboorderinfestasies. Veldeksperimente is gedoen tussen Januarie 2007 en Mei 2008. Alle mielieplante wat gebruik is, was in die kelkstadium en ongeveer vyf weke na opkoms. Bespuitings is gedoen met behulp van 'n CO_2-druk rugsakspuit en die toediening was in die kelke van die plante gerig. Voor die aanvang van hierdie studie is die sone van stamboorderskade slegs as "diep binne" of in die "geel-groen" gedeelte van die kelk beskryf. Die posisie van vreetskade op die kelkblare was bykans identies vir *B. fusca* en *C. partellus*. Blare 3 en 4 van die kelk het die meeste skade getoon het en enige insekdoder wat op hierdie twee blare dieper as 80 en 70 % van die blaar lengte beweeg, kan as suksesvol beskou word. Verhoogde afstand van beweging is verkry deur die byvoegmiddels Break-Thru S240 en Agral in vergelyking met die res van die byvoegmiddels. Die byvoegging van Break-Thru S240 tot verskilende insekdoders teen *C. partellus* het 'n verhoging in die effektiwiteit van die verskillende insekdoders van tussen 14 en 58 % gehad. Break-Thru

S240 het egter nie 'n effek op die effektiwiteit van insekdoders teen *B. fusca* oor die 14-dae periode gehad nie. Die effektiwiteit van hierdie insekdoders het afgeneem van 98 % op dag 2 tot 30 % op dag 14. Die effek van Break-Thru S240 op die afstand van beweging van die spuittoedienings teen die kelkblare af is bepaal deur verskillende dosisse van die organo-silikoon (0, 50, 100, 200, 400 en 600 ml ha^{-1}) teen 'n enkele watervolume toe te dien asook 'n vasgestelde dosis van die organo-silikoon teen verskillende watervolumes (2 en 3 l 100 m^{-1}). Die toediening van Break-Thru S240 teen die geregistreerde dosisse (100 en 200 ml ha^{-1}) het tot 'n verhoging van tussen 9 en 12 % in die afstand van beweging af in die kelkblare gelei in vergelyking met die kontrole behandeling gelei. Die byvoeging van break-Thru S240 tot verskillende watervolumes (0.5, 1, 2, 3 en 6 l 100 m^{-1}) het gelei tot 'n verhoging in die afstand van beweging teen die kelkblare van die plant af, van 12,5 % in vergelyking met die 0.5 l 100 m^{-1} toediening. Hierdie studie verskaf data rakende die effek van Break-Thru S240 op insekdodertoedienings wat gebruik sal word vir produk-registrasiedoeleindes.

Sleutelwoorde: *Busseola fusca*, *Chilo partellus*, chemiese beheer, organo-silikone

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CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

The two stem borer species largely responsible for damage to sorghum and maize in South Africa are the African maize stem borer, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) and the Chilo borer, *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) (Kfir *et al.*, 2002).

Insecticides currently registered for curative control of these stem borers on maize are all intended for whorl application (Nel *et al.*, 2002). Chemical control of stem borers in South Africa is particularly important because yield losses of up to 80 % can occur in individual fields of maize and sorghum. The potential area for stem borer insecticide application on maize and sorghum in South Africa is approximately 2 million and 100 000 hectares respectively. Van den Berg and Nur (1998) estimated that the potential market for stem borer insecticides in South Africa was approximately $US 7 million. De Groote (2001) reported stem borer induced yield loses in Kenya ranging between 34 - 43 % with a total value of US$ 76 million. Van Rensburg (1999) reported yield losses up to 100 % in conditions favouring stem borer population increases in South Africa. Adeyemi *et al.* (1966) reported yield loss of 5 % for every 10 % attacked plants in south western Nigeria.

Effective chemical control of stem borers is hampered by the cryptic feeding of larvae deep inside plant whorls. Insecticide applications into plant whorls often do not reach these larvae due to poor insecticide movement downwards into whorl leaves. Further complications in the chemical control of *C. partellus* is the overlapping of generations due to staggered pupation (Kfir, van Hamburg & van Vuuren, 1989) and the recurrence of infestation of the same planting at later crop growth stages (Van den Berg & Van Rensburg, 1992). In some situations *C. partellus* and *B. fusca* may occur as mixed populations in the same planting (Van den Berg, 1997a). Such mixed populations complicate chemical control in that the infestation patterns of these stem borer species are different (Van den Berg & Van Rensburg, 1996). Once larvae bore into stems, they can not be reached by any spray application of insecticides. Van den Berg and Van Rensburg (1992) found that monocrotophos was effective in stem borer control, however, the withdrawal of this systemic insecticide from the world market further reduced the options for effective chemical control of stem borers in maize.

The target area where stem borer larvae feed on the tightly rolled furl leaves inside the whorl is below the so-called "dew-line" of the maize plant. Very often liquids such as rain, dew or spray formulations of insecticides do not penetrate into the tightly rolled furl leaves, due to high surface tension. After an insecticide application has dried on maize whorl leaves, it spatially moves away from the target area over time as leaves grow out of the whorl. The insecticide is then no longer present in the target area where stem borer larvae feed. Contact between larvae and insecticides are therefore reduced over time since the larvae do not move outside of the whorl until 10 – 14 days after they started feeding in plant whorls. The result is that chemical control of these species is often uneconomical or ineffective (Van Rensburg & van Hamburg, 1985).

The volume of water required per hectare to ensure high efficacy of insecticides applied for stem borer control, plays a important role. When insecticides are applied using a tractor-mounted sprayer approximately 300 litres of water ha^{-1} is applied. With aerial applications, only 30 - 40 litres of water per hectare are used (Van den Berg & Van Rensburg, 1996). This low volume of water used during aerial application is often considered insufficient to reach stem borer larvae deep inside plant whorls.

When using insecticides with a contact mode of action it is important that the leaf or target area should be reached and covered uniformly in order to ensure optimal efficacy. One of the ways that stem borer control could be improved is by increasing the downwards movement of insecticides into the whorls of plants. Van den Berg and Van Rensburg (1996) indicated that whorl application was superior to applications with drop arms against stem borers during the pre-flowering period of maize and sorghum. It was further emphasized that the plant whorl should be targeted during insecticide applications. Two of the requirements for effective stem borer control in maize and sorghum are the persistence of the insecticide on the leaf itself, as well as good whorl coverage by the insecticide (Van den Berg & Van Rensburg, 1992, 1993).

1.2 Approaches to chemical control of stem borers in maize and sorghum

According to Jotwani (1982) chemical control is considered the heart and sole of integrated pest management. However, the use of insecticides is widely criticised in various ways although the limitations and disadvantages have been highlighted from time to time. Such disadvantages arise due to misuse, untimely use, over-dosages or the unnecessary use of chemical insecticides (Jotwani, 1982). The popularity of chemical insect control is due to their spectacular and rapid action, against a generally wide host range. However, the application methods of such chemicals require a good knowledge of the specific pest's life history, peak period of activity, and the stage in the lifecycle where the insect is most vulnerable (Kishore, 1989).

Pest status is essentially an economic concept, for example whether or not and to what extent an insect causes sufficient damage to crops to necessitate control measures (Kumar, 1984. Cited by Bell & McGeoch, 1996). The pest status of an insect should therefore be determined by the extent of yield losses it causes and the cost of control measures for that specific pest (Bell & McGeoch, 1996).

Based on the amount of previous research done, Bell and McGeoch (1996) determined the pest status of lepidopterous insect pests of cultivated plants and crops in South Africa. The latter authors calculated the pest status for lepidopterous pests and compared it to a similar study by Moran (1983), 15 years earlier. A summary of the importance of these stem borer species is provided in table 1.1.

Table 1.1. The pest status as well as the rank of importance of the three stem borer species that attack maize in South Africa

Species	Rank (Moran, 1983)	Rank (Bell and McGeoch, 1996)
Busseola fusca	2nd	4th
Chilo partellus	17th	6th
Sesamia calamistis	4th	8th

The pest status value and the ranking of *B. fusca* remained amongst the top four Lepidoptera on crops in South Africa and remained the most important stem borer on maize between 1983 and 1996. Van Rensburg (1999) described *B. fusca* as one of the most serious pests of maize and sorghum. What is troubling though, is that both the pest status and the ranking of *C. partellus* showed a drastic increase during the same period. Van Rensburg (2000) ascribed this increase in importance to the increase in the geographical distribution of *C. partellus*. Although these rankings are more than ten years old it shows the importance of stem borers on maize and sorghum in South Africa. *Chilo partellus* has been reported to increase in importance because it is displacing *B. fusca* from its indigenous areas (Kfir, 1997) resulting in a possible higher pest status than during the mid 1990's.

According to Van den Berg and Drinkwater (2000) *Sesamia calamistis* (Hampson) (Lepidoptera: Noctuidae) is becoming an increasingly important pest, especially under pivot irrigation systems, in the inland regions of South Africa. *Sesamia calamistis* occurs throughout the northern parts of South Africa where maize is planted (Overholt *et al.*, 2001).

1.2.1 *Chilo partellus*

Because of the relatively short life cycle of *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae), there may be as many as four to five moth flights per season. Periods of high moth-flight activity takes place during October, mid- November until mid-December and from the end of January until the first week in May (Bate *et al.*, 1990; Van den Berg, 1997b; Van Rensburg, 2000). In the main maize producing parts of the country, first generation *Chilo* moths originate from over-wintering larvae (Van Rensburg, 2000). These moths lay their eggs on early planted maize and sorghum, causing early infestation of these crops within two weeks after emergence. This second generation may cause infestation in later plantings of maize and sorghum. Larvae of different generations and different sizes might be found in the same plantings because of these overlapping generations (Van Rensburg, 2000).

Chemical control of *C. partellus* is effective when applied during the period of egg hatching and occurrence of the first three instars. Thus, insecticides should be applied when the larvae are still in the whorl and before they enter the stem (Ganguli *et al.*, 1997). Chemical control against *C. partellus* and *B. fusca* should only take place when the Economic Injury Level (EIL), set at 10 % leaf damage, is reached (Van den Berg, 1997a, Van den berg & Nur, 1998). Any applications before this might result in economical losses (Van Rensburg, 2000). According to Bate and Van Rensburg (1992) the Economic Threshold level (ETL) for chemical control of *C. partellus*, in commercial maize, is reached when 40 % of the plants show symptoms of larval feeding in the whorls.

In studies conducted by Van den Berg and Van Rensburg (1996) insecticides applied at early plant growth stages did not prevent reinfestation of *C. partellus* in the same planting. However, a single application during the flag-leaf stage gives optimum results at low infestation levels. A general rule of thumb for effective control of *C. partellus* in case of early plantings (before 15th November) is that insecticides must be applied at late growth stages of the plant and in case of late plantings (after 15th November) an early insecticide application is needed with the possibility of a follow-up application (Van den Berg, 1997a).

Ganguli *et al.* (1997) conducted efficacy studies on five insecticides applied against *C. partellus* namely cypermethrin, deltamethrin, endosulfan, triazophos and carbofuran in the leaf whorl. The order of efficacy of these insecticides were deltamethrin > cypermethrin > endosulfan (Ganguli *et al.*, 1997). These results confirm those of Van den Berg and Van Rensburg (1996) that pyrethroids were highly effective for control of *C. partellus*.

1.2.2 *Busseola fusca*

Because of the longer life cycle of *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) there are only three main moth flights per season spaced approximately nine weeks apart. However, because of low temperatures on the eastern highveld, only two moth flights occur per season with an even greater time interval between the two flights (Van

Rensburg *et al.*, 1985). This second moth flight, which occurs between the beginning of January and the end of February (Van den Berg, 1997b), is always considerably larger than the first which takes place during the middle of November and the first week of December (Van den Berg, 1997b). Late planted maize is generally more severely infected than early plantings (Van Rensburg, 1999) showing that differences in time and size of the moth flights respectively will be affected by the planting date of crops. *Busseola fusca* only infests plants over a limited range of growth stages in the pre-flowering stage meaning that reinfestation of the same planting occurs only to a very limited extent (Van Rensburg & Van den Berg, 1992).

The ETL for *B. fusca* is also set at 10 % whorl damage for both maize and sorghum, and, if timed correctly insecticide application can be very effective (Van Rensburg, 1999; Van den Berg & Nur, 1998). In a study conducted by Van Rensburg and Van den Berg (1992) it was found that the number of *B. fusca* larvae on sorghum was reduced more successfully with early insecticide applications than with late applications. With the application of a spray mixture of endosulfan 35 % EC and deltamethrin 2,5 % EC sprayed at a dosage of 7,5 and 0,4 ml 100 m^{-1} respectively, it was found that in maize, where *B. fusca* predominated, the timing of insecticide application was less important than with *C. partellus* (Van Rensburg & Van den Berg, 1992).

1.2.3 *Sesamia calamistis*

One of the biggest constraints to development of effective control measures against *Sesamia calamistis* (Hampson) (Lepidoptera: Noctuidae) is the fact that there is no visible damage to the whorls of plants to indicate the presence of infestations. This is due to the direct penetration of the first instar larvae into stems from behind leaf sheaths (Van den Berg & Drinkwater, 2000).

Various insecticides such as pyrethroids and organophosphates are registered for control of *S. calamistis* on sweet-corn (Van den Berg & Drinkwater, 2000). In sweet corn programme application of insecticides is done and sprays are directed onto the stems. This takes place two weeks after emergence and is then repeated every two weeks until after the flowering period. When maize ears emerge, insecticide applications should be directed onto the ears (Van den Berg & Drinkwater, 2000). Egwatu and Ita (1982) found that a single application of carbofuran, at planting, adequately reduced the number of *S. calamistis* on maize.

Economically important *S. calamistis* infestations of maize under dry-land conditions are rarely reported. Although there might be some larvae present in fields, the populations are usually low and damage is usually only detected on the ears of the plants (Van den Berg & Drinkwater, 2000).

1.3 Potential advantages and disadvantages of chemical control

It is widely agreed on that insecticides are essential tools in pest management. However, the misuse, overuse and unnecessary use of any insecticide must be avoided at all costs (Metcalf, 1980). For chemical control to be environmentally acceptable there must be a broad-based holistic approach to insect pest management. Integrated Pest Management (IPM) is one of the best known and probably the only environmentally acceptable pest control strategy in agricultural systems (Deedat, 1994).

The initial function of pesticides was to increase the production of food supply and protecting the health of people and the environment. These goals have largely been met, however, some undesirable side effects that had serious impacts on the use of insecticides have been reported (Deedat, 1994).

1.3.1 Adverse effects on non-target species

All insects have natural enemies that, in addition to weather and food supply, cause a reduction in population densities. This process, unaided and often unrecognized by man, is known as natural control. It is important to recognize the impact of natural control factors and, where possible, encourage its implementation and action. Biological control is the use of natural enemies to control insect pests. Today, biological control plays an increasingly important role in IPM programs for agriculture as well as for urban environments (Knutson & Michels, 2004; Van den Berg & Nur, 1998).

Some insecticides such as carbaryl, dichloro-diphenyl-trichloroethane (DDT) and carbofuran have a broad-spectrum activity against a variety of animals and insects, and had been widely used against most of the known insect pests. In almost all situations of intensive insecticidal treatment in fields or any other agricultural system, treatments resulted in "biological deserts" where all insects as well as their biological control agents were destroyed by such insecticides (Deedat, 1994). These high application levels of insecticides may induce the rapid resurgence of target pests in the absence of their natural enemies as well as a selection of other secondary pests that were also previously controlled by natural enemies (Deedat, 1994).

1.3.2 Direct and indirect hazards of insecticide use and insecticide residues

The use of insecticides in modern agriculture is based on the deposition of toxic persistent residues. With regard to many insecticides, persistence is an advantageous attribute, however, it could not be utilized without negative effects on the environment. Many insecticides are highly persistent and non-degradable. High levels of such insecticides are detectable in the air, water and soil. Exposure of humans and non-target organisms to such insecticides might have a negative effect on their health. Conditions of cancer as well as mutagenic effects may occur in humans as a result of such over exposure (McEwen & Stephenson, 1979, cited by Deedat, 1994; Van den Berg & Nur, 1998).

1.3.3 Insect resistance to insecticides

In many farming systems, chemical control is being used with great relief to farmers. Insecticides are very effective in controlling arthropod pests. There is, however, the disadvantage that the timing of application must be accurate in order for the insecticide to be most effective (Stern *et al.*, 1959). Over the past few years a huge problem regarding the application of insecticides became evident. Some insect pests have developed resistance to these insecticides due to rapid life cycles, gene plasticity and the repetitious use of the same insecticides in successive growing seasons (Van den Berg & Nur, 1998).

Other studies reported that the application of insecticides as control method gave conflicting results in increasing yield (Harris, 1962). Such genetically acquired resistance of insects to insecticide toxicity continues to be an evident obstacle in the successful use of insecticides in agricultural systems (Metcalf, 1980). The general assumption is that successful insecticide applications against pests in commercial crops should take place with the first signs of damage to the crops (Van Rensburg *et al.*, 1988). However, when the cost to benefit ratio of insecticide applications is taken into consideration, the number of eggs or larvae per plant give a much better indication to when insecticides should be applied in order to enhance the efficacy of the insecticide against *B. fusca* on maize (Van Rensburg *et al.*, 1988).

It was pointed out by Hall and Norgaard (1973) that a fixed quantity of insecticide will kill a larger number of insects when the pest population density is greater. The decision to spray is furthermore hampered by the presence of more than one insect species on the crop. Factors such as inter-relationships between the pests, beneficial predator and parasitic species, the persistent toxicity of some insecticides, resistance of plants to pests and the availability of food all contribute to the growth rate of a pest population (Hall & Norgaard, 1973).

1.4 Stem borer biology and its interaction with maize

1.4.1 *Chilo partellus*

The spotted stem borer *C. partellus* was first reported in Africa during the 1930's in Malawi (De Groote, 2001). The presence of *C. partellus* in South Africa was first reported in 1958 (Van Hamburg, 1979). This species originated from Asia where it is considered a pest of both maize and sorghum. Since the first reports of the presence of this pest in Africa, it has spread to most countries in sub-Saharan Africa, except for West-Africa (Overholt *et al.*, 2001). Figure 1.1 indicates the countries in southern and eastern Africa where *C. partellus* occurs. Overholt *et al.* (2001) used GIS mapping systems to predict the potential distribution area of *C. partellus* in Africa. In recent years *C. partellus* become more important in maize production in South Africa due to an increase in its geographical distribution (Van Rensburg, 2000).

Although *C. partellus* is absent in the cooler eastern and western parts of the South African Highveld, it is more common in the warmer north-western parts of the country. Larval feeding activity may occur throughout the year in the sub-tropical parts of the Limpopo Province, Mpumalanga as well as in the Makatini-flats of Kwazulu-Natal (Van Rensburg, 2000).

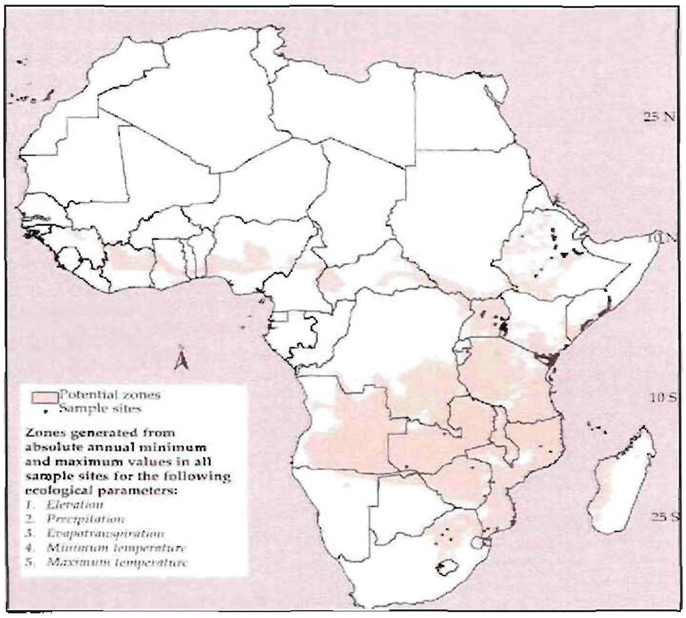

Figure 1.1. Potential distribution area of *Chilo partellus* in Africa (Overholt *et al.*, 2001).

The only stage in the life cycle of *C. partellus*, that causes damage to crop plants, is the larval stage. The larval stage (Fig. 1.2) causes damage to plants by feeding inside the whorls of plants. As a result of their feeding activity the upper surface of the leaf is eaten away so that only a thin layer of cells remain on the leaves. When the leaves grow out, this type of damage is observed as windows on the leaves. Larger larvae feed a hole through the rolled young leaves. This damage is known as "shot hole" damage (Fig. 1.5) because of the row of holes next to each other on the leaf (Drinkwater *et al.*, 2002).

The egg batches are laid on leaves near the midrib of the leaf and resemble flattened, ovoid and scale-like structures (Fig. 1.3). These egg batches may contain between 50 – 100 eggs and take 7 - 10 days to hatch depending on temperature. Larvae take between 18 and 35 days to reach maturity and a length of approximately 25 mm. Pupation may take between 7 - 10 days and takes place inside the stem. The wingspan of moths is between 20 – 30 mm across and the males are smaller and darker than the females (Fig. 1.4). The life cycle of *C. partellus* takes between 29 and 33 days to complete (Hill, 1987).

Damage on plants as a result of larval tunnelling, may be that of "dead heart", where the whorl leaves die off due to death of the growth point. In cases of severe infestation, tunnelling may result in plants that lodge because of weak stems (Drinkwater *et al.*, 2002). Both damage to leaves and stems will result in yield loss due to a reduction in growth of the plant, because of a lack in translocation of nutrients and water. Infestations of *C. partellus* may occur at virtually any crop growth stage. The shorter duration of the life cycle of the larvae of *C. partellus*, and thus the shorter total life cycle, allows for more than one generation to occur in the same planting (Van Rensburg & Van den Berg, 1992).

Ear damage might also occur when plants are attacked by *C. partellus*. This is because of the multiple moth flights resulting in more than one generation per plant. Because this second moth flight is always larger than the first, moths will oviposit on less susceptible plants resulting on large numbers of larvae occurring on a single plant. It was found with *B. fusca* that, if the second generation is not controlled effectively, it will result in severe ear damage and finally in significant yield loss (Van Rensburg *et al.*, 1988).

The larvae migrate from the whorl downwards, on the outside of the stem, to the point where they penetrate into the stem (Hill, 1987). After the larvae penetrate the stem of their host, usually just above an internode, tunnelling occurs inside the stem. This tunnelling effect is only visible when the stem is split open (Fig. 1.6). Because of the small size of the young larvae when they enter the plant, the entrance holes are not clearly visible. Some larvae may exit the stem just before they pupate, thus the exit holes are larger than the entrance holes. However, when the larvae pupate they do so inside the stem (Hill, 1987).

When *C. partellus* attacks the ears of maize plants, it will seldom be that the primary ear is damaged. Feeding is mainly done on the kernels of the secondary and sometimes the tertiary ears. When damage does occur on ears (Fig. 1.7), as a result of *C. partellus* feeding activity, the damage is most likely to be qualitative in nature rather than quantitative. Thus, damage to the ears of maize plants will have very little effect, if any, on the yield of the specific crop (Drinkwater *et al.*, 2002). According to Van Rensburg (2000), crop damage and yield loss is largely ascribed to stem damage and not to direct ear damage.

Figure 1.2. The larva of *Chilo partellus*.

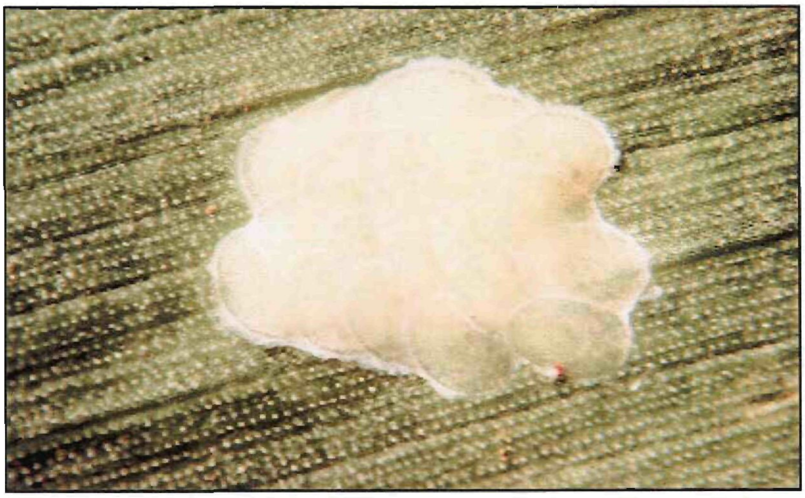

Figure 1.3. An egg batch of *Chilo partellus*.

Figure 1.4. *Chilo partellus* moth.

Figure 1.5. Shot hole damage on leaves, caused by stem borer feeding.

Figure 1.6. *Chilo partellus* larval damage to a grain sorghum stem.

Figure 1.7. Ear damage caused by *Busseola fusca* larvae.

1.4.2 *Busseola fusca*

Busseola fusca, indigenous to Africa, is widely distributed throughout sub-Saharan Africa. Populations in east and southern Africa seem to be adapted to different environments than those in West Africa. The regions in south and east Africa where *B. fusca* occurs are indicated in figure 1.8. *Busseola fusca* is restricted mainly to mid- and high elevation areas in the eastern and southern parts of Africa whereas in West Africa *B. fusca* can be found at all elevations (Overholt *et al.*, 2001).

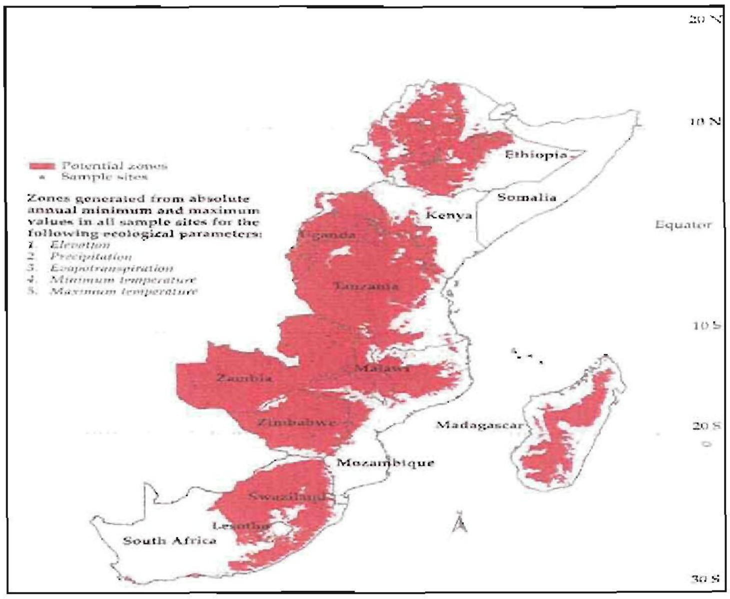

Figure 1.8. Potential distribution of *Busseola fusca* in Africa (Overholt *et al.*, 2001).

Busseola fusca moths (Fig. 1.9) lay their eggs in batches between leaf sheaths and the stem. The number of eggs in these batches (Fig. 1.10) may vary between 10 and 80, with an average of 30 - 70 eggs per batch (Van Rensburg *et al.*, 1987). The young larvae, emerging from the eggs, crawl upwards on the outside of the plant and settle in the tightly rolled furl leaves while some of them will also bore into the stem, but only after they have reached the third instar. These young larvae have a distinct dark brown colour which makes them easy to identify (Fig. 1.11). The entire life cycle takes about nine weeks to complete (Van den Berg, 1997b).

Busseola fusca tends to infest plants over a limited range of growth stages during the pre-flowering period, with the result that re-infestation does not occur or that it occurs only to a limited extent in the same planting (Van Rensburg & Van den Berg, 1992). The fully grown larvae over-winter as diapause larvae inside stem bases beneath the soil surface. During spring these diapause larvae pupate and moths emerge after the first rains. From this pupal stage the first moth flights of the season takes place (Van Rensburg, 1999). Larval feeding damage is similar to that caused by *C. partellus*.

Figure 1.9. *Busseola fusca* moth.

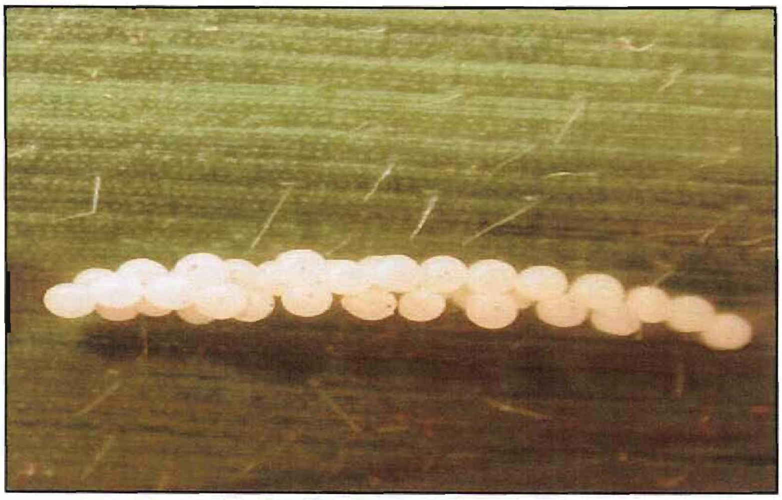

Figure 1.10. *Busseola fusca* egg batch.

Figure 1.11. *Busseola fusca* larvae inside a whorl leaf.

1.4.3 *Sesamia calamistis*

Sesamia calamistis occurs throughout most of tropical Africa and is considered to be of only moderate importance in southern Africa. The countries in south and east Africa where *S. calamistis* occurs is indicated in figure 1.12. Although it has a very wide distribution throughout this region, its population density is typically low. However, it is considered to be much more damaging in western Africa (Overholt *et al.*, 2001). In South Africa, *S. calamistis* is also known as the pink stem borer and it largely occurs in coastal areas and in Mpumalanga. It is becoming an increasingly important pest of sweet corn as well as maize under centre pivot irrigation systems, in the North-West and Limpopo Provinces (Van den Berg & Drinkwater, 2000).

Although the general biology of *S. calamistis* is similar to that of other stem borers there is one major difference in larval behaviour. An outstanding characteristic of its larval behaviour is that neonate larvae do not migrate to plant whorls after eggs hatch. Moths (Fig. 1.13) lay their eggs between leaf sheaths and the stem (Fig. 1.14) (similar to *B. fusca*) but newly hatched larvae as well as older larvae (Fig. 1.15) feed on the leaf sheath for a short time before penetrating the stem directly (Fig. 1.16) (Van den Berg & Drinkwater, 2000). The larvae) therefore seldom leave the protection of the stem except when they migrate to other plants (Harris, 1962). Oviposition at late plant growth stages results in larval infestation of maize ears.

These larvae feed on husk leaves and then penetrate the ears (Annecke & Moran, 1982). The total life cycle takes between 41 and 71 days, at 26°C and 21°C respectively (Van den Berg & Drinkwater, 2000).

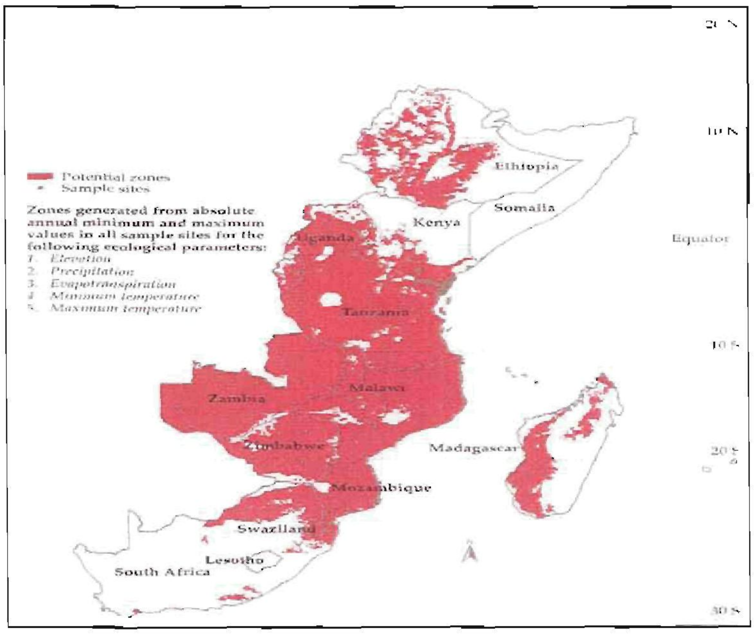

Figure 1.12. Potential distribution of *Sesamia calamistis* in east and southern Africa (Overholt *et al.*, 2001).

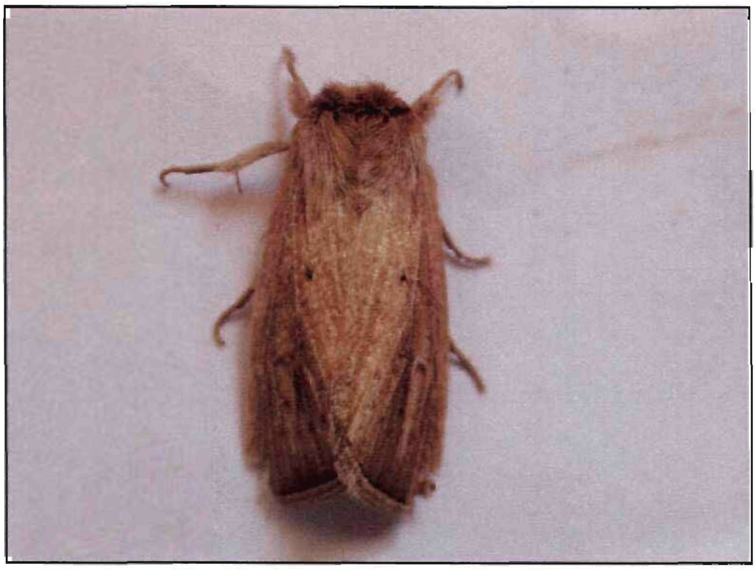

Figure 1.13. The moth of *Sesamia calamistis*.

Figure 1.14. Egg batch of *Sesamia calamistis*.

Figure 1.15. Larva of *Sesamia calamistis*.

Figure 1.16. Stem damage resulting from direct penetration of *Sesamia calamistis* larvae into the stem.

Typical dead heart symptoms and wilted whorls are the first symptoms present in a *S. calamistis* infested field of young maize plants. Such symptoms may be the result of larvae that have over-wintered in that specific field or larvae that hatched from eggs laid on young plants. It is known that up to 10 % reduction in plant population may occur as a result of *S. calamistis* infestation. In older plants infestation levels may be as high as 40 % on ears and 70 % in stems on individual fields (Van den Berg & Drinkwater, 2000).

Infestation levels at the beginning of seasons are relatively low. As the season progresses so does the level of infestation in maize plants. Highest levels of infestation occur during late summer and autumn in the winter rainfall regions of South Africa. The increase in pest status of *S. calamistis* in the northern regions of South Africa can be contributed to higher production levels of seed-maize and sweet-corn under pivot irrigation (Van den Berg & Drinkwater, 2000).

1.5 Potential yield losses due to stem borer infestations and economic threshold levels

Davis and Pedigo (1990) reported that up to 32 % of stem borers in the United States of America will attack more than one plant during its life cycle. Thus, yield reduction in maize or sorghum might be the cause of both primary and secondary stem borer attack.

These yield losses are then known as primary and secondary yield losses. Primary and secondary yield losses on maize respectively, might be as high as 58 % and 74 % respectively in the United States of America.

Such losses caused by stem borer attack on maize plants resulted in the development of the economic injury level (EIL). This EIL is a theoretical value that, if attained by the pest population, will result in economic damage. Although the EIL is expressed as a pest density it is actually the level of injury that is indexed by the pest numbers. Thus, it is a actually a degree of injury which could be described in terms of injury equivalents, which is the total injury produced by a single pest over an average lifetime (Pedigo *et al.*, 1986).

The EIL varies between different pests, between different crops as well as between different varieties of a specific crop. For the maize variety "Katumani", planted in Kenya, the EIL of stem borers was set at 3.9 larvae per plant at a growth stage of 20 - 40 - day old plants (De Groote, 2001). However, Van Rensburg (1999) calculated the economic threshold level (ETL) for stem borer control on maize in South Africa to be when 10 % of plants on the field show symptoms of whorl damage. It is however, important that when ETL's are used to determine whether to spray insecticides or not, scouting must be done on a regular basis to ensure the correct timing of insecticide application (Van Rensburg, 1999).

A reasonable EIL model will relate crop damage to an economical value, pest density and time of infestation. The EIL represents the critical level of damage, a population slightly higher than the population represented by the ETL that is relative to the current biological and economical conditions. However, the operable criterion for decision making is the ETL. The ETL is subjected to changes in the EIL variables since it is a direct function of the EIL. The ETL may vary with logistical consideration associated with time delays that varies from situation to situation (Pedigo *et al.*, 1986).

Chemical control measures should only be implemented when the ETL is reached and when the natural mortality factors cannot prevent the pest population from reaching the EIL. The difference in density between the EIL and ETL provides a margin of safety for the time delay which occurs between pest detection and the control action (Stern *et al.*, 1959). As was mentioned earlier, the EIL and ETL may differ depending on the area, season, crop and human perspectives.

The most important aspect regarding the success of a pest control program is that it depends on the aim of keeping the insect population below the experimentally established injury levels rather than attempting to eliminate all the insects (Stern *et al.*, 1959).

Many factors have limited the development of new ETL's and the application of existing ETL's. Five of these factors are provided by Pedigo (2004):

1. Lack of thorough mathematical definition of the ETL
2. Lack of valid EIL's
3. Inability to make cost effective and accurate population estimates
4. Inability to predict critical ETL variables such as market values and insect population trends
5. Lack of simple means to incorporate external factors, especially environmental costs into EIL's.

1.5.1 The effect of numbers of insects on yield loss (The EIL concept)

Insect pests may have a variety of complex effects on the crops they feed on. The quantitative relationships between the intensity of infestation and its effect on crop yield usually contribute to the form of the response curve. It is common practice to estimate the yield of unattached crops by extrapolating the regression on yield to the point of zero infestation, but this can be misleading if there is an unsuspected threshold level, or the upper part of the threshold curve is markedly curved (Bardner & Fletcher, 1974).

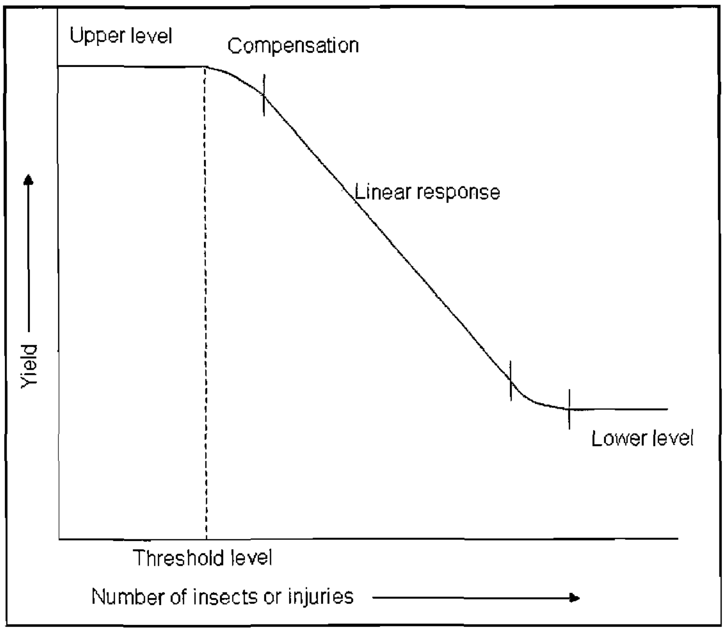

Figure 1.17. The general response curve (Bardner & Fletcher, 1974).

The general crop response curve has a sigmoid curve (Fig. 1.17) and consists of an upper level connected to a lower level by a straight line. At the upper level a small change in insect numbers can make a large difference in yield but once the lower level is reached an increase in numbers of insects has very little effect on yield. The data plotted on the x-axis relates to the number of insects or injuries in or on a single plant, while the data plotted on the y-axis relates to the potential yield of the specific plant or cultivar (Bardner & Fletcher, 1974).

Due to plant compensation or tolerance the plant is able to sustain low densities of one, two or even five insects/injury per plant, without any significant decrease in the yield of the plant. However, when the threshold level is reached, the number of insects/injury per plant has an increasing effect on the yield of that plant. The lower level indicates where an increased insect population will have no additional effect on the yield of the crop because damage has already been done (Bardner & Fletcher, 1974).

The threshold or boundary level, at the point where the upper level starts to curve, indicates the number of insects or injury a plant is able to sustain before the effect is visible in the yield of the plant (Bardner & Fletcher, 1974). This is due to increased competition between the pests or competition between different types of injuries (Bardner & Fletcher, 1974).

1.6 Organosilicones and their effects as adjuvants for insecticidal spray applications

With the above mentioned problems associated with chemical control strategies, it is obvious that any technology resulting in increased contact between pest and insecticide, will contribute to improved chemical control. Surfactants or wetting agents are commonly used in pesticide formulations to improve physico-chemical characteristics of the spray solution and to increase the efficacy of foliage-applied agrochemicals (Knoche, 1994). Complete spreading of the droplets may be expected with the addition of an organosilicone such as Break-Thru S240, to spray formulations. In a review on organosilicones Stevens (1993) noted that these compounds may have great potential as adjuvants for insecticides. Organosilicones reduce the surface tension of the spray solutions to very low levels, thus improving the adhesion and retention of droplets on plant surfaces (Stevens *et al.*, 1993).

Experiments conducted by Van den Berg and Viljoen (2007) showed that the addition of Break-Thru S240 resulted in a significant increase in the distance of movement of the spray application down into the whorls of maize plants. This distance of movement can however be increased by increasing the water volume application rate. They further evaluated the effect of Break-Thru S240 on the efficacy of various insecticides and found that the addition of Break-Thru S240 had an increasing effect on the mortality of insects in the sprayed plants. These findings as well as some other results obtained through experiments conducted with Break-Thru S240, will be provided and supported in the chapters that follow.

Water is used to dilute most agrochemicals before application. It was recognised back in 1949, that water is unable to stick to the waxy, hydrophobic, foliar surfaces of target plants (Stevens *et al.*, 1993). Ford and Furmidge (1967) pointed out that a reduction in the surface tension of water is a dynamic property of organosilicones. When sprayed droplets make contact with the waxy foliar surface of a plant, the reaction of the droplet will be to bounce off, spread in diameter on the surface or splashing in all directions (Manzello & Yang, 2003). With the use of organosilicones, the adhesion and retention of droplets to the waxy leaf surface of the plant will be increased since these organosilicones reduces the surface tension of the spray formulation to very low levels (Stevens *et al.*, 1993).

Chemical control of stem borers is often uneconomical or ineffective. Conventional insecticides does not reach larvae where they feed, deep inside the whorl leaves, but only penetrate down to the so called "dew-line" (Van den Berg & Viljoen, 2007). When organosilicone surfactants, such as Break-Thru S240 are added to the insecticidal spray formulation the surface tension of the spray formulation will be lowered significantly and the sprayed formulation will be able to penetrate further downwards into the whorl (Stevens *et al.*, 1993). Adhesion of larger droplets, minimal drifting of these larger droplets as well as addition of organosilicones increase the efficacy of insecticidal treatments by resulting in better coverage of the plant, less drift and better adhesion to the leaf surface (Stevens *et al.*, 1993).

The exceptionally low surface tension of water, imposed by such organosilicones enables such mixtures to penetrate minute cavities such as stomata (Wood & Tedders, 1997). Thus, penetration deeper into the plant whorl would also be achieved. On the contrary the penetration of such cavities on leaf surfaces may lead to a reduction in gas exchange by the plant which in turn may lead to a reduction in growth and yield. Fortunately such symptoms only occur when plants are repeatedly sprayed with such mixtures (Wood & Tedders, 1997).

Stevens *et al.* (1993) noted that organosilicones may have great potential as adjuvants applied with insecticides. Wood and Tedders (1997) also observed that organosilicones have the ability to suppress aphid populations. Since these aphids are not particularly mobile, spray coverage will play a role in the ability of an organosilicone to suppress population densities (Wood & Tedders, 1997).

1.7 Objectives of this study

The general objective of this study was to determine the effect of Break-Thru S240 on the efficacy of chemical stem borer control.

Specific objectives were:

- to determine and quantify the position of stem borer feeding activity inside maize whorls.
- to determine the effect of different dosages of Break-Thru S240 on the distance of movement of spray applications into plant whorls.
- to determine the influence of water volume during application, on the distance of movement of Break-Thru S240 into plant whorls.
- to determine the effect of Break-Thru S240 on the efficacy of systemic and contact insecticides applied against *Chilo partellus* and *Busseola fusca.*
- to determine the effect of Break-Thru S240 added to a systemic insecticide as a preventative control method against stem borers.
- to compare the efficacy of different adjuvants on the distance of movement of water into plant whorls.

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CHAPTER 2: THE EFFECT OF VARIOUS ADJUVANTS ON THE MOVEMENT OF SPRAY APPLICATIONS INTO THE WHORLS OF MAIZE PLANTS

2.1 Introduction

The African maize stem borer, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) and spotted stem borer, *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) are important pests that attack maize and sorghum throughout sub-Saharan Africa (Kfir *et al.*, 2001). Chemical control of these stem borers is complicated by cryptic feeding of larvae deep inside plant whorls where they do not easily come into contact with insecticides. This target area (inside the whorl) where the larvae feed on the tightly rolled whorl leaves is below the so-called "dew-line" of a maize plant where rain, dew or spray formulations of insecticides do not easily penetrate into (Van den Berg & Viljoen, 2007).

When organosilicone surfactants are added to insecticide spray formulations the surface tension of the spray formulation is lowered significantly and the sprayed formulation is able to penetrate further downwards into the whorl of the plant (Stevens *et al.*, 1993). The addition of organosilicones to spray applications increases the efficacy of insecticide treatments by resulting in better coverage of the plant, less drift and better adhesion of droplets to the leaf surface (Stevens *et al.*, 1993).

Surfactants or wetting agents are used worldwide with pesticide applications to improve physico-chemical characteristics of spray solutions and to increase the efficacy of foliage-applied agrochemicals (Knoche, 1994) even at reduced dosage rates (Holloway *et al.*, 2000). Water is used to dilute most agrochemicals before application and then as a carrier of the insecticide onto the plant. When organosilicone surfactants are added to insecticide spray formulations the surface tension of the formulation is reduced rapidly to levels lower than can be achieved by conventional adjuvants (Stevens *et al.*, 1993). This exceptionally low surface tension of water, imposed by organosilicones, enables insecticide mixtures to penetrate minute cavities such as the stomata of leaves and to penetrate further downwards into the whorls of maize plants (Wood & Tedders, 1997;

Van den Berg & Viljoen, 2007). Ford and Furmidge (1967) pointed out that a reduction in the surface tension of water is a dynamic property of organosilicones that will enhance penetration of water into the plant or water retention onto the leaf. In a review on organosilicones, Stevens (1993) already noted that these compounds may have great potential as adjuvants for insecticides.

Technology that result in increased penetration of insecticides into plant whorls may result in improved control of stem borers which feed inside whorls. The aims of this study were to determine and quantify the position of stem borer feeding activity inside maize whorls as well as to determine the effect of different agricultural tank-mix adjuvants on the distance of movement of water into the whorls of maize plants.

2.2 Materials and methods

2.2.1 Position of feeding activity of borer larvae inside whorls of maize plants

An experiment was conducted during the 2006/07 growing season in a maize field subjected to natural stem borer infestation at Potchefstroom. Forty eight 5-week old plants that showed visual symptoms of stem borer feeding damage inside the whorl leaves were collected and dissected. Whorls were separated from the rest of the plant by cutting off the stem at the level of the youngest fully unfolded leaf (Fig. 2.1). This loosened the whorl from the stem and facilitated easy unfolding of the rest of the six or seven younger leaves that constitute the whorl of the plant.

Leaves were numbered according to age. Leaf 1 was the highest leaf on the plant stem with a fully unfolded ligule and also formed the outermost leaf that could still be considered part of the whorl. Leaf number 7 was the soft yellow-green leaf tightly rolled inside the whorl and also the youngest leaf of the whorl. All leaves were rolled open and their lengths measured as indicated in figure 2.2. Firstly the total leaf length, as indicated by line A was measured. Thereafter the lowest (deepest) position of stem borer feeding damage on the each damaged leaf was determined by measuring the distance from the tip of the leaf to the damage site (indicated by line B) (Fig. 2.2). The latter distance was then expressed as a percentage of the total leaf length.

2.2.2 Effect of various agricultural tank-mix adjuvants on movement of spray applications into plant whorls

An experiment was done to compare the effect of various adjuvants on the distance of movement of spray applications down into whorls of maize plants. Each of the adjuvants was applied together with a colorant dye (2 % per volume) at the two dosages at which they are registered for agricultural tank-mix purposes in South Africa. The experiment was conducted during the 2006/07 growing season in Potchefstroom. The experimental design was a randomized block with 11 treatments and five replicates. Five different adjuvants were applied at the dosages at which it is currently registered for insecticide applications in South Africa. An application of water alone served as the control treatment. All treatments were applied at 2 l water 100 m row^{-1} length.

The experiment was laid out in a 1.2 hectare block of maize planted at an inter-row spacing of 1.5 m and an intra-row spacing of 0.2 m. Plot rows was 8 m long and there was a 2 m space between the plot rows. The experiment commenced five weeks after seedling emergence. Treatments were applied by means of a CO_2-pressurised knapsack sprayer with a delivery pressure set at 7 l CO_2 $min.^{-1}$, using a hollow cone nozzle. The spray was directed into the whorls of maize plants. Spraying commenced early in the morning (06:00) to minimize the effect of wind on spray drift.

Five plants from each replicate were collected in the late afternoon, 9 hours after spray application. Plants were cut off at soil level and stored in an upright position overnight. The whorl was separated from the rest of the plant by cutting off the stem at the level of the youngest fully unfolded leaf. This loosened the whorl from the stem and facilitated easy unfolding of the rest of the five to seven younger whorl leaves. The leaves of the whorl were numbered according to age as described above.

The length of each leaf blade that formed part of the whorl, as well as the distance of movement of the spray application down each leave, indicated by the colorant dye was determined (Fig. 2.3). The distance of movement into the whorl was then expressed as a percentage of the total leaf length. This was done for each of the five youngest leaves in the whorl. Because of the small size of leaves 6 and 7, the difficulty to observe the colorant on these leaves and the fact that not all plants always had these two leaves, the data collected regarding these leaves were not analysed. The distance of movement, expressed as a percentage, into the five different leaves was pooled before analysis.

2.2.3 Data analysis

The numbers of damaged leaves were determined and expressed as a percentage of the total number of leaves examined for damage. The deepest position of damage symptoms on leaves, expressed as a percentage of the length of each leaf, was determined for each of the whorl leaves and mean values determined for each leaf number.

Analysis of variance (Anova) was conducted with Statistica software (version 7.0) to determine differences between the various adjuvants as well as the different dosage treatments. Data were Arcsine transformed before analysis. Untransformed data are however provided in tables. A Tukey-test was conducted for post hoc comparisons using Statistica software (version 7.0).

2.3 Results and discussion

2.3.1 Position of feeding activity of stem borer larvae inside whorls of maize plants

The stem borer population in maize consisted of a mixed population of *B. fusca* and *C. partellus*. *Busseola fusca* made up 53 % of the population.

Because leaves 1 and 2 were too old for young stem borer larvae to feed on these leaves were omitted from analyses but are provided in figures 2.7 and 2.8. The leaves with the highest incidence of larval feeding damage were leaves 3 and 4, which made up 52 % of the total number of leaves that were checked for damage (Fig. 2.4). Leaves 3 and 4, together with the three remaining younger leaves, made up 85 % of the damaged leaves respectively. Leaves 3 – 7 can be considered to be the most important in terms of stem borer feeding activity and therefore chemical control. Leaves 1 and 2 are the oldest whorl leaves where larvae prefer not to feed any more and within a short period of time these leaves will not be part of the whorl any more. Successful insecticide penetration into leaves number 3 and 4 is therefore important because these leaves made up the largest proportion of the damaged leaves and also represented the site where most of the larvae were feeding inside whorls. It should however be kept in mind that at least 20 % of all *C. partellus* larvae occur behind the leaf sheaths (Van Rensburg & Van den Berg, 1992) and that even highly effective whorl applications do not reach these larvae.

The position of larval feeding damage caused by *B. fusca* and *C. partellus* was similar and the data were therefore pooled. The site of feeding damage on leaves, expressed as a percentage, should be taken as "control distance" against which all treatments should be evaluated. Since leaves 3 and 4 made up the largest proportion of damaged leaves, it may be concluded that any application that moves further than the 80 and 70 % distances on leaves 3 and 4 respectively (Fig. 2.5), can be considered to be successful.

2.3.2 Effect of Break-Thru S240 and other agricultural tank-mix adjuvants

Significant differences were observed between the distances that spray applications moved down into whorls after application with various adjuvants (P = 0.0001). The shortest distance of movement down into plant whorls was observed with Solitaire applied at 100 ml ha^{-1} and the control treatment where only water was applied (Table 2.1). There were significant differences between the distances of movement resulting from various adjuvants (P = 0.0028) (Fig. 2.6) applied at both higher and lower dosages of some of the treatments (P = 0.0001) (Fig. 2.7). The distance of movement obtained by the Agral treatment at 200 ml ha^{-1} was significantly higher than all other treatments except Break-Thru S240 applied at 200 ml ha^{-1} (Table 2.1).

The distance of movement into whorls of spray applications to which various adjuvants have been added is presented in figure 2.6. Data on leaves 6 and 7 were not provided in figures 2.7.and 2.8. This was done because these leaves are tightly rolled in the middle of the whorl, and, because of its morphology or total absence in many cases, it was impossible for adjuvants to move down into these leaves.

As expected, Break-Thru S240 applied at the higher dosage rate, resulted in increased movement into the whorl compared to the lower dosage rate (Figure 2.7). The same tendency was observed with Agral and Nu-Film P at higher dosages. Complement Super and Solitaire, both applied at 50 ml ha^{-1} differed from the water treatment at the lower of the two dosage rates on leaves 6 and 7 (Fig. 2.7). Agral and Break-Thru S240 both applied at 200 ml ha^{-1} resulted in the highest distances of movement into plant whorls. The distances of movement observed in this evaluation of various adjuvants were greater than that needed to reach the target zone as indicated in figure 2.4. Because of pressure from the European Union, where all NPE's were banned during 2005, the use of all NPE's, such as Agral, as agricultural tank-mix adjuvants will be banned from South Africa in the near future (Cecilia van Rooyen, Syngenta; personal communication). This increases the necessity of research on non-NPE adjuvants such as Break-Thru S240 which remains one of the few tank-mix adjuvants available for agricultural purposes in South Africa.

All the adjuvants applied at the lower registered dosage rates as well as the water treatment penetrated deeper into leaves 3, 4 and 5 than the lowest site of stem borer feeding activity (Fig. 2.8). The same was observed when the higher of the two registered dosages was applied. However at higher dosage rates Break-Thru S240, Agral and Nu-Film P moved further down whorl leaves than the other adjuvants.

The blue bars in both figures 2.7 and 2.8 serves as an indication of the depth of stem borer feeding activity inside the different whorl leaves. When the depth at which feeding damage occurs was compared to the distance of movement of the different spray treatments down each of the whorl leaves, it was observed that all treatments resulted in movement deeper down into the whorl than the site of feeding of larvae.

2.4 Conclusions

The use of agricultural tank-mix adjuvants resulted in increased downward movement of spray applications into plant whorls up to or even past the site of larval feeding. Although there were significant differences between results obtained with the various adjuvants, differences were comparatively small.

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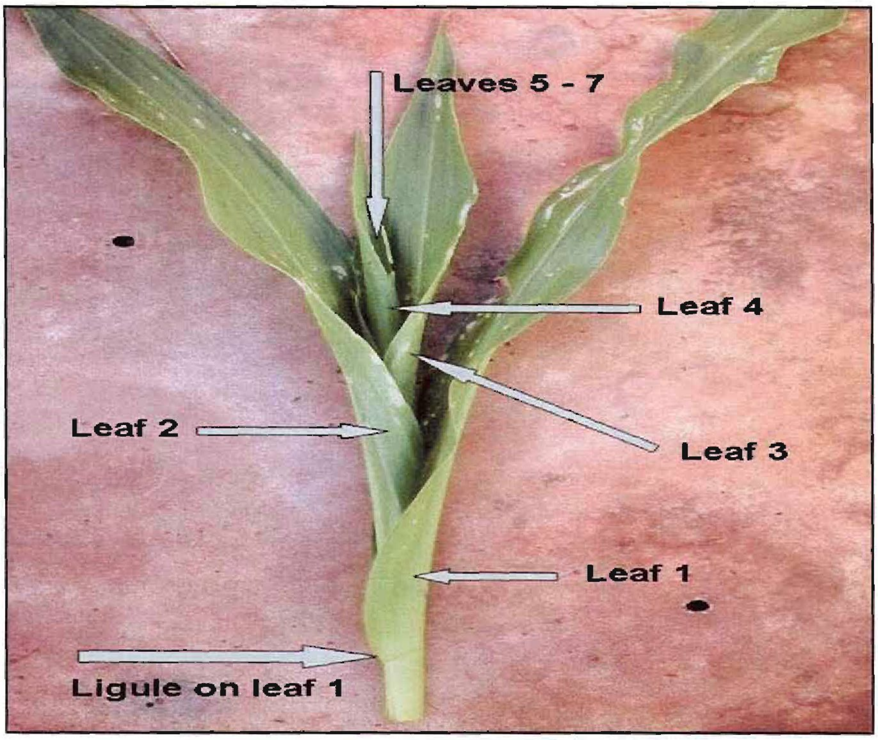

Figure 2.1. Plants were cut just below the ligule of the last fully unfolded leaf to separate the whorl from the rest of the plant.

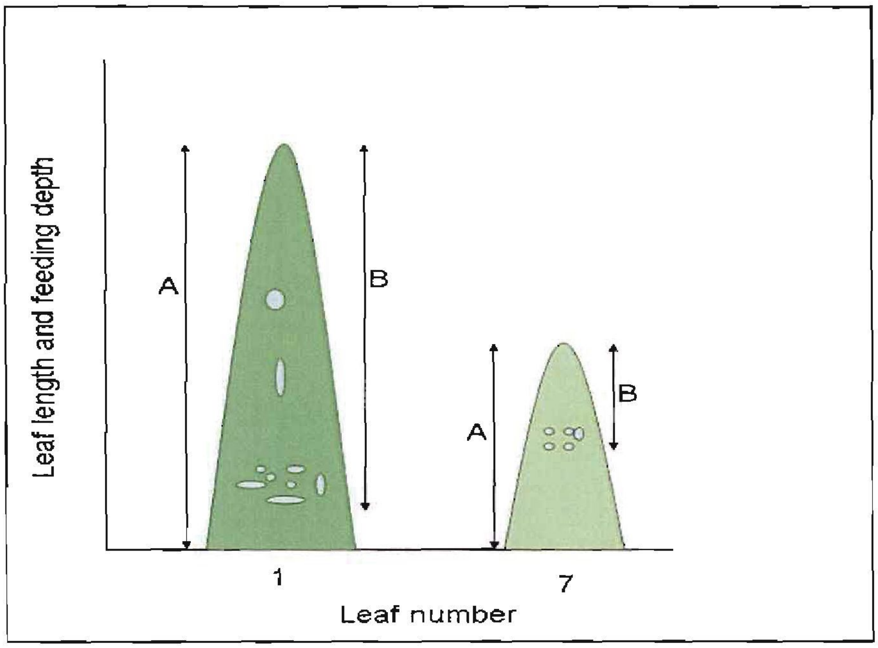

Figure 2.2. A graphical presentation of the measurements taken on whorl leaves. A = total leaf length, B = position of lowest (deepest) signs of stem borer feeding activity.

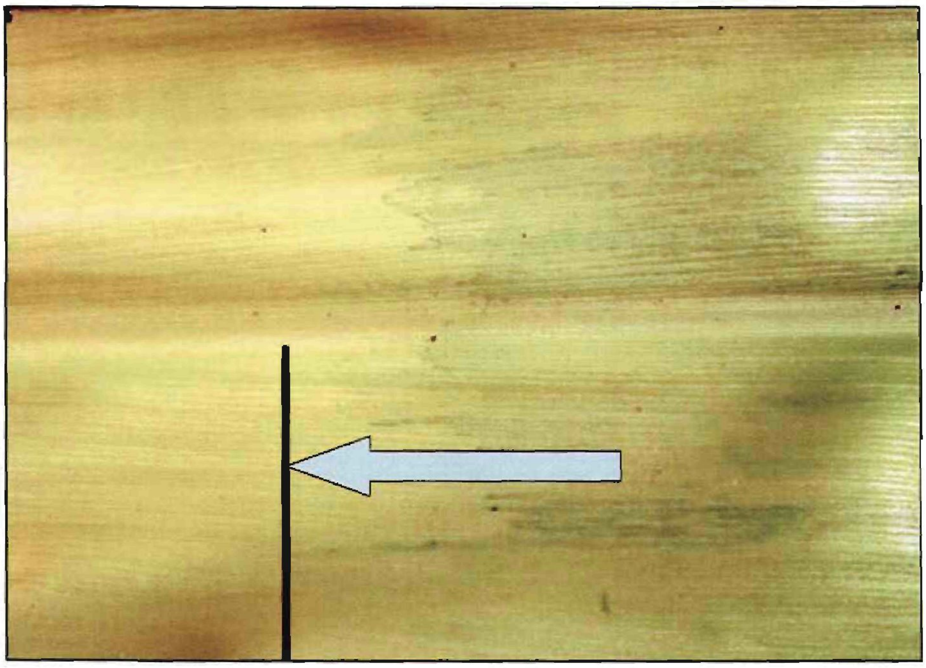

Figure 2.3. Blue colorant dye indicating the distance of spray movement down into the whorl of a maize plant. The black line indicates the level to which the spray application moved into the particular whorl leaf.

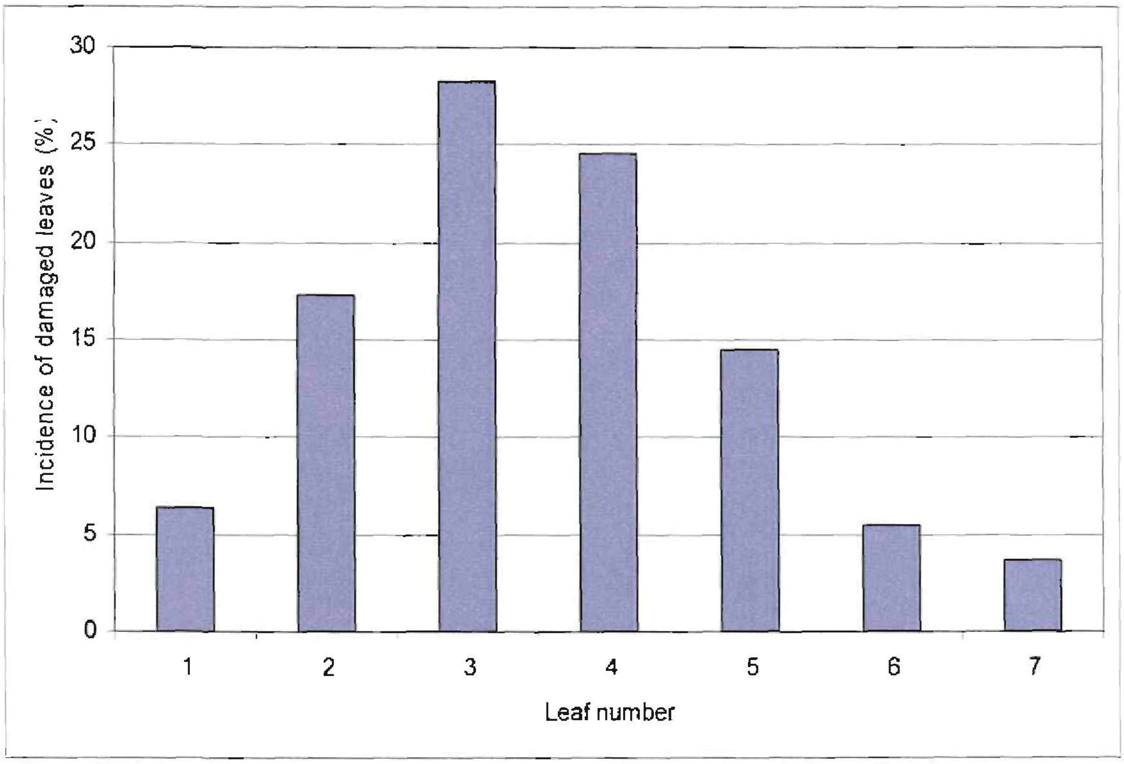

Figure 2.4. The proportion of whorl leaves of maize plants exhibiting stem borer feeding damage (Leaf 7 is the youngest).

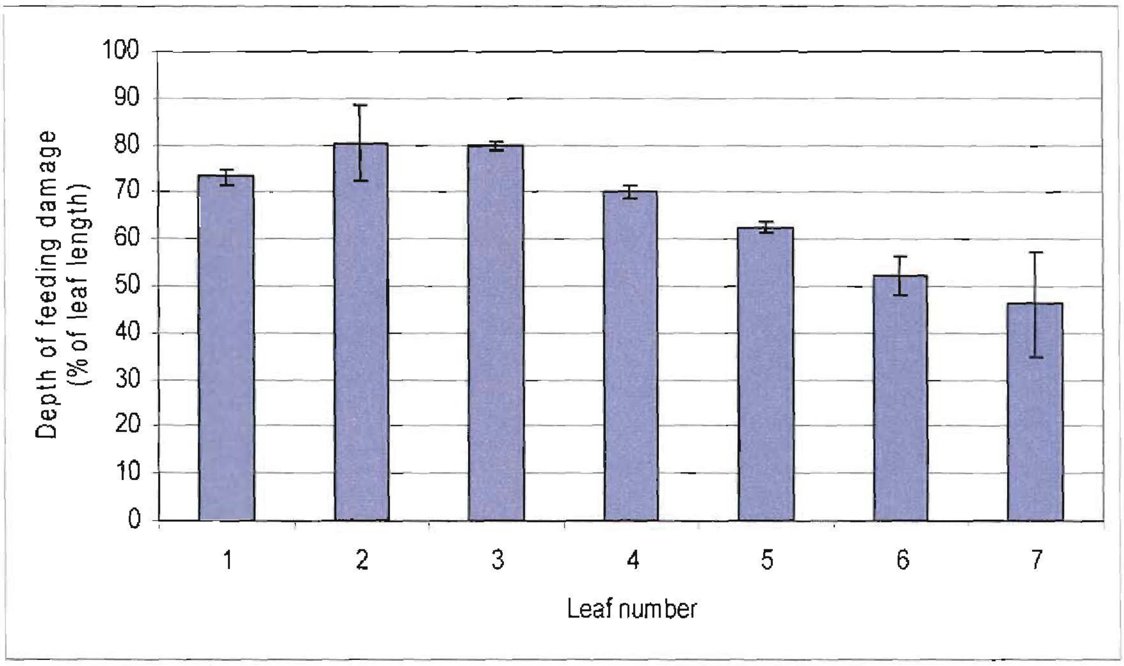

Figure 2.5. Deepest position of stem borer larval feeding damage inside whorl leaves of maize plants expressed as a percentage of the length of each of the seven leaves that forms the whorl (Leaf 7 is the youngest) (Bars indicate Standard Deviations).

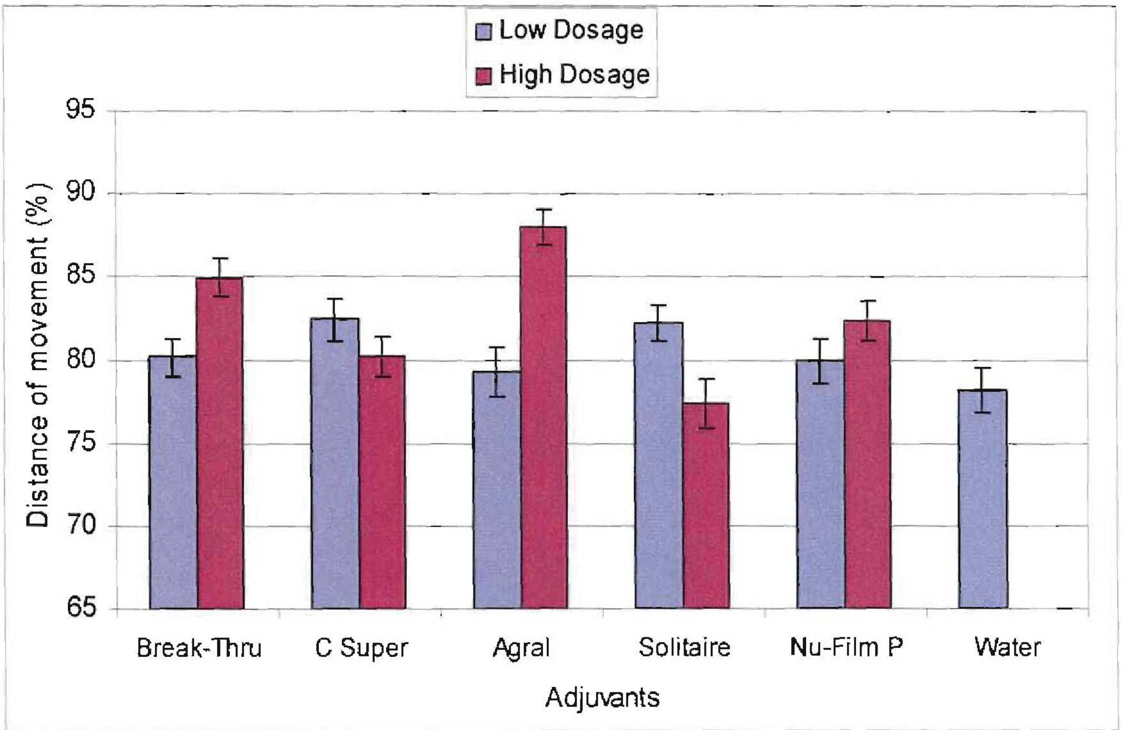

Figure 2.6. Distance of movement of different spray applications and water into plant whorls obtained by various adjuvants, each applied at two dosages (Bars indicate Standard Errors).

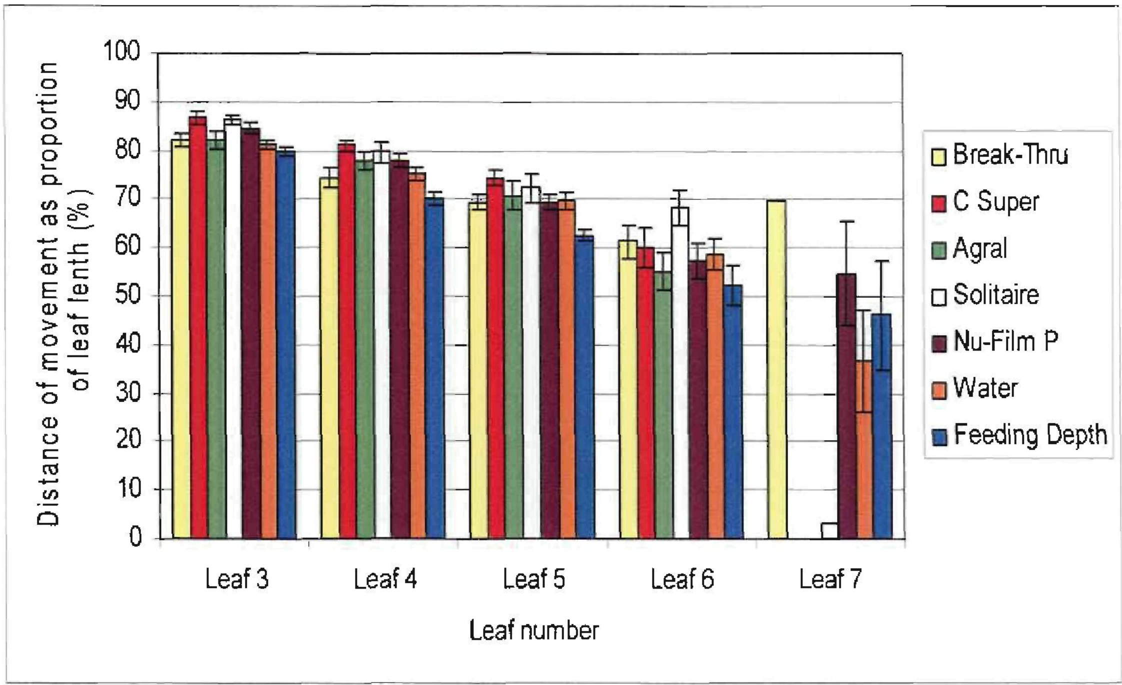

Figure 2.7. Feeding depth and distance of movement (percentage of leaf length) of spray applications with different adjuvants applied at low dosage rates (Bars indicate Standard Errors).

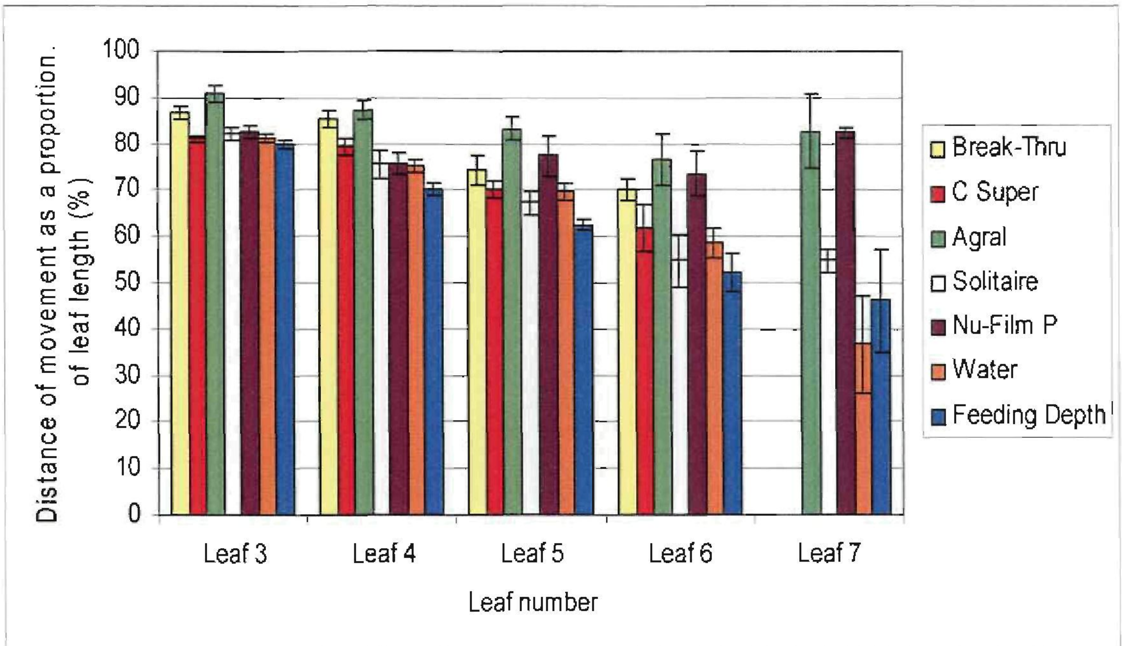

Figure 2.8. Feeding depth and distance of movement (percentage of leaf length) into plant whorls of spray applications with different adjuvants applied at high dosage rates (Bars indicate Standard Errors).

Table 2.1. Mean percentage distance of movement of treatments with various adjuvants down whorl leaves (data combined for 5 leaves).

Treatment	Distance of movement into whorl (%)*
Solitaire (100 ml ha^{-1})	77.4 a
Water (Control)	78.2 a
Agral (100 ml ha^{-1})	79.3 a
Nu-Film P (150 ml ha^{-1})	79.9 a
Break-Thru (100 ml ha^{-1})	80.2 a
Complement S (100 ml ha^{-1})	80.2 ab
Solitaire (50 ml ha^{-1})	82.2 ab
Nu-Film P (300 ml ha^{-1})	82.4 ab
Complement S (50 ml ha^{-1})	82.4 ab
Break-Thru (200 ml ha^{-1})	84.9 bc
Agral (200 ml ha^{-1})	88.0 c

*Means within column followed by the same letter do not differ significantly at $P = 0.05$, according to Tukey's multiple range test.

CHAPTER 3: THE EFFECT OF BREAK-THRU S240 ON THE EFFICACY OF FOLIAR APPLIED CONTACT AND SYSTEMIC INSECTICIDES AGAINST *CHILO PARTELLUS* AND *BUSSEOLA FUSCA*

3.1 Introduction

The rapid distribution of the stem borer *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) throughout most of the maize production areas in South Africa during the 1980's have complicated chemical control strategies used against stem borers (Bate *et al.*, 1990; Van den Berg & Van Rensburg, 1996). Before the mid 1980's maize plants were largely attacked only by *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) and were controlled relatively easy (Van Rensburg *et al.*, 1988).

Research regarding the infestation patterns of the two stem borer species, in maize and grain sorghum indicated that *B. fusca* tends to infest plants over a limited range of growth stages during the pre-flowering period (Van Rensburg & Van den Berg, 1992 b) where they feed in the whorls of young plants (Van den Berg & Van Rensburg, 1993). Re-infestation by *B. fusca* of the same planting occurs only to a limited extent because of its relatively long life cycle (Van Rensburg & Van den Berg, 1992 b). With the shorter duration of the life cycle, *C. partellus* usually infest maize plants resulting in different developmental stages of this species occurring in the same planting (Van den Berg & Van der Westhuizen, 1995). In such infestations at least 20 % of all larvae occur behind the leaf sheaths of maize plants (Van Rensburg & Van den Berg, 1992 b) while the others feed inside the whorls of plants where they may not come into contact with insecticides (Van den Berg & Viljoen, 2007).

Insecticide sprays registered for the control of stem borers in maize and sorghum are all intended for whorl application (Van Rensburg & Van den Berg, 1992 a). Ganguli *et al.* (1997) pointed out that chemical control of stem borers in India are often effective when restricted to the period of egg hatching and the first three instars of the life cycle.

However, insecticides applied at early crop growth stages did not prevent *C. partellus* from re-infestation of the same planting in South Africa (Van den Berg & Van Rensburg, 1996).

The efficacy of insecticides depends on the timing of application as well as on the area of application on the maize plant (Nwanze & Muller, 1987). For optimal insecticide efficacy, applications should be applied during the period of egg hatching as well as the first three instars of the stem borer's life cycle, when the larvae are inside the whorl and before they migrate downwards to enter the stem (Ganguli *et al*., 1997). Van den Berg and Van Rensburg (1991) pointed out that a single application of pyrethroids such as deltamethrin, cypermethrin or esfenvalarate, during the late whorl or flag leaf stages of the maize plant's life cycle, will probably be most effective. However, a single application of an insecticide such as endosulfan, shortly before tasseling in maize and panicle emergence in sorghum resulted in yield increase (Van Rensburg & Van den Berg, 1992 a).

Systemic insecticides applied at planting are used as a preventive control strategy against various potential insect pests of maize, including nematodes, leafhoppers and also *C. partellus* and *B. fusca*. The general perception is that these pesticides provide efficient control against insect pests for a period of four to six weeks after application (Knowledge *et al*., 1999). One of the concerns regarding systemic insecticides however, is the translocation of the insecticide throughout the plant. In an experiment conducted with a seed dressing insecticide, Drinkwater (2003) observed poor systemic translocation in maize plants.

Spray retention is an important means by which surfactants can modify the activity and efficacy of agro-chemical sprays (Stevens, 1993). Increased stem borer control was observed in a study conducted by Van den Berg and Viljoen (2007) where the organo-silicone Break-Thru S240 was used as an adjuvant. Such organosilicones are commonly used in insecticide formulations since it improves the physico-chemical characteristics of the spray solution and increase the effect of foliage applied sprays (Knoche, 1994). With the addition of an organosilicone to a spray formulation, complete spreading of spray droplets and an improvement in the efficacy of the insecticide may be expected

(Dent, 2000). Stevens (1993) noted that organosilicones may have great potential as adjuvants in insecticide formulations since the adhesion of spray droplets to leaf surfaces are increased through a reduction in water tension.

The aims of this study were to determine the effect of Break-Thru S240 on the efficacy of insecticides applied against *C. partellus* and *B. fusca* as well as to determine the effect of Break-Thru S240 on the comparative efficacy of insecticides with a contact and systemic mode of action.

3.2 Materials and methods

3.2.1 Calibration of the knapsack sprayer

Rational, judicious use of insecticides makes out an important part of pest control. To ensure high levels of insecticide efficacy it is important to deliver the required dosage of insecticide to the target surface (Dent *et al.*, 1993).

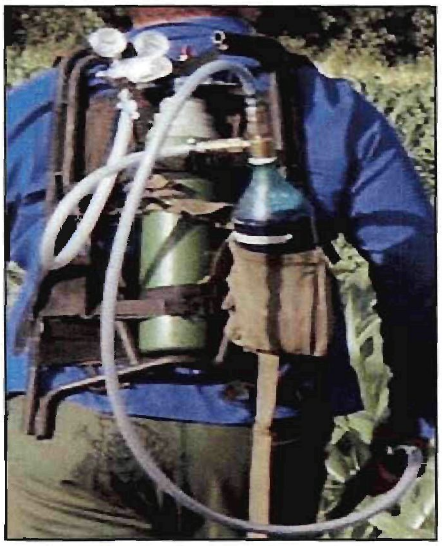

Figure 3.1. The knapsack sprayer used for the application of insecticides during this study.

One way to calibrate a knapsack sprayer is with the speed-width-output method. This requires a few important steps and was also the method used to calibrate the sprayer used in these experiments. The most important aspect of calibration is the walking speed of the sprayer operator. A consistent walking speed over a distance of 100 m ensures a consistent application rate.

Calibration is done by determining the time it takes to walk 100 metres while spraying into a measuring-jug. Walking speed should be adjusted, and set at a level that could be maintained for long walking distances, until the exact desired amount of water is sprayed over the 100 m distance (Dent *et al.*, 1993). The correct procedure when calibrating a knapsack sprayer is described in figure 3.2.

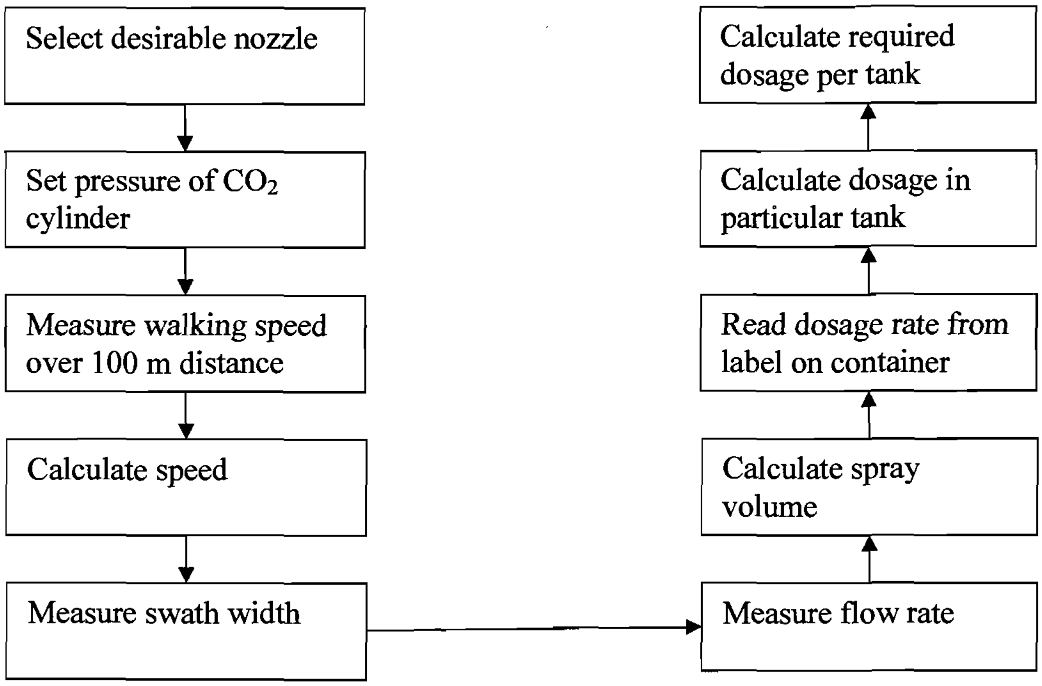

Figure 3.2. Flow diagram of the steps in the calibration procedure for the speed-width-output method (Dent *et al.*, 1993).

It is however important to simulate this whole calibration experiment on the terrain where the actual insecticide application will be done, wearing all the protective clothing, since the terrain and clothing may have an influence on walking speed (Dent *et al.*, 1993). This is also the way the CO_2-pressurised knapsack sprayer, used in these experiments, was calibrated.

3.2.2 Effect of Break-Thru S240 on the efficacy of insecticides against *Chilo partellus*

The efficacy of insecticides with a contact mode of action was evaluated against *C. partellus* on a maize field subjected to natural infestation. The experiment was conducted on a maize field near Mafikeng in the North-West province of South Africa during the 2006/07 growing season. The incidence of infested plants at the site was 30 % and only *C. partellus* larvae were present. A randomized block design consisting of 13 treatments with six replicates was used. Treatments consisted of 5 insecticides each applied without and with the adjuvant Break-Thru S240. These insecticides were, λ – cyhalothrin, polythrin, deltamethrin, esfenvalarate and α – cypermethrin. Break-thru S240 was applied at a dosage rate of 200 ml ha^{-1} in all designated treatments except for λ-cyhalothrin where the adjuvant was applied at 0, 50, 100 and 200 ml ha^{-1} respectively. An unsprayed control treatment was also included in the experiment. These insecticide treatments are shown in figure 3.3.

The trial was situated within a larger planting of maize that was planted under centre pivot irrigation. Plants were five weeks after emergence when treatments were applied. The plot rows differed in length since plots were marked such that each plot row contained at least ten plants showing visual signs of whorl damage caused by *C. partellus*. The inter-row width was 1.35 m and the intra-row width was 0.2 m resulting in a plant density of approximately 80 000 plants ha^{-1}.

Insecticides were applied by means of a CO_2-pressurised knapsack sprayer (Fig. 3.1) at a spray volume of 2 l 100 m^{-1} row length with a delivery pressure set at 7 l min^{-1}, using a hollow cone nozzle. The insecticide spray was directed into the whorls of plants. Five days after insecticide application ten plants in each plot row that showed feeding damage in the whorl were collected and the whorls dissected. The number of larvae that survived the spray application was counted. This number was then expressed as a percentage in terms of the number of larvae in the unsprayed control treatment.

3.2.3 Effect of Break-Thru S240 on the efficacy of insecticides against *Busseola fusca*

An experiment was conducted to determine the effect of the addition of Break-Thru S240 on the persistence of insecticides with a systemic as well as a contact/systemic mode of action, applied as preventative sprays against *B. fusca*. This experiment was conducted in a greenhouse at the North-West University. Maize plants (cultivar CRN 3505) were planted in pots, 25 cm in diameter and 30 cm deep. Each pot contained four plants that were eventually thinned out to two plants. Insecticides were applied when plants were four weeks old. Insecticides were applied by means of a CO_2-pressurised knapsack sprayer at a spray volume of 2 l 100 m^{-1} row length with a delivery pressure set at 7 l min^{-1}, using a hollow cone nozzle. The insecticide spray was directed into the whorls of plants. Spray application was done outside the greenhouse. The potted plants were returned to the greenhouse, three hours after insecticide application.

The experimental design was a randomized block with nine treatments. Two different insecticides were each applied without and with three different dosage rates of break-Thru S240. The ninth treatment was water which served as the control. Each treatment consisted of sixty six maize plants (replicates). Treatments consisted of an insecticide with a systemic (benfuracarb) and contact/systemic (carbosulfan) modes of action. The insecticides were applied without adjuvants as well as in combination with these dosage rates of Break-Thru S240.

Six plants of each treatment were artificially infested with first instar *B. fusca* larvae at 2, 5, 8, 11 and 14 days after the insecticide application. Ten first instar *B. fusca* larvae were placed into the whorls of plants using a camel hair brush. The number of surviving larvae on each plant was determined three days after inoculation of each of the respective treatments. On the first three sampling dates, six pots were sampled for each insecticide treatment while only five were sampled on the last two sampling dates.

3.2.4 Data analysis

The data from the field experiment with C. *partellus* were expressed as percentage control in terms of the unsprayed control treatment where no insecticides were applied. The data were analysed by means of an Anova and were not transformed. All post hoc comparisons were done by using Tukey tests. Statistica software (version 7.0) was used.

Data from the greenhouse experiment with *B. fusca* was expressed as the number of surviving larvae per plant and analysed by means of a factorial analysis. Repeated-measures analysis of variance (Anova) was used to determine the effect of insecticides on the number of surviving larvae over the period of 14 days. The Tukey test was used for all post hoc comparisons. Data on percentage larval survival were Arcsine transformed. Untransformed data are presented in tables. All analysis was done by using Statistica software (version 7.0).

3.3 Results and discussion

3.3.1 Effect of Break-Thru S240 on efficacy of insecticides against *Chilo partellus*

The number of larvae that survived the insecticide applications was significantly ($P = 0.0001$) lower than the unsprayed control treatment (Fig. 3.3; Table 3.1). Although not significant, a tendency of lower larval survival was observed for all except one insecticide treatment to which Break-Thru was added (Table 3.1). There was no significant difference ($P = 0.8417$) in terms of larval control obtained between the 50, 100 and 200 ml ha^{-1} Break-Thru S240 dosage rates applied with λ – cyhalothrin. The addition of Break-Thru to esfenvalarate did not result in increased efficacy of this insecticide.

The percentage increase in control achieved by adding Break-Thru S240 to the different insecticides is provided in figure 3.4. The addition of Break-Thru S240 to insecticides resulted in an increase in control ranging between 13.8 % where Break-Thru S240 was applied to λ – cyhalothrin, and 57.7 where Break-Thru S240 was applied to deltamethrin compared to the treatments where no Break-Thru was added.

3.3.2 Effect of Break-Thru S240 on efficacy of insecticides against *Busseola fusca*

A general decrease in insecticide efficacy over time can be observed in the decline of numbers of surviving larvae over time, when data are pooled over treatments (Table 3.2). There were significant differences (P = 0.0267) in larval survival between the different treatments applied against the *B. fusca* after the 14-day period (Table 3.3). The number of surviving larvae also did not differ significantly (P = 0.2481) between days, from day 5 onwards (Figs. 3.5 and 3.6). However, there was a significant difference (P = 0.0001) between insecticide treatments on each of the respective infestation days (Figs. 3.5 and 3.6).

Larval mortality obtained by treatments with benfuracarb, applied without and with Break-Thru S240 at different dosages is shown in figure 3.5. Benfuracarb treatments with and without the different Break-Thru S240 dosages resulted in a decrease of 45 to 13 % over the 14 days after application. Larval mortality obtained by treatments of carbosulfan is shown in figure 3.6. When newly hatched larvae were put on carbosulfan treated plants, two days after spray application, mortality rates of 98 % were observed. Mortality rates subsequently decreased rapidly over time to 30 % on days 11 and 14 after application.

These results indicate a general tendency of decreased insecticide efficacy over time. Although mortality rates of between 20 – 58 % were still achieved by insecticides 14 days after application, less than 60 % died if larvae were put on plants eight days after application. Timing of any insecticide application is crucial in order to obtain efficient results before significant damage may occur to crops. These results indicate that a follow up application of insecticides would most likely be needed if stem borer eggs hatch one week after a preventative spray has been applied and that the use of Break-Thru S240 will not extend the period of effective control.

3.4 Conclusions

The addition of Break-Thru S240 to different insecticides applied against *C. partellus*, resulted in increased levels of control ranging between 12 and 58 %. This indicated that the addition of Break-Thru S240 as a tank-mix adjuvant to insecticides intended for stem borer control increased the efficacy of the insecticide. The addition of Break-Thru S240 to insecticides, with the contact/systemic and systemic modes of action, did not increase the period of efficacy of these insecticides applied against *B. fusca*. Mortality rates of *B. fusca* larvae remained above 55 % eight days after insecticide application after which it declined to levels as low as 20 %. Systemic insecticides will therefore not be effective when applied as preventative applications against stem borer infestations.

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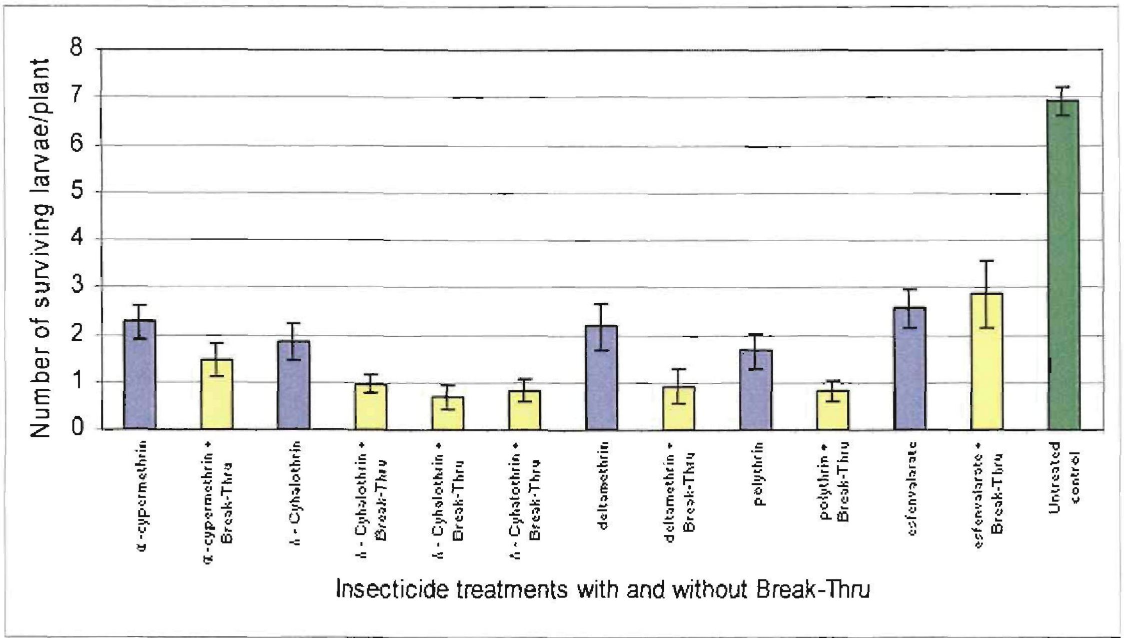

Figure 3.3. The mean number of *Chilo partellus* larvae per maize plant recovered after application of different insecticides applied with and without Break-Thru S240 (Bars represent Standard Errors).

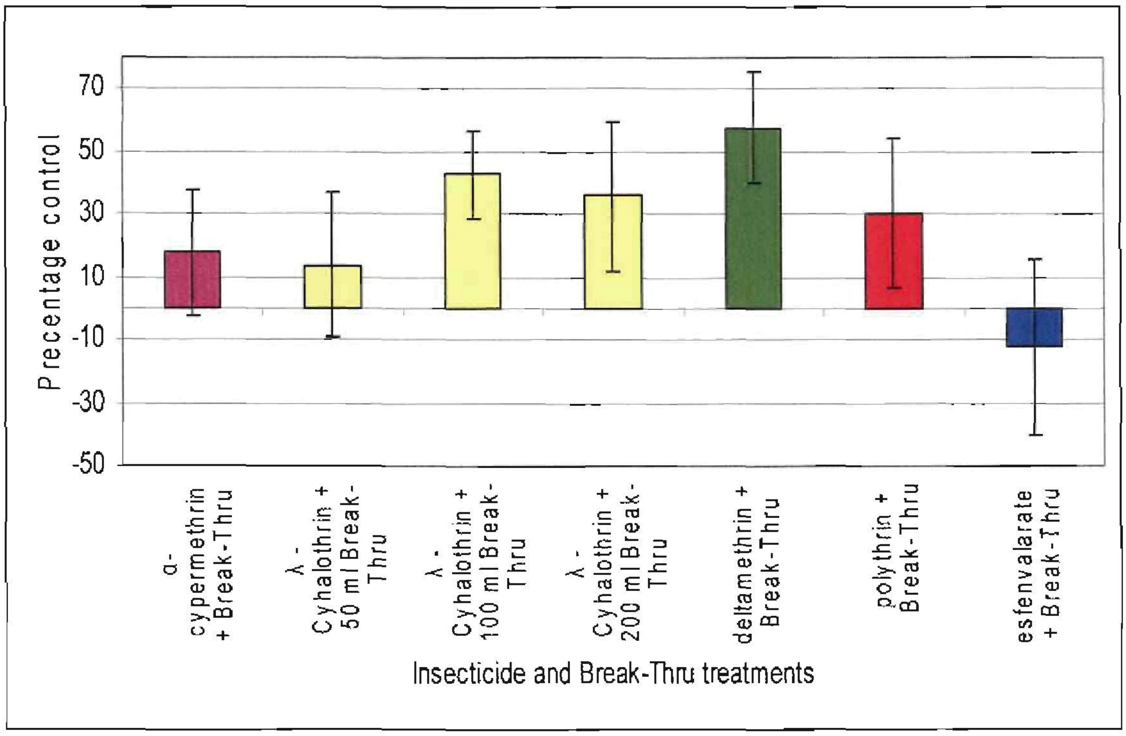

Figure 3.4. Percentage increase in control of *Chilo partellus* provided by insecticides after addition of Break-Thru S240 calculated in terms of insecticide treatments without Break-Thru S240. (Bars represent Standard Errors).

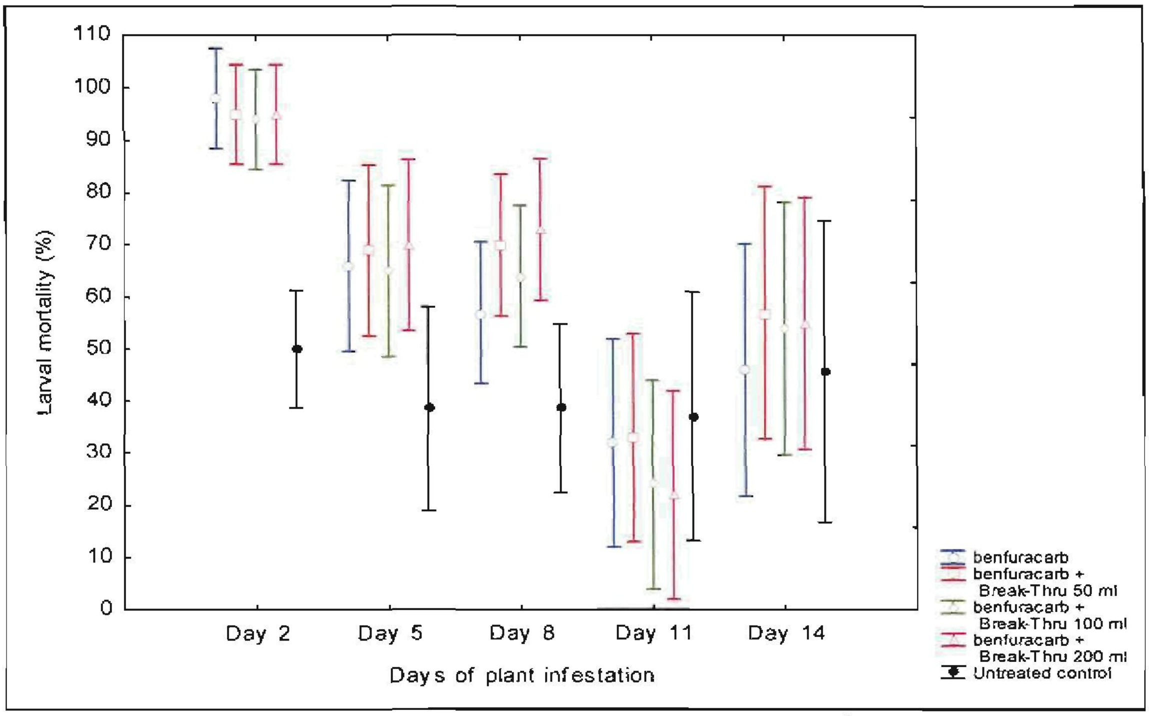

Figure 3.5. The effect of Break-Thru S240 on the efficacy of benfuracarb applied for control of *Busseola fusca* larvae over a period of 14 days after insecticide application. (Bars represent Standard Errors).

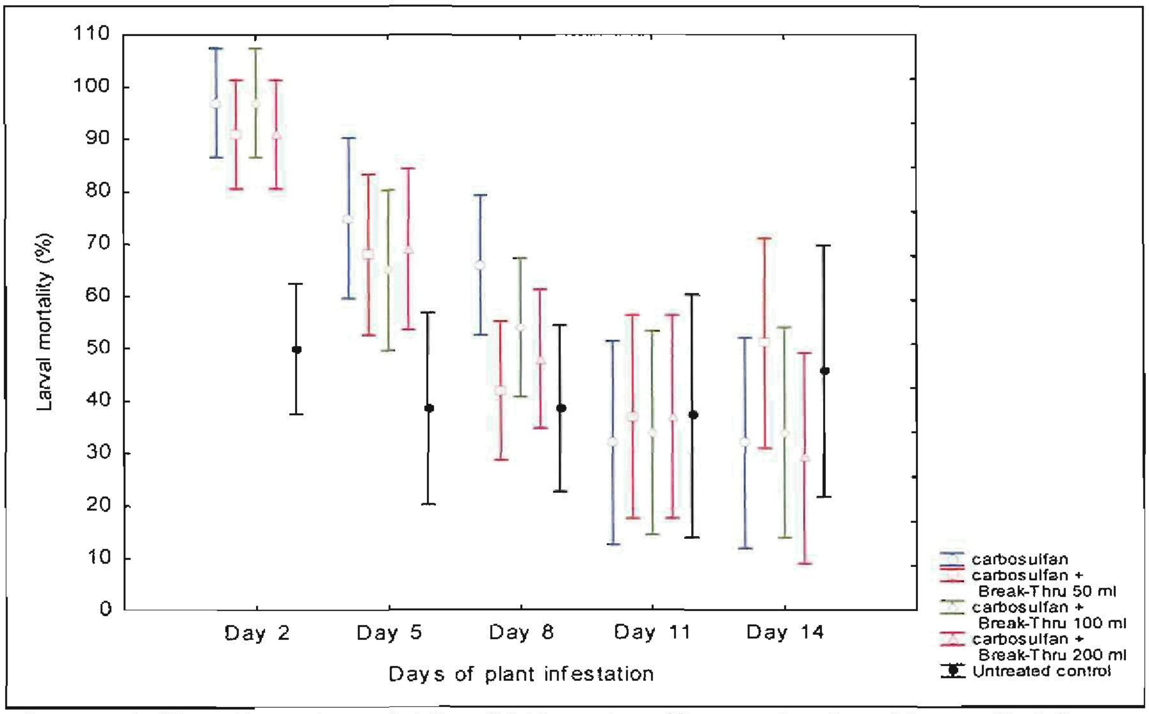

Figure 3.6. The effect of Break-Thru S240 on the efficacy of carbosulfan applied for control of *Busseola fusca* over a period of 14 days after insecticide application. (Bars represent Standard Errors).

Table 3.1. Effect of different insecticides applied with and without Break-Thru S240 on survival of *Chilo partellus* in maize.

Treatment	Mean number of surviving *Chilo partellus* larvae plant^{-1}
λ – cyhalothrin + Break-Thru (100 ml ha^{-1})	0.71 a
λ – cyhalothrin + Break-Thru (200 ml ha^{-1})	0.79 a
Polythrin + Break-Thru (100 ml ha^{-1})	0.80 ab
Deltamethrin + Break-Thru (100 ml ha^{-1})	0.91 ab
λ – cyhalothrin + Break-Thru (50 ml ha^{-1})	0.96 ab
α – cypermethrin + Break-Thru (100 ml ha^{-1})	1.46 ab
Polythrin	1.65 ab
λ – Cyhalothrin	1.85 ab
Deltamethrin	2.18 ab
α – cypermethrin	2.24 ab
Esfenvalarate	2.56 ab
Esfenvalarate + Break-Thru (100 ml ha^{-1})	2.84 b
Untreated control	6.92 c

*Treatment followed by the same letter does not differ significantly at P = 0.05, according to Tukey's multiple range test.

Table 3.2. Number of surviving *Busseola fusca* larvae recovered per plant three days after infestation on the respective dates (combined data for all treatments).

Day of insecticide application	Mean number of surviving *Busseola fusca* larvae
Day 2	0.8 a
Day 5	3.3 b
Day 8	4.3 b
Day 11	5.6 c
Day 14	6.8 d

*Means within columns followed by the same letter do not differ significantly at P = 0.05, according to Bonferoni's multiple range test.

Table 3.3. The effect of the addition of Break-Thru S240 to systemic insecticides on survival of *Busseola fusca* in maize over a 14 day period (combined data for all treatments).

Treatment	Mean number of surviving *Busseola fusca* larvae plant^{-1}	
benfuracarb + 50 ml Break-Thru	4.7	a
carbosulfan + 50 ml Break-Thru	4.9	a
benfuracarb + 100 ml Break-Thru	5.7	a
untreated control	5.8	a
benfuracarb	6.0	a
benfuracarb + 200 ml Break-Thru	6.4	a
carbosulfan + 100 ml Break-Thru	6.6	a
carbosulfan	6.8	a
carbosulfan + 200 ml Break-Thru	7.1	a

*Means within columns followed by the same letter do not differ significantly at P = 0.05, according to Tukey's multiple range test.

CHAPTER 4: THE EFFECT OF WATER VOLUME AND DOSAGE RATE OF BREAK-THRU S240 ON THE DISTANCE OF MOVEMENT OF SPRAY APPLICATIONS INTO MAIZE WHORLS

4.1 Introduction

Chemical control of the maize stem borers *Busseola fusca* (Lepidoptera: Noctuidae) and *Chilo partellus* (Lepidoptera: Crambidae) is often uneconomical or ineffective (Van den Berg & Van der Westhuisen, 1995). Conventional insecticides often do not reach larvae where they feed deep inside the whorl leaves of maize plants, but only penetrate up to the so called "dew-line" of the whorl (Van den Berg & Viljoen, 2007). When organosilicone surfactants are added to insecticide spray formulations the surface tension of the spray formulation is lowered significantly. This exceptionally low surface tension of water, imposed by organosilicones, enables insecticide mixtures to penetrate minute cavities such as stomata of leaves (Wood & Tedders, 1997).

Surfactants or wetting agents are commonly used in agricultural pesticide spray formulations to improve physico-chemical characteristics of the spray solution and to increase the efficacy of foliage-applied agrochemicals (Knoche, 1994). Complete spreading of the droplets may be expected with the addition of organosilicones to the spray formulation. In a review on organosilicones applied in sprays on pea leaves, Stevens (1993) noted that these compounds may have great potential as adjuvants for insecticides. This is due to the fact that larger droplets can be used in order to minimize drift. The adhesion of these large droplets will be enhanced by the organosilicone. Organosilicones reduce the surface tension of spray solutions to very low levels and more rapidly than hydrocarbon-based surfactants, thus improving the spreading of such large droplets on plant surfaces (Stevens *et al.*, 1993).

Water is the carrier or diluting agent for most of the agrochemical sprays used in the agricultural sector and also serves as the carrier of insecticides onto the plant. Because of the high surface tension of water, such spray formulations may be poorly retained on the waxy, hydrophobic, surfaces of the target plant's leaf surface (Stevens *et al.*, 1993).

Thorough coverage of the target area is a very important factor affecting the efficacy of insecticides against stem borers (Pedigo, 2002). In order to ensure sufficient plant coverage by the spray mixture, it is important that the correct water volume is used in the application. Different application strategies require different water volumes as application rate. For example aerial applications are limited to 30 – 40 l of water ha^{-1} because of weight limitations. Application by means of tractor mounted sprayers may be done at volumes of 200 - 300 l of water ha^{-1}. These dosages may increase up to 600 l of water ha^{-1} if insecticides are applied through a centre pivot irrigation system. The type of crop as well as the type of pest should be taken into consideration when water volumes and dosage rates are determined (Pedigo, 2002).

The aims of this study were to determine the effect of different dosages of the organosilicone, Break-Thru S240, applied at different water volumes on the depth of movement of a spray application into maize plant whorls as well as to determine the potential of Break-Thru S240 to cause phytotoxicity symptoms when applied at higher dosage rates.

4.2 Materials and methods

4.2.1 Effect of different dosages of Break-Thru S240 on the distance of movement of spray applications into plant whorls

An experiment was conducted during the 2006/07 growing season at the experiment farm of the Agricultural Research Council, Potchefstroom. The experimental design was a randomized block with 12 treatments and four replications. Treatments consisted of six different Break-Thru S240 dosages each applied with both two and three litres of water 100 m^{-1} row length respectively. Included in these treatments were the two dosages at which Break-Thru S240 is registered as adjuvant for insecticide applications in South Africa (100 and 200 ml ha^{-1}). A blue colorant dye (2 % per volume) was added to facilitate observation of the distance that the spray mixture moved down the plant's whorl leaves (Fig. 4.1).

The experiment was laid out in a 1.2 hectare block of maize planted at an inter-row spacing of 1.5 m and an intra-row spacing of 0.2 m. Plot rows were 8 m long. The experiment commenced five weeks after seedling emergence. The spray applications were applied by means of a CO_2-pressurised knapsack sprayer with a delivery pressure set at 7 l min.$^{-1}$, using a hollow cone nozzle. The insecticide spray was directed into the whorls of plants. Spraying commenced in the early morning (06:00) to minimize the effect that wind might have on the drifting of spray droplets.

The first five plants from each replicate were collected in the late afternoon 10 hours after spray application. Plants were cut off at soil level and stored in an upright position overnight. This was done to eliminate the effect that dew or rain could have had on the movement of spray applications on plants if they were left on the field over night. Data collecting commenced the following morning. The whorl was separated from the rest of the plant by cutting off the stem at the level of the youngest fully unfolded leaf. This loosened the whorl from the stem and facilitated easy unfolding of the rest of the five youngest whorl leaves.

The leaves of the whorl were numbered according to age, with leaf 1 being the youngest leaf with an unfolded ligule and leaf 5 being the tightly rolled leaf inside the whorl and the youngest leaf of the whorl. Because of the small size of leaves 6 and 7 and the difficulty to observe the colorant on these leaves the data collected from these leaves were not used in any analysis since this could have resulted in inaccuracies. The distance of movement into the five different leaves was pooled for each leaf number and the means determined.

The length of each leaf blade that formed part of the whorl, as well as the distance of water movement down each leaf was determined using the method described in Chapter 3.2.2. This distance of movement into the whorl was then expressed as a percentage of the total leaf length.

4.2.2 The effect of Break-Thru S240 on the distance of movement of spray applications at different water volumes

This experiment was conducted to determine the effect of different water volumes during application on the distance of movement down the whorl leaves, of a spray application to which Break-Thru S240 was added. The experiment was laid out as a randomised block design with ten treatments and five replicates. Treatments consisted of five different water volumes each applied with and without Break-Thru S240 at a single dosage rate of 200 ml ha^{-1} respectively. The field trial was situated in the same field as described above using the same knapsack sprayer and CO_2 pressure. Plants were collected and the data recorded as described above.

4.2.3 The potential of Break-Thru S240 to cause phytotoxicity symptoms on maize plants when applied at higher dosage rates

This experiment was conducted during the 2007/08 growing season at the experiment farm of the Agricultural Research Council, Potchefstroom. The experimental design was a randomized block with 20 treatments and four replicates. Treatments consisted of nine different Break-Thru S240 dosages and a control treatment in which only water was applied. Each of these ten treatments was applied with a blue dye colorant as described above. Each treatment was applied at an application rate of 2 l water 100 m^{-1} row length. The application rates of Break-Thru S240 were (0, 50, 100, 200, 400 and 600 ml ha^{-1}). The last two dosage rates were higher than the registered dosage rates of 100 and 200 ml ha^{-1} in South Africa.

The experiment was laid out in a 1.2 hectare block of maize planted at an inter-row spacing of 1.5 m and an intra-row spacing of 0.2 m. Plot rows was 5 m long, containing approximately 15 plants, and there was a 2 m distance between plots within rows. The spray applications were done five weeks after seedling emergence. One week after spray application, the first ten plants in each plot row was checked for phyto-toxicity symptoms that could possibly result from the Break-Thru S240 and/or the blue colorant dye applications.

Phytotoxicity symptoms were rated on a scale from 1 to 5. A value of 1 represented plants with no visible phytotoxicity symptoms; a value of 2 represented plants with slight damage to the fully unfolded leaves, while a 3 represented plants that showed damage to the older whorl leaves that was not yet fully unfolded. Plants that showed severe damage to the whorl leaves rated a 4 and plants that were dead rated a 5. A mean damage rating was calculated for each plot.

4.2.4 Data analysis

Data were analysed by means of analyses of variance by using Statistica software (version 7.0). The three factors were: Break-Thru S240 dosage rate (0, 50, 100, 200,400 & 600 ml ha^{-1}), water volume (2 and 3 l water 100 m^{-1} row length) and leaf number (1 – 7). Anovas' were also conducted for each of the three factors. Distance of movement of the spray mixture down the particular leaf was expressed as a percentage of the total leaf length. Anovas' were conducted to determine the interaction between dosage and volume, volume and leaf number as well as dosage and leaf number. Tukey tests were used for all post hoc comparisons.

Mean rating values and standard errors were determined for the phytotoxicity symptoms observed in each treatment.

4.3 Results and discussion

4.3.1 Effect of different dosages of Break-Thru S240 on the distance of movement of spray applications into plant whorls

An example of the effect of Break-Thru S240 on water movement into whorl leaves as well as the movement of the spray application down the whole plant is shown in figure 4.1.

The addition of Break-Thru S240 to spray applications resulted in a significant increase in the distance of movement of applications into the whorls of the plants ($P = 0.0001$) (Table 4.1). There were however no significant differences in the distance of movement obtained by the two different water volumes ($P = 0.9303$) (Table 4.1). There was a significant interaction between the different Break-Thru S240 dosage rates and the two different water volume application rates ($P = 0.0001$) (Table 4.1). Significant differences ($P = 0.0001$) were observed between the distance of movement of spray formulations into the five different leaves that formed the whorl (Table 4.2).

The distance of movement calculated as a mean of the percentage movement on all leaves of a treatment provides a measure to compare between treatments. The control treatment moved down 76 % into the whorl. There was an increase of 10 % between the control and Break-Thru S240 applied at 50 ml ha^{-1}. When applied at 100 and 200 ml ha^{-1}, Break-Thru S240 treatments moved 9 and 12 % further down than the control treatment. At the extreme dosage of 600 ml ha^{-1} the Break-Thru S240 treatment moved 23 % further into the whorls than the control treatment (Fig. 4.2).

The distance of movement into each of the individual whorl leaves increased as the dosage of Break-Thru S240 in the spray formulation increased (Fig. 4.3). However, the movement down leaf five (youngest leaf) was less than the movement down leaves one to four. There was significant differences ($P = 0.001$) (Table 4.1) between the treatment where no Break-Thru S240 was added and the rest of the Break-Thru S240 application rates. This increase in movement in terms of the untreated control ranged between 6 % on leaf one and 13 % on leaf five.

The distance of movement of the spray application into plant whorls increased as the dosage of Break-Thru S240 increased (Fig. 4.2). When Break-Thru S240 was added at 50 ml ha^{-1} at the higher water volume of 3 l 100 m^{-1} row length (300 l water ha^{-1}), the increase of movement down into the whorl was only 3% higher than the control treatment. Although there was a tendency of increased movement of the spray application at the higher water volume, the increase was less than at the lower water volume of 2 l water 100 m^{-1} row length (Fig. 4.2).

There was no significant difference between the distance of movement of the spray formulation on leaves 1 and 2 (Table 4.2). However, the distance of movement on the other leaves differed significantly from each other as well as from the first two leaves.

However, a marked increase in the distance of movement of the spray formulation, down into the whorls of maize plants, was observed on the youngest leaf (leaf 5) compared to the other leaves, indicating that the distance of movement into the whorl was increased with the addition of Break-Thru S240 at higher dosages (Fig. 4.3). Significant differences ($P = 0.0001$) (Table 4.1) in the movement of the spray formulations were observed between the 200 and 400 ml ha^{-1} Break-Thru S240 dosages on all five whorl leaves (Fig. 4.3).

The distance of movement of the 200 ml ha^{-1} dosage rate ranged between 9 % on leaf 1 up to 16 % on leaf 5 while with the 400 ml ha^{-1} dosage the distance of movement ranged between 12 and 33 % from leaves 1 to 4. A significant difference ($P = 0.0001$) (Table 4.1) between the 400 and 600 ml ha^{-1} Break-Thru S240 dosages could only be observed on leaf 5. The distance of movement of the 600 ml ha^{-1} dosage ranged between 13 % on leaf 1 up to 38 % on leaf 5 (Fig. 4.3).

The furthest downwards movement down leaves 4 and 5, which were the two most inner and the youngest leaves of the whorl, was achieved at the 200 and 400 ml ha^{-1} Break-Thru S240 dosages. The highest level of penetration (100 %), into each of the five leaves was obtained with the 600 ml ha^{-1} Break-Thru S240 dosage rate (Fig. 4.3). However, phytotoxicity symptoms appeared inside the whorl where leaf tissue was still very soft, yellow and not exposed to sunlight. This damage was either caused by the high dosage rate of Break-Thru S240 that could have burned the leaves or by a chemical reaction between the Break-Thru S240 and the blue dye colorant that was used. Examples of such damage are shown in figure 4.4. These observations prompted a follow-up study on phytotoxicity of Break-Thru S240 and the possibility that the colorant could contribute to these symptoms.

The distance of movement required by a spray application to reach the site where stem borer larvae were feeding (Chapter 2) was exceeded by all applications where Break-Thru S240 was included. This indicates that Break-Thru S240 application at dosages of as low as 50 ml ha^{-1} resulted in sufficient movement down whorl leaves and that it can be used effectively with insecticides applied against stem borer larvae inside maize whorl leaves.

4.3.2 The effect of Break-Thru S240 on the distance of movement of spray applications at different water volumes

The addition of Break-Thru S240 to the spray application had a significant effect ($P = 0.0001$) (Table 4.3) on the distance of movement down the whorls of maize plants. There were no significant differences ($P = 0.4574$) between distances of movement into whorls after application at different water volumes (Table. 4.3). However, the distances of movement of the spray applications into each of the five whorl leaves differed significantly ($P = 0.0001$) (Table 4.3). There were significant interactions observed between dosage and volume ($P = 0.0001$) as well as volume and leaf number ($P = 0.0004$) (Table 4.3).

There was significantly ($P = 0.0001$) (Table. 4.3) further movement of spray applications into plant whorls when Break-Thru S240 was added to the treatments (Fig 4.5). The addition of Break-Thru S240 to spray applications at very low application rates of 0.5 and 1 l water 100 m^{-1} row length resulted in increased movement into plant whorls (Fig. 4.5). At spray application rates of 2 l water 100 m^{-1} row length and higher this increase was not observed. Reduced movement was observed at the very high water volume of 6 l water 100 m^{-1}. The latter observation can probably be ascribed to run off from the maize plant instead of penetration down whorls.

Analysis of combined data for each of the water volumes indicated that there was not sufficient downward movement of the application at 0.5 l ha^{-1} to reach the zone (Fig. 4.6) where stem borer larvae feed inside the plant (leaves 3 and 4) (Chapter 2). All applications moved down the whorl deep enough to reach stem borer feeding depth on leaves 3 and 4 (Fig. 4.6 and 4.7). However, at 0.5 l ha^{-1} the spay application did not move down far enough to reach the feeding site of larvae on leaf 4. This may cause larvae to survive insecticide applications when they are feeding on the fifth leaf of the whorl and deeper.

4.3.3 The potential of Break-Thru S240 to cause phytotoxicity symptoms on maize plants when applied at higher dosage rates

Figure 4.8 indicates the different Break-Thru S240 treatments that were applied as well as those treatments that contained the blue dye colorant. Each Break-Thru S240 dosage was applied with and without the colorant. It is evident from figure 4.10 that, when the Break-Thru S240 dosage of 250 ml ha^{-1} is exceeded, visible phytotoxicity symptoms appear on leaves. At Break-Thru S240 dosage rate below 150 ml ha^{-1}, the addition of the colorant resulted in no or only negligible signs of phytotoxicity. However, at higher dosages the addition of the colorant contributed to the severity of phytotoxicity symptoms.

Although the relationship between the severity of phytotoxicity and yield was not determined, it was estimated that severity ratings of 3 and higher could result in yield losses. Although pronounced distances of movement were observed with the 400 and 600 ml ha^{-1} application rates, the use of Break-Thru S240 at these high dosage rates is not economically viable and it resulted in phytotoxicity. In crops such as citrus Break-Thru S240 is sprayed at dosages as high as 500 ml ha^{-1}. This is however, done with water volumes ranging between 5000 and 10 000 l of water making the concentration of Break-Thru S240 applied on citrus much lower than the concentration in an insecticide application on maize where water volumes of 250 to 300 l ha^{-1} is applied.

4.4 Conclusions

The addition of Break-Thru S240 resulted in a significant increase in the distance of movement of water down into the whorls of maize plants. This may result in increased efficacy of chemical control against *C. partellus* and *B. fusca*. The most effective dosages of Break-Thru S240 in terms of distance of movement were the 100 and 200 ml ha^{-1} applications at between 100 – 300 l water ha^{-1}.

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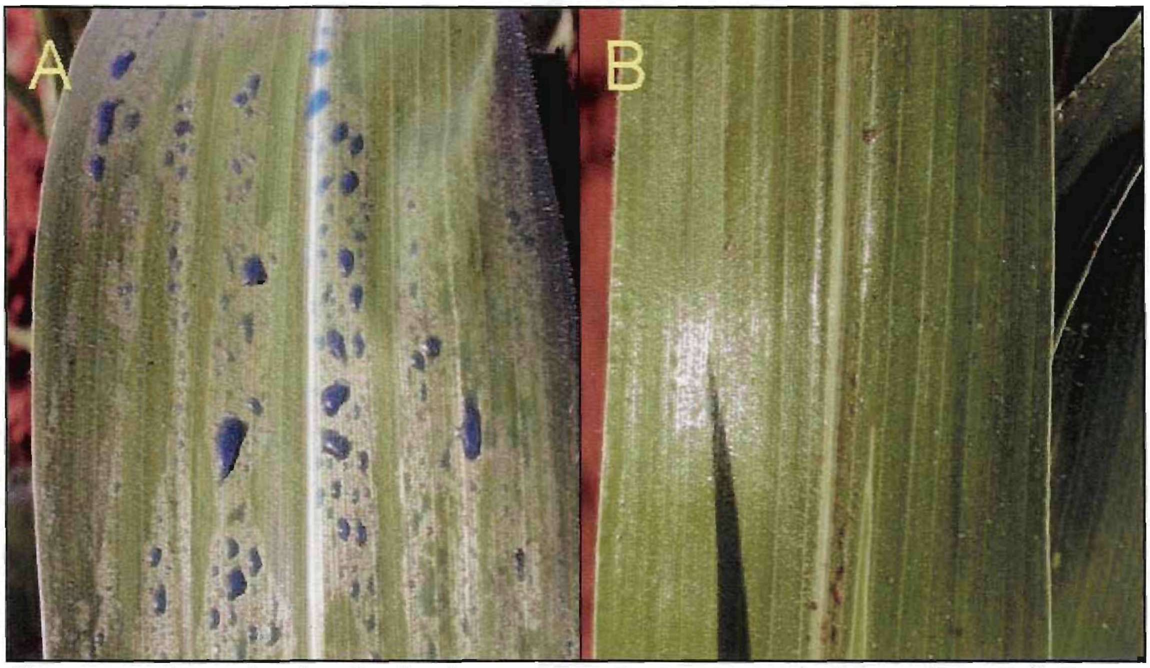

Figure 4.1. Water droplet distribution on maize leaves sprayed with a mixture of water and a blue colorant without (A) and with (B) Break-Thru S240 added to the mixture (dosage: 200 ml ha^{-1}).

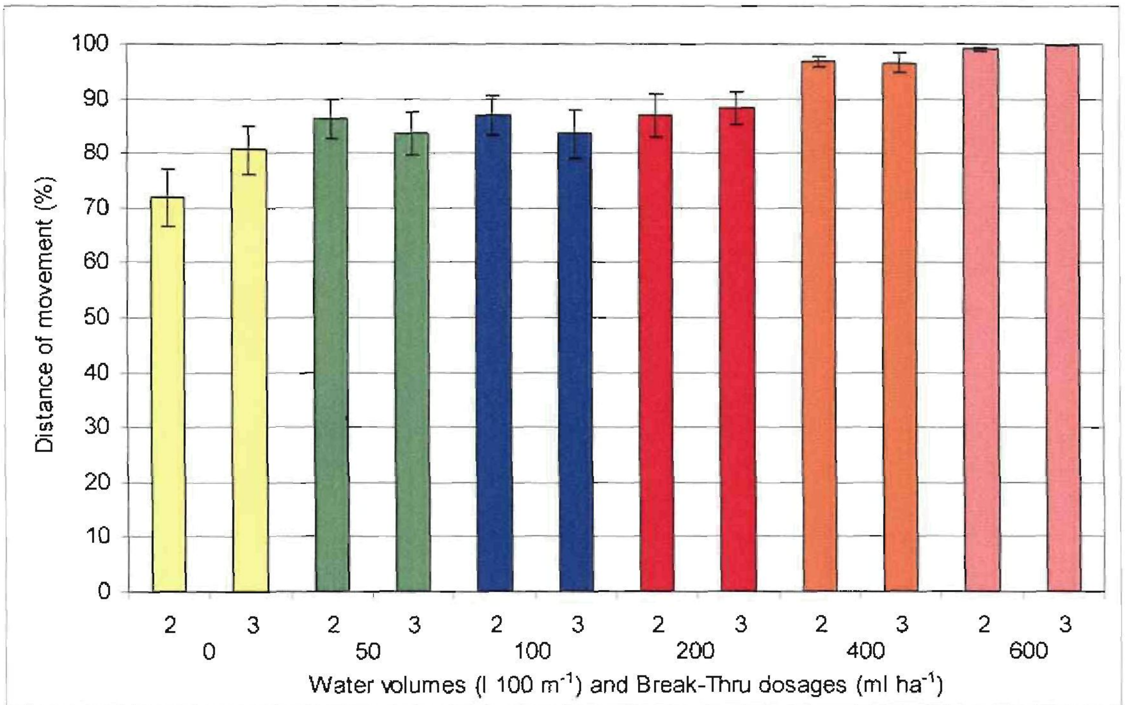

Figure 4.2. Distance of movement into whorls of maize plants of application of water at different volumes and Break-Thru S240 at six dosages.

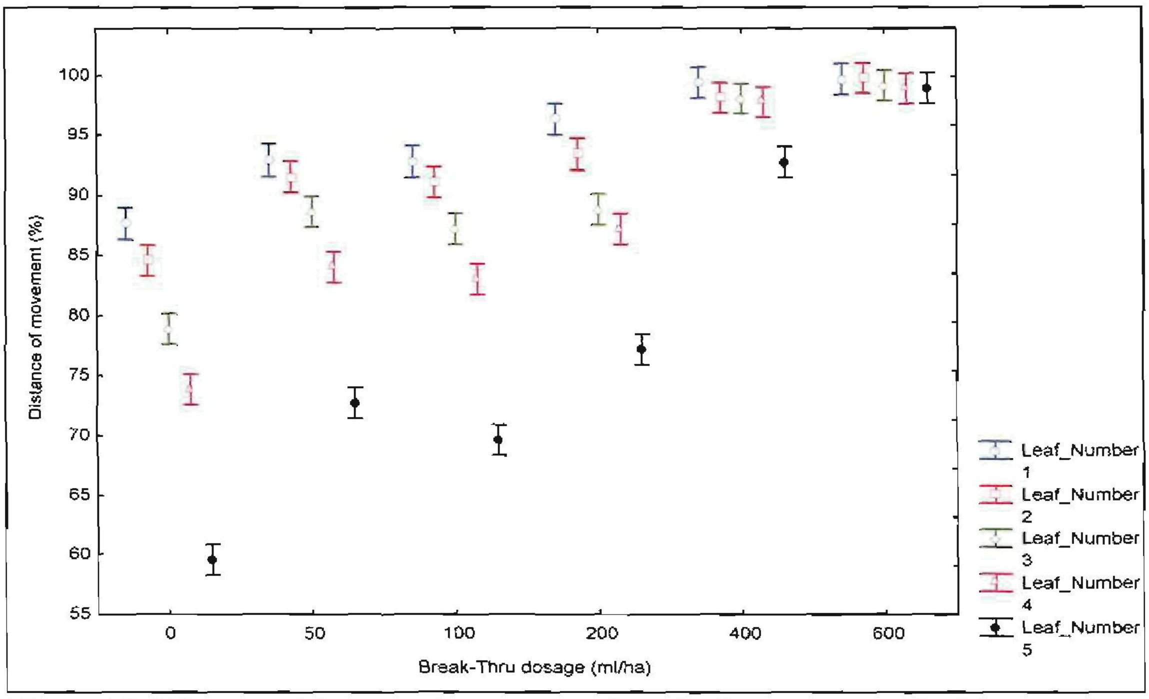

Figure 4.3. Distance of downwards movement into the five youngest whorl leaves of maize obtained with applications at 2 l water and different dosages of Break-Thru S240.

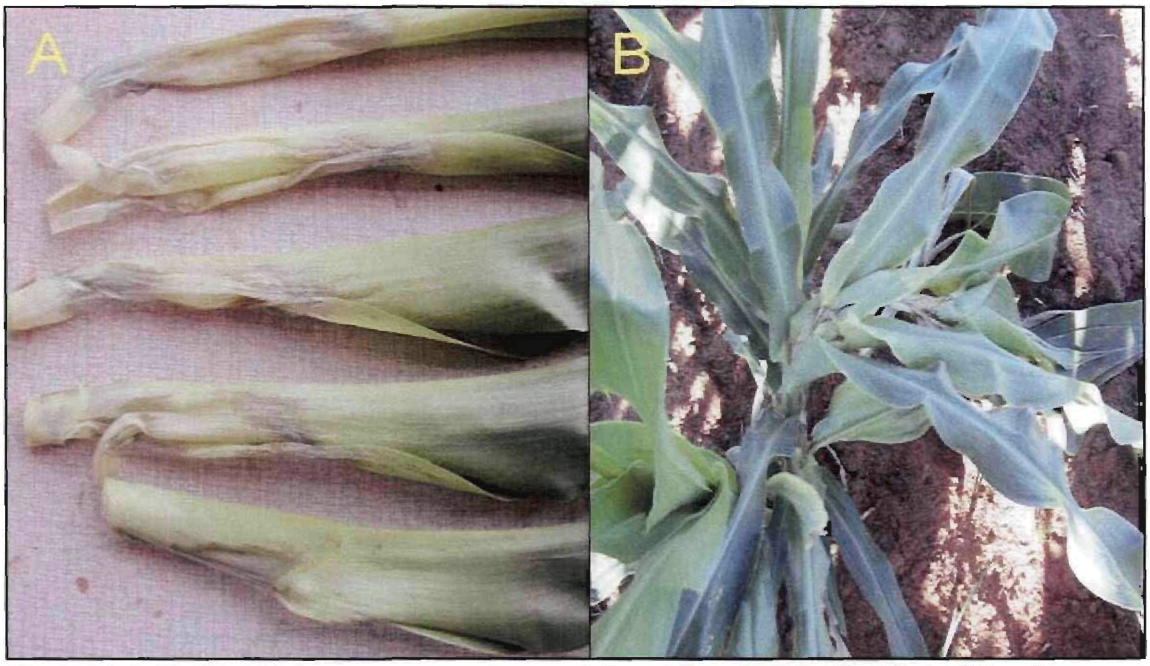

Figure 4.4. Phytotoxicity symptoms observed five days after application of Break-Thru S240 at a dosage rate of 600 ml ha^{-1}, on the lower parts of the whorl leaves (A) and on the whole maize plant (B).

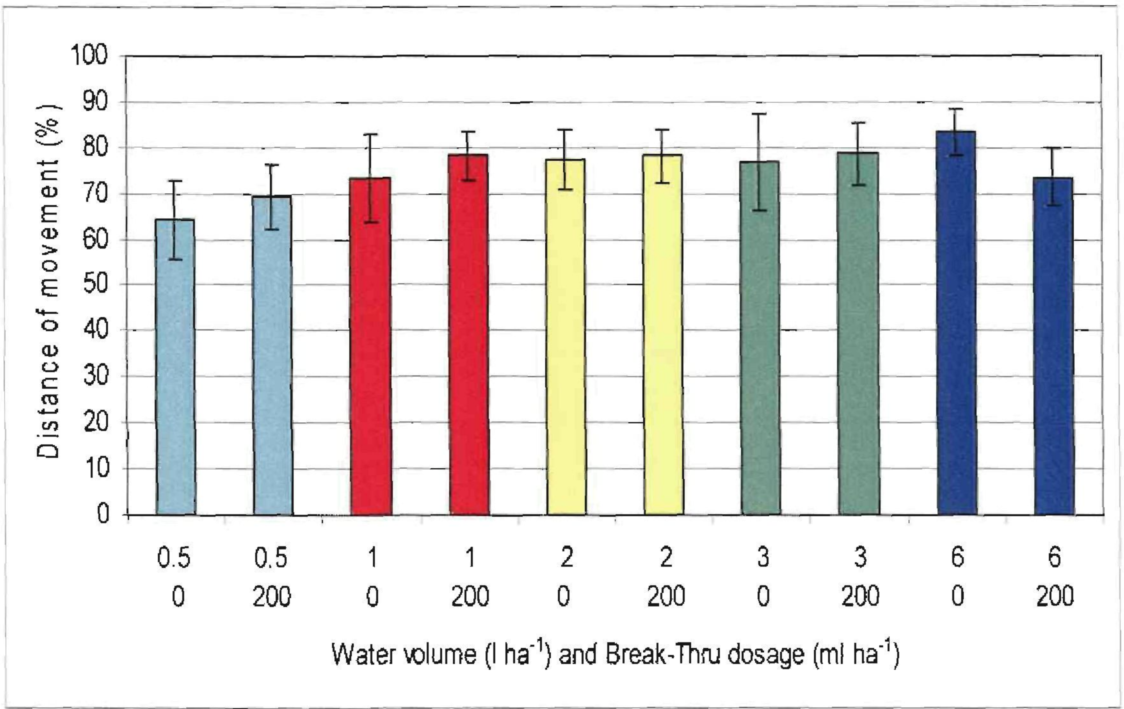

Figure 4.5. Distance of downward movement into whorls of applications at different water volumes, applied without and with Break-Thru S240 at 200 ml ha^{-1} into whorls of maize plants.

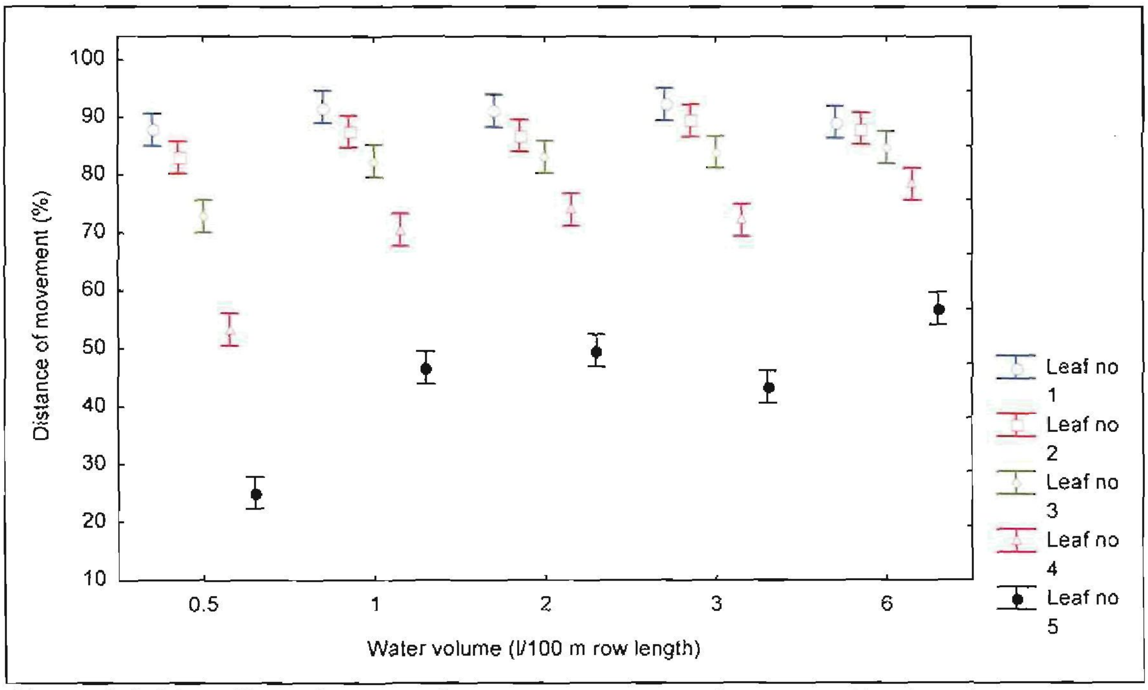

Figure 4.6. The effect of water volume on movement of spray applications into different whorl leaves.

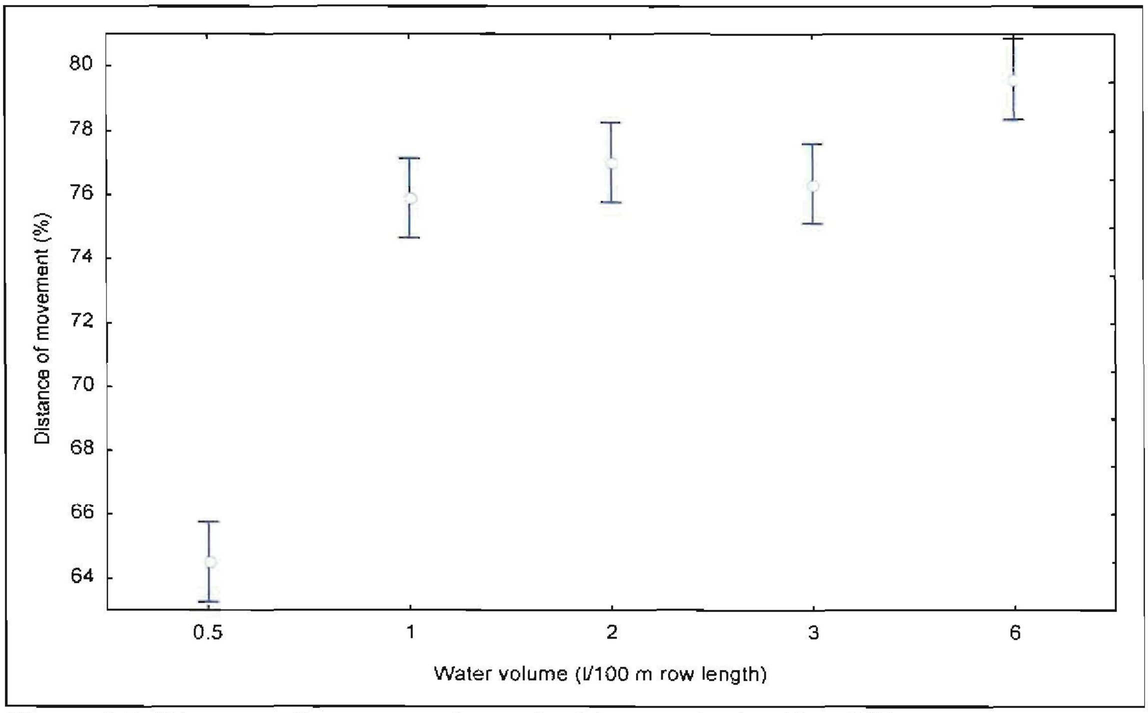

Figure 4.7. Distance of movement into whorl leaves obtained by different water volume application rates.

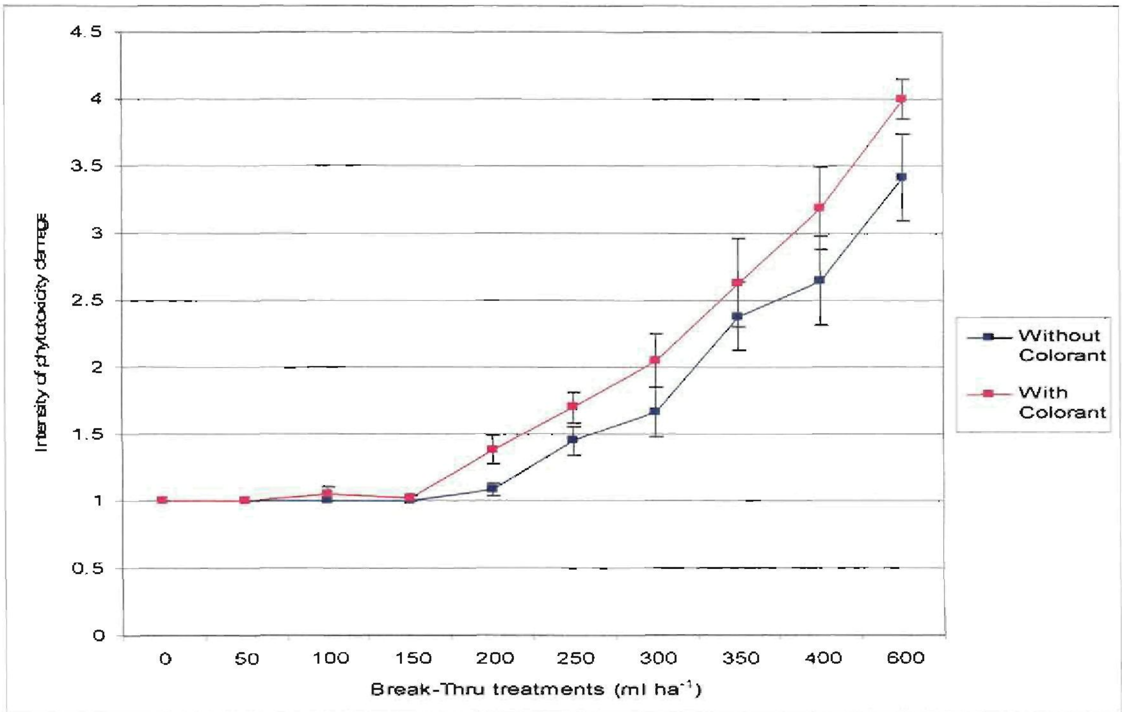

Figure 4.8. A comparison the phytotoxicity symptoms resulting from Break-Thru S240 applications at different dosages with and without the blue dye colorant.

Table 4.1. Effects of different dosage rates of Break-Thru S240 and water volume on distance of spray movement into plant whorls.

Main effects	Significance values	
Treatment	F-value	P-value
Dosage (A)	[5; 964] = 54.19	0.0001
Volume (B)	[1; 946] = 0.01	0.9303
Leaf number (C)	[4; 964] = 173.41	0.0001
Interactions		
A x B	[5; 946] = 9.60	0.0001
A x C	[20; 964] = 0.87	0.7440
B x C	[4; 946] = 0.86	0.5065

*Means within column followed by the same letter do not differ significantly at P = 0.05, according to Tukey's multiple range test

Table 4.2. Distance of movement of the different spray applications containing different Break-Thru S240 dosages into each of the 5 leaves that was measured.

Leaf number	Distance of movement (%)
5	78.4 a
4	87.4 b
3	90.1 b
2	93.1 c
1	94.8 c

*Means within column followed by the same letter do not differ significantly at P = 0.05, according to Tukey's multiple range test.

Table 4.3. Effects of different water volumes and Break-Thru S240 dosage rates on the distance of movement of water applications into whorls of maize plants.

Main effects	Significance values	
Treatments	F-value	P-value
Dosage (A)	[1; 825] = 2.32	0.0001
Volume (B)	[4; 825] = 22.17	0.1283
Leaf number (C)	[4; 825] = 223.76	0.0001
Interactions		
A x B	[4; 825] = 7.16	0.0001
A x C	[4; 825] = 0.91	0.4574
B x C	[16; 825] = 3.06	0.0004
A x B x C	[16; 825] = 1.30	0.1915

*Means within column followed by the same letter do not differ significantly at P = 0.05, according to Tukey's multiple range test.

CHAPTER 5: CONCLUSIONS

Chemical pest control can be considered the heart and sole of integrated pest management (IPM) (Jotwani, 1982). The banning of insecticides such as monocrotophos from the agricultural market, the development of insect resistance to insecticides and to genetically modified Bt maize, in the case of *Busseola fusca* (Van Rensburg, 2007) provides new opportunities for pest management and a unique challenge for pest management practitioners in general (Van Wyk, 2006). It was reported by Huang *et al.* (2003) that biotechnology can be used as a substitute for chemical control. However, in areas where resistance against Bt maize has already developed, the use of chemical control strategies will be a necessity.

It is well known that insecticide applications are often ineffective (Mercer, 2007). This can be ascribed to several factors such as the use of the wrong sprayer and nozzle type, poor distribution of droplets and wrong droplet size, improper impaction and deposition, poor retention to the plant as well as poor uptake by the plant. The cryptic feeding of lepidopterous stem borer larvae inside plant whorls particularly contributes to the problem of poor control in crops such as maize. Technology that would result in an increase in movement of insecticides into plant whorls could result in improved control of stem borers. Surfactants such as Break-Thru S240, Agral and Nu-Film P are commonly used in pesticide formulations to improve the physico-chemical characteristics of the spray solution and to increase the efficacy of foliage-applied agrochemicals. However, the effects of these compounds on insecticide movement into maize whorls have not been previously evaluated.

Prior to this study, a pilot study (Van den Berg and Viljoen, 2007) showed that addition of Break-Thru S240 to insecticides resulted in increased stem borer mortalities in maize. The latter authors speculated that the addition of Break-Thru S240 resulted in increased movement of insecticide sprays into plant whorls. The general objective of the current study was to determine if organosilicones added to spray mixtures resulted in increased movement of spray applications into plant whorls and increased efficacy of chemical stem borer control.

Prior to this study the feeding site of stem borer larvae inside plant whorls was described as "deep inside" the whorl or in the "yellow-green" area of whorl leaves. In order to have a reference point against which movement of spray applications into whorl leaves can be evaluated and compared the need existed to quantify the depth (zone) of feeding damage on leaves. In this study the site of feeding damage on leaves, expressed as a percentage, were used as "control distance" against which all treatments were evaluated. Since leaves 3 and 4 made up the largest proportion of damaged leaves, it can be concluded that any application that moves further than the 80 and 70 % distances on leaves 3 and 4 respectively, can be considered to be successful.

Different adjuvants resulted in different distances of movement of spray applications down into whorl leaves. This study showed that the area where larvae feed inside the whorl was largely in leaves 3 and 4 of the whorl. Although insecticide applications usually moved into this feeding zone, the addition of adjuvants resulted in movement further into the feeding zone. This study showed that Break-Thru S240 and Agral were superior to other adjuvants. Agral, used in this study, is an example of a nonylphenol ethoxilate (NPE). Because of pressure from the European Union, where all NPE's were banned during 2005, the use of all NPE's as agricultural tank-mix adjuvants will be banned from South Africa in the near future (Cecilia van Rooyen, Syngenta; personal communication). This increases the necessity of research on non-NPE adjuvants such as Break-Thru S240 which remains as one of the few tank-mix adjuvants available for agricultural purposes in South Africa.

The distance of movement into each of the individual whorl leaves increased as the dosage of Break-Thru S240 in the spray formulation increased. However, the movement down the inner most leaf was less than the movement down leaves 1 to 4.

Although there was a tendency of increased movement of the spray application at the higher water volume of 300 l ha^{-1}, the increase was less than at the lower water volume of 2 l water 100 m^{-1} row length. The most effective dosages of Break-Thru S240 in terms of distance of movement were 100 and 200 ml ha^{-1} applied at between 100 – 300 l ha^{-1}.

When Break-Thru S240 was applied at different water volumes it resulted in a significant increase in the distance of movement down the whorls of maize plants. Through a reduction in water tension insecticides will be carried deeper into plant whorls which will enhance it's efficacy against *C. partellus* and *B. fusca*. It was found that the most effective dosages of Break-Thru S240 were between 50 and 200 ml ha^{-1} which includes the currently registered dosages of 100 and 200 ml ha^{-1} recommended for use with insecticides on grain crops in South Africa.

Although large increases in the distances of movement were observed at dosages ranging between 400 and 600 ml ha^{-1}, the use of Break-Thru S240 at these high dosage rates is not economically viable and it resulted in phytotoxicity. Insecticides are generally applied at water volumes of 300 l ha^{-1} with tractor mounted sprayers, 30 - 45 l ha^{-1} in aerial applications and more that 600 l ha^{-1} in centre pivot irrigation systems. The higher the water volume the higher the distance of movement of spray applications into whorl leaves. The addition of Break-Thru S240 to an insecticide application, especially with aerial applications, would probably result in increased movement into plant whorls followed by increased efficacy.

The current study showed that the addition of Break-Thru S240 to insecticides with a contact action resulted in increased levels of control of *Chilo partellus* ranging between 14 - 58 %. This indicates that the addition of Break-Thru S240 as a tank-mix adjuvant to insecticides intended for stem borer control resulted in increased efficacy of insecticides. The improved efficacy observed with contact insecticides was not observed with systemic insecticides to which Break-Thru S240 was added applied against *B. fusca*. The systemic insecticides applied against *B. fusca* were not any more effective at 11 days after infestation and results showed that in this particular evaluation Break-Thru did not contribute to increased efficacy of insecticide. Insecticide efficacy decreased to levels of control ranging between 60 and 30 % on days eight and eleven respectively, after spray application. Under field conditions, these low levels of control would necessitate a follow-up application of insecticides for stem borer control.

This study showed that the organosilicone Break-Thru S240 can be effectively used as an adjuvant to increase the efficacy of insecticides applied for stem borer control on maize and that adjuvants in general resulted in an increase of movement of spray applications into plant whorls.

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