# EFFICACY OF IMAZAPYR HERBICIDE SEED DRESSING ON MAIZE (*Zea mays* L.) IN THE CONTROL OF WITCHWEED [*Striga asiatica* (L.) Kuntze] AND THE EVALUATION OF CIMMYT IMAZAPYR RESISTANT MAIZE HYBRIDS FOR AGRONOMIC PERFORMANCE

**A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CROP PRODUCTION**


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**ABSTRACT**

The parasitic weed *Striga asiatica* (L.) Kuntze is one of the major constraints in maize production in Zimbabwe. Studies were conducted in the 2010 and 2011 rainy season to evaluate the effects of imazapyr seed dressing on *Striga* suppression and grain yield at Henderson Research Station, CIMMYT Harare and Muzarabani. Imazapyr was applied at 30 g/25kg of maize seed. A pot experiment was conducted at Henderson Research Station to find the effect of seed dressing with imazapyr on *S. asiatica* infestation. The experiment was a factorial design with five untreated imazapyr resistant maize lines and five treated lines. The lines used were J437-27, J437-29, J437-30, J450-2, and J450-3. Field experiments were conducted at CIMMYT-Harare and Muzarabani sites to evaluate the imazapyr resistant maize lines for agronomic performance. There were significant differences (P<0.05) among the imazapyr resistant (I.R) maize lines in *Striga* suppression. The treated hybrids showed suppressive effects of imazapyr on *Striga*. There were no significant differences among the treated plots due to the delay in *Striga* emergence. Field trials conducted at CIMMYT showed that if the StrigAway maize is grown in a field not infested with *Striga* the hybrids will perform to the same standard as other improved maize varieties and the farmer will not have the benefit of imazapyr seed dressing in the absence of *Striga* infestation. Analysis of variance showed highly significant differences (P<0.05) among the lines. The best performing hybrids were J450-2 and J437-29 with an average yield of 7t/ha while the lowest yielder among the hybrids recorded was J437-30 with an average yield of 5.8t/ha. There was highly significant difference in response to Maize Streak Virus disease infection. The line J450-2 had the highest MSV score showing it had least resistance to MSV and J437-30 had the lowest MSV score indicating that it is the most tolerant hybrid. The line J437-29 had the least score for grey leaf spot of 1.7 among treated lines while line J450-2 had the least score for grey leaf spot among the untreated lines. Line J437-27 had the least score of 2.5 for leaf rust among the treated lines. The line J450-2 had the least score of 1.2 for ear rot (*Sternocapella maydis*) among both treated and untreated lines. Overall the results for grain yields and disease infection at CIMMYT-Harare and Muzarabani showed that the lines J450-2 and J450-3 have the best potential and are recommended for further screening in field trials. At Muzarabani, maize grain yield were significantly different among the hybrids at (P<0.05). However J450-3 had a higher yield with the least obtained from treated J437-29 with a yield of 4.5t/ha.

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## DEDICATION

To my husband Collins, son Collins Jr, daughters Phoebe and Farirai, and my late father.

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# CHAPTER ONE

# INTRODUCTION

Witchweed [*Striga asiatica* (L) Kuntze] belongs to the *Scrophulariaceae* family. This is a genus of root parasitic plants (Berner, Kling and Singh, 1995). Most *Striga* species are of no agricultural importance but those that parasitize crop plants can be extremely damaging. In Africa the damage caused by these parasites can be devastating to resource-poor farmers whose lives can be threatened by complete yield loss. The witchweed decimates maize (*Zea mays*), millet (*Pennisetum sp*), sorghum (*Sorghum bicolor*) and upland rice (*Oryza sativa*) throughout sub-Saharan Africa from the high plateau of east Africa where peasant farmers struggle to survive on tiny fields of maize to the arid savannas of northern Nigeria where farmers rely on sorghum. African farmers today are fighting a tough battle against the *Striga* scourge. *Striga* is nevertheless more than just an unwanted weed growing in fields meant to produce food (Doggett, 1984). In Africa the witchweed problem is intimately associated with human population growth that leads to extreme pressure on land resources (Berner *et al*., 1995).

Traditional cropping systems included prolonged fallow, rotations and intercropping which were common practices that kept *Striga* infestations at tolerable levels (Dogget, 1984). However, with greater use of monocropping and very little or no fallow due to increased land pressure, the populations of these parasites gradually increased and became threats to food production (Parker and Riches, 1993).

Weed surveys conducted in the communal areas of Zimbabwe revealed that *S. asiatica* and other striga species such as *Striga hermonthica* infested maize (*Zea mays* L), sorghum (*Sorghum bicolor* (L) Moench) and millet (*Penisetum glaucum* (L) R. Br.) in all the provinces of Zimbabwe (Chivinge, 1988). This weed was the second most aggressive in Mashonaland Central and the third most aggressive in Midlands and Masvingo (Chivinge, 1988).

The history of the *Striga* problem in Zimbabwe dates back to the start of the twentieth century. The first *S. asiatica* damage was noted in maize in the Fingo "native" area near Bulawayo (Sowyer, 1904). However surveys have shown that *S. asiatica* is mainly a problem in the smallholder farming sector (Chivinge, 1988). Smallholder farmers who grow cereals live mainly in the marginal low rainfall, poor soil fertility areas (Natural Regions lll, lV and V of Zimbabwe). It is characteristic that *S. asiatica* causes the greatest damage under these conditions (Parker, Hitchcock and Ramaiah, 1977). Pest and disease control methods for these resource- poor farmers are mainly cultural and in some cases no control methods are employed (Chanyowedza, 1996).

**1.1 Witchweed – socioeconomic implications on smallholder farmers.**

There are several socio-economic problems associated with *S.asiatica* infestation on the smallholder farmer. *Striga asiatica* attack on cereals especially maize and sorghum in Zimbabwe has always been associated with high crop losses. Yield losses of 25-100 % in maize commonly occur especially under conditions of low fertility and erratic rainfall (Musselman, 1987). Crop plants have been observed to wilt even under adequate moisture conditions (Chivinge, 1988). Damage is made serious and control options reduced as a result of the weed's ability to inflict most of its damage before emerging above ground (Chivinge, 1988). Land abandonment has also been another problem that the smallholder farmer has also to bear with as a result of *S.asiatica* infestation.

There have been reports of total abandonment of fields as a result of heavy *S. asiatica* infestation and about 10 % of smallholder farmers on whose farms *S. asiatica* is a problem have abandoned their lands (Agronomy Institute, 1989). As most smallholder farmers do not have enough land with each household being allocated five to six ha (Munguri, 1997) land abandonment due to *S. asiatica* would negatively affect food security and income generation.

Parker and Riches (1993) reported that 5 % crop yield loss occurs for every *S. asiatica* plant per square meter while yield losses of 30-50 % are common under typical field infestations. In Zimbabwe, maize grain losses under sandy soils which favor *S. asiatica* growth have been observed to go as high as 100 % (Mabasa, and Malusalila, 1993). These socioeconomic problems imposed on the already cash strapped SH farmer lead to a further decline in national food security.

### 1.2 Problems of *S. asiatica* management

Although the majority of smallholder farmers in Zimbabwe are aware of the *Striga* problem, very few farmers put any effort to control the weed. One of the problems associated with *Striga* control is the fact that the weed is so prolific and produces large quantities of seed. Doggett (1984) reported that *S. asiatica* can produce up to 90 000 seeds per plant.

Pieterse (1991) reported that each plant produces a large number of tiny seeds which remain viable for up to 20 years. To worsen the problem, the seeds only germinate under the influence of a germination stimulant produced by the roots of certain plants (both hosts and non hosts) and thus can remain in the soil for long periods (Dogget, 1984). The seeds also have different maturity times and do not germinate at the same time.

*Striga* is an obligate parasite attacking crops of the Graminae family where it causes irreversible damage to these crops before it emerges above ground. It draws its water, carbon and mineral requirements from the host plants because *S. asiatica* seed is too minute to supply the growing seedling with enough food (Parker and Riches, 1993). The fact that the weed causes most of its damage before it emerges above ground renders it very difficult to control leaving the affected farmers with little choice but to watch their crops dying.

Musambasi (1997) observed that most of the technologies developed for *Striga* management are not compatible with socioeconomic status of the target farmers. Although *S. asiatica* has been reported on 79 % of the SH farmers land and that about 8.9 % of these had abandoned their lands due to *S. asiatica* infestations, it is important for the farmers to acknowledge this parasitic weed as a major production constraint and seek relevant methods of effectively managing it. At the moment most farmers cannot afford to implement special weeding operations specifically for *S. asiatica* and this tends to perpetuate the problem as more seeds are added to the soil seed bank (Musambasi, 1997).

Most of the technologies for the management of *S. asiatica* and other *Striga* species currently used require numerous resources in the form of labor and equipment. Unfortunately, the majority of SH farmers do not have access to these resources (Chivinge, Mashingaidze, and Mujuru, 1995). Timson (1935) suggested that hand and machine cultivation be thoroughly done every 10-15 days after *S. asiatica* emergence.

Although this may reduce the number of *Striga* plants setting seed, the method is tedious and labor intensive and therefore less attractive to SH farmers who are currently confronted with labor problems as most of the young and able bodied people leave for urban areas. The weed emerges close to the host plants making hand and machine weeding difficult.

*Striga* control has been researched in Africa for over 50 years and has focused on agronomic practices, host plant resistance and herbicide applications. While these methods are effective, none of these methods have been widely adopted by farmers for several reasons;

i. Their benefits are seen only in the medium long-term since effects build slowly over several seasons.

ii. They require an understanding of *Striga* life cycle which farmers usually lack.

iii. They require rotating land out of maize when population pressure requires intensification of land use for food production.

iv. While host plant resistance exists, the gains are inadequate and ineffective under high levels of infestation.

v. Conventional “over-the-top” herbicide applications are prohibitive in cost and *Striga* emerges from the soil.

It is in light of the problems mentioned that greenhouse and field trials were conducted to evaluate the efficacy of imazapyr seed coating on imazapyr resistant maize hybrids in the control of *Striga* infestation. Imazapyr kills the *Striga asiatica* before it attaches to the host rendering it its effectiveness while other herbicides like MCPA and 2, 4 D are post emergence herbicides they kill the *Striga* which have emerged whilst the *Striga* would already have made the damage. The hypotheses tested and objectives are outlined below.

**1.3 Study Objectives**

The main objective of the study was to evaluate the efficacy of imazapyr on *Striga* control through seed dressing on Imazapyr Resistant (I.R) maize

The specific objectives were as follows:

i. To assess the effectiveness of imazapyr coated imazapyr resistant –maize seed on *Striga* control and grain yield.

ii. To determine yield, agronomic characteristics and resistance to ear rot disease caused by *Sternocapella maydis* and maize streak virus disease.

## 1.4 Hypotheses

i. Application of imazapyr to imazapyr resistant maize seed, controls *S. asiatica* and increases maize seed yields.

ii. There are some lines with high yield and resistance to ear rot and maize streak virus disease among the selected hybrids.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Parasitic Plants

Parasitic plants depend on the host for part or all of their nutritional requirements (Parker and Riches, 1993). Parasitism occurs in at least 17 plant families and about 3000 species of flowering plants are parasitic (Kuijt, 1969). Parasitic plants are directly linked to their hosts by a structure known as the haustorium. This organ penetrates host tissue (Riopel and Timko, 1995) and forms a vascular conduit for the movement of water, nutrients and organic compounds from host to parasite. As noted by Kuijt (1991), the traditional understanding of haustorial function is via a xylem-xylem bridge. However there is great variation in the structure of the haustorium between parasitic plant species (Riopel and Timko, 1995). There are parasitic plants with few or no xylem contacts and large number of parenchyma cells positioned at the endophyte interface. In some species, e.g. *Cuscuta* and *Orobanche,* solutes are obtained from host phloem via specialized transport cells in the haustorium.

Parasitic plants can be classified on the basis of the position of haustorial attachment and the presence or absence of chlorophyll (Musselman and Press, 1995). Root parasites have haustoria attached to the below-ground parts of their hosts, for example, *Striga* and *Orobanche*. On the other hand, shoot parasites have haustoria attached above-ground parts of their host, for example *Cuscuta.* Parasites that contain chlorophyll are termed hemiparasites, for example *Striga* species, and are able to carry out some photosynthesis.

Holoparasites lack chlorophyll, for example, *Orobanche*, and they cannot utilise $CO_2$. *Cuscuta* has been noted to be on the boundary between the holo- and hemiparasitism, with species containing no or only trace amounts of chlorophyll. Parasitic plants can either be obligate or facultative, although the later perform much better when attached to a host. Parasitic angiosperms are distributed between both annuals like Euphrasia and perennials like the leafy mistletoes life forms (Musselman and Press, 1995).

## 2.2 What are parasitic weeds?

Parasitic weeds are plants that parasitise agricultural and forest crops leading to reduced productivity. Parker (1991) indicated that the most important plant families containing parasitic weeds were the Scrophulariaceae, Orobanchaceae, Convolvulaceae, Viscacea and Loranthaceae.

## 2.3 The biology of *Striga asiatica*

The effective control of any pest in agriculture largely depends on a detailed understanding of its biology and behavior. Unlike other weed species, *Striga* wholly depends on the host for its survival and perpetuation.

### 2.3.1 *Striga asiatica* lifecycle

#### 2.3.1.1 Germination and germination requirements

Seed germination has been described as the emergence and development from the embryo of those essential structures which, for the seed in question are indicative of its ability to produce normal plants under favorable conditions (Lang, 1965).

The germination of *Striga* and other obligate root parasites is highly complex and significant to the ecology of the species and to the understanding of the control methods (Parker and Riches, 1993). *Striga asiatica* is well adapted to conditions of semi-arid tropics (Doggett, 1984).

*Striga asiatica* and most other *Striga* species are obligate parasites, capable of limited seedling growth before the seed resources are exhausted (Doggett, 1984). Without a host, *Striga* seedlings will die only after a few days (Worsham, 1987), thus it is essential that seeds germinate within a few millimeters of a suitable host. Seedlings of parasitic flowering plants need to quickly find a suitable host to survive. The seeds of *Striga* are very small (Doggett, 1988; Sahai and Shivanna, 1982; Kuijt, 1969), are produced in large numbers, exhibit dormancy (Worsham, 1987) and most require a chemical stimulant from the roots of a host plant to complete the germination process. *Striga* seeds have specialized germination requirements which include an after-ripening period, conditioning and exposure to germination stimulant for example sorgoleone, sorgolaeton and alectrol (Saunders 1933; Reid and Parker 1979; Williams, 1961).

**2.3.1.2 After-ripening**

Saunders (1933) stated that, in South Africa, *S. asiatica* required a period of at least 6 months following seed shed before germination would occur and this may be an evolutionary adaptation to prevent germination at the end of the rainy season when there are no hosts. Germination would then steadily improve up to 18 months when a plateau is reached. Fresh seed germinated to a level of only 5%. Kust (1963) published details of tests with *S. asiatica* in U.S.A which confirm that freshly harvested seed gives very low germination percentages and that the length of after-ripening period varies from 4-6 weeks at 35$^0$C to about 12 weeks at 40$^0$C to 40 weeks at 0$^0$C. However the length of the after-ripening period varies with different *Striga* species and geographical regions. Other reports of temperature influencing the after-ripening period were made by Patterson, Musser, Flint and Eplee (1982) and Solomon (1952). Parker (1984) has reported an "induced dormancy" for *S. asiatica* and *S. hermonthica* when already after ripened seeds have been buried in the soil. The seeds may acquire a form of dormancy which is not broken by the normal conditioning and stimulant treatment.

#### 2.3.1.3 Conditioning

A further complication in the germination of *Striga* seeds is their inability to germinate even in the presence of a suitable stimulant until they have imbibed water for at least few days and ideally 1-2 weeks at a suitable temperature (Parker and Riches 1993; Worsham 1987; Parker 1981). Several terms have been used for this requirement. The term pre-treatment was first used for this process in the germination sequence and the term pre-conditioning has also been used (Brown and Edwards 1944).

The optimum temperature and period of conditioning vary from species to species. Brown and Edwards (1944) found that a conditioning period of 21 days at 22$^0$C was optimum for germination of *S. asiatica* seeds. When the conditioning period was extended beyond the optimum, the germination of the seed gradually declined and reached zero (Vallance, 1950; Reid and Parker, 1979).

The seeds enter a state of dormancy which was designated “wet dormancy” (Vallance, 1950). Seeds of *S. asiatica* reached this non germination state after about 50 days of conditioning at $23^0$C. It has been hypothesized that the unfavorable effect of excess soil moisture in the development of *Striga* is associated with the “wet dormancy” phenomenon (Musselman, 1987).

### 2.3.2 The Haustorium

One of the most striking features of many parasitic plants is a poorly developed root system (Worsham, 1987). The haustorium is the salient feature of parasitic plants. The haustorium is a specialized organ of absorption of a parasitic plant. Soon after germination, the radical tip is transformed and penetrates and attaches to the host root. After successful attachment and penetration, the haustorium functions primarily for transferring nutrients and water from host to parasite (Parker, 1984). Stewart and Press (1990) reported that, differences in metabolite composition between host and parasite demonstrate that the haustorial cells have specialized biochemical functions related to the regulation of solute transfer and that the haustorium plays an active metabolic role in the nutrition of parasitic plants. Several theories have been proposed for the mechanism of haustorial induction in parasitic plants, each generally involving haustorial inducing signals. In *Striga asiatica,* a simple quinone 2,6-dimethoxy-p-benzo-quinone is sufficient for the quantitative induction of the haustorial development in young seedlings. Evidence has been presented consistent with the theory that a parasite derived-enzyme oxidatively releases 2,6-dimethoxy-p-benzo-quinone from host root surface. Such a mechanism suggests an active screening process on the part of the parasite and ensures intimate host parasite association before the induction of the haustoria (Chang and Lynn, 1986).

### 2.4 Factors influencing severity of *Striga* attack

Ramaiah and Parker (1981) reported that the distribution and severity of *Striga* infestation in the field is influenced by a number of climatic, soil and cultural factors. Soil moisture has been found to play an important role in influencing the severity of attack by *Striga. Striga* appears to thrive on intermittent dry conditions and conversely suppressed by continuous soil moisture (Ogborn, 1972).

This is perhaps a result of “wet dormancy” but may be because of lower soil temperatures, dilution and leaching of root exudates increased fungal attack or possibly due to reduced photosynthesis and hence reduced vigor of root growth. High densities of *Striga* are usually associated with areas of low fertility, particularly low nitrogen status. Conversely, high N helps to suppress the weed, though it is not known which of a complex of possible mechanisms is mainly responsible for this effect (Cechin and Press, 1994). The possibilities include a reduction in stimulant exudation (Teferegan, 1973) a change in host physiology resulting in reduced susceptibility to attachment, the reduced vigour of the *Striga* radicle, a reduced  root/shoot ratio accompanied by reduced flow of photosynthesis to the root or increased leafiness of the crop resulting in greater shade and lower soil temperatures (Ramaiah and Parker, 1981).

### 2.5 Parasitic effects on hosts, with special emphasis on *Striga*

The effects of plant parasites on their hosts are variable (Graves, 1995). In some situations, the effects are undetectable and in extreme cases the host may die. In infected cereals, the most striking effects of the parasite are lower stem weights and lower seed (grain) yield, sometimes resulting in zero reproductive effort (Seel *et al*., 1992). In many *Striga*-cereal associations, stunting of internode elongation is observed, resulting in much packing of the leaves within the canopy compared with uninfected plants (Stewart and Press, 1990).

### 2.6 What is the impact of *Striga*?

*Striga* infestation is the consequence of monocropping with cereals which host the parasite and declining soil fertility which weakens the host plant rendering it vulnerable to *Striga* attack. As a result of these cropping practices, *Striga* infested areas have developed very high levels of long lived *Striga* seeds in the soil with only some breaking dormancy each season when stimulated by crop exudates. Each season every year, infestation by *Striga* becomes worse contributing to the downward spiral of poverty that in bad years in Africa can lead to starvation. Yield loss due to *Striga* damage ranges from 20-80%. *Striga* infests an estimated 20-40 million hectares of farmland cultivated by poor farmers throughout sub-Saharan Africa (AATF, 2006).

The tiny seeds are carried in runoff eroded soil and contaminate traded seed to infest an ever increasing area. In Kenya, an estimated 75 000 ha of land are infested with *Striga*. Every year *Striga* damage to crops accounts an estimated US$7 billion in yield loss in sub Saharan Africa and affects the welfare and livelihood of over 100 million people (AATF, 2006).

### 2.7 Crop losses due to *Striga* species

It is difficult to determine accurate crop losses attributable to parasitic weeds for a number of reasons, including difficulties of creating plots with and without the parasite, the damage of crops that occurs before the parasite emerges, variability in soil fertility and variability in *Striga* infestation from field to field and inter-seasonable variation (Parker, 1991; Parker and Riches, 1993). There is also lack of basic survey work in some regions such that the extent of the *Striga* problem is unknown. Therefore, the current estimates that are available may not be very realistic and are likely to underestimate the severity and extent of the problem. Carson (1988) recorded losses varying from 0-3% per emerged *Striga* plant per square meter in maize and 1 to 10% per *Striga* plant per square meter in sorghum. About 56% maize yield reduction was recorded from a density of 11 emerged parasites per square meter by Bebawi and Farah (1981). Dogget (1965) estimated about 5kg maize loss per *Striga* plant per square meter. Carson (1989) deduced that losses due to *Striga hermonthica* in sorghum were 20 to 35 % from infestation of 3 to 5 emerged parasites per square meter. Mboob (1991) reported that millet and sorghum yield losses are in order of 10 to 40 % and maize loss frequently exceeds 60%. The grain in Africa actually infested by *Striga* is estimated at 21 million ha and the overall loss in grain production amounted to 4.1 million tons (Souerborn, 1991).

## 2.8 Genetic variability within *Striga*

The genetics of parasitism can be classified as either a simple or complex depending upon the absence (simple) or existence (complex) of multiple races or strains of the parasite. Races are distinguished by altered virulence or altered specificity. Altered specificity is usually manifested in the form of new race that overcomes the resistance of certain host genotypes.

A high degree of variability exists within *Striga* as indicated by the variation in germination and pre-treatment requirements and interaction with no host factors. Ramaiah (1987) observed that both *S.asiatica* and *S. hermonthica* have strains which are specific to different crops (intercrop specific strains) and strains within different crops (intra-crop specific strains). Their work showed that the intercrop specificity was mainly observed between sorghum and millet crops. *Striga* strains which attack sorghum do not attack pearl millets and vice versa.

Even though there are only three species of *Striga* which cause economic losses in sorghum, millet and maize, Ramaiah (1987) reported that virulence variability within these species makes breeding programmes more complicated. *Striga* is expected to have considerable genetic variability because as resistance mechanisms appear in host populations, new forms of the parasite largely resistant to these mechanisms will most likely get selected for. These resistance *Striga* strains will reproduce and form distinct populations.

Ramaiah (1987) reported variability in *Striga* species for (1) germination stimulant requirements, (2) pre-conditioning requirements, (3) chromosome number and (4) pollination systems. Studies by Bharatakakshmi and Jayachandra (1979) in South India revealed that *S. asiatica* has strains that are specific to sorghum, millet and finger millet and their specificity is based on germination stimulant compounds. Variations in chromosome numbers have been reported in the United States and in India. Kondo (1973) reported n=12 chromosomes in *Striga asiatica* of North Carolina in United States, whereas in India, Rao (1965) reported n=20 chromosomes in *S. asiatica, S. densiflora, S. anguistifolia and S. gesneriodes.* The differing chromosome numbers indicated that *Striga* has undergone considerable evolutionary changes and therefore wide genetic variability was expected. The variations which have occurred in these areas dictate the need for investigation of the locally occurring *S. asiatica* populations.

Although Ramaiah (1987) reported clear evidence of crop specific strains within each species of *Striga*, there is very little information on the presence of virulence variability in *Striga* strains attacking the same crop. Some variability in *S. asiatica* attacking sorghum in India was observed. At Akola in Maharashtra State, IS5603 was resistant, but was susceptible at Patancheru in Andra Pradesh indicating that *S. asiatica* differed in virulence in these two places. These differences in virulence between sites meant that should a relatively resistant crop variety be developed, its resistant may not hold in different geographical areas.

## 2.9 Striga in Zimbabwe

Obilana, Knepper and Musselman (1987) described seven *Striga* species occurring in Zimbabwe. These include *Striga gesnerioides* (Wild) Vatke, *Striga asiatica* (L) Kuntze, *Striga bilabiata* (Thunb) Kuntze, *Striga elegans* Benth, *Striga angustifolia* (Don) Saldana, *Striga macrantha* (Benth.) and *Striga forbesii* Benth. The problem of parasitic weeds is not new in Zimbabwe (Mabasa, 1991). Sowyer (1904) reported that the first *S. asiatica* damage in Zimbabwe was noted in maize in the Fingo area near Bulawayo. Although *S. forbesii* is limited in terms of its distribution, it causes more damage to maize and sorghum than *S. asiatica* but the latter bears more economic importance because of its wide distribution (Obilana *et al.*, 1987).

From weed and pest surveys done in Zimbabwe, Striga seriously hampers production in the smallhoder farming sector (Page *et al.*, 1985). *Striga asiatica* and other *Striga* species were found to infest cereals mainly maize, sorghum, and pearl millet in. It was reported as the second most aggressive weed in Mashonaland central and third most aggressive in the Midlands and Masvingo (Chivinge, 1988).

### 2.9.1 Distribution

*Striga asiatica* is widely distributed in Zimbabwe and is common in areas of low fertility and erratic rainfall where 75% of the smallholder farmers are located (Mabasa and Malusalila, 1993). Crops affected include maize, sorghum and millet. It has been found causing damage in cultivated fields at Matopos, Chiredzi, Buhera, Mutare, Darwendale and Masvingo in Zimbabwe. The natural hosts of this parasitic weed include *Digitaria,* *Chloris, Andropogon, Heteropogon, Hyperthelia* and various other local grasses (Mabasa and Malusalila, 1993).

### 2.9.2 *Striga* research activities

Research on *Striga* in Zimbabwe dates back to the 1930's and 1940's (Timson, 1945) and results of the work were used to formulate *Striga* control recommendations (Thomas, 1970). There was no *Striga* research thereafter since it was assumed that the problem had been solved. *Striga* only began to feature as a major cereal production constraint after 1980 when agricultural activities were focused in the SH farming sector. Renewed interest in *Striga* research was started by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in 1986/87 with the initiation of a programme for screening sorghum for *S. forbesii* resistance/tolerance on large scale commercial farms around Kwekwe (Mabasa, 1991). In 1988/89 the Weed Research Team under the Agronomy Institute started research on *Striga.* A survey was conducted in the communal areas to determine the distribution of *Striga* and how farmers control the weed. The survey revealed that farmers controlled the weed by burning, hand weeding and early planting. *Striga* control trials were initiated in the Chiwundura communal area in 1989/90 summer season. These were mainly to determine the effects of planting dates, herbicides, manure and fertilizer on *Striga* in maize, sorghum, and pearl millet. The field trials indicated that maize supported the largest number of *Striga* (Agronomy Research Institute Annual Report, 1989).

In the 1992/93 rainy season, evaluation of sorghum and maize for *S.asiatica* resistance/tolerance and the determination of the effects of the herbicides and nitrogen on *S. asiatica* were continued at Henderson Research Station and Chiwundura communal area. During the same period, trials to determine the effects of herbicides, time of ridging, use of sunflowers and legumes intercropped with maize on *S. asiatica* were initiated in the Chinyika Resettlement area of Manicaland by the University of Zimbabwe (Mabasa and Malusalila, 1993).

### 2.10 How is *Striga* Controlled?

The control of *Striga* on smallholder farms has not been successful. Although *Striga* control methods are available to the smallholder farmers, there is no single method that is both effective and feasible (Mboob, 1991).

#### 2.10.1 Mechanical methods

Hand hoeing and hand pulling is within the reach of farmers. Carson (1988) indicated that hand pulling of *Striga asiatica* improved the yields of maize. However, in most cases, damage occurs before the parasite emerges. The persistence of *Striga* emergence increases the frequency of hand hoeing or hand pulling and as a result the demand for labor is very high (Timson, 1931; 1935). Because the damage occurs before *Striga* emergence, the farmers have no mechanism to detect its presence before it emerges so as to control it.

### 2.10.2 Herbicides

Tattersfield and Cronin 1958 used 2, 4-D and MCPA at the rate of 1.1kg/ha, MCPA had a better effect on *Striga* than 2, 4-D. Dicamba has also been reported to be effective on *S. asiatica* when applied as a systemic herbicide (Eplee and Norris, 1995). Herbicide technology is hardly used by smallholder farmers and lack of knowledge and high costs are some of the factors that prohibit wider use (Chivinge, 1988). Because 2, 4-D and MCPA have to be applied post emergence to the parasite, it discourages farmers to use the herbicide when crop damage has already occurred.

### 2.10.3 Trap Crops

Trap cropping involves the use of trap crops or false hosts (sunflowers, groundnuts, cowpeas and bambara nuts), that induce germination of the parasite but prevents its development. The use of crop rotations could be attractive to farmers, because they involve low financial inputs. Kroschel and Sauerborn (1996) reported that control methods which require no financial inputs like hand pulling and crop rotation, were most attractive to 54 to 92% of the smallholder farmers interviewed in Northen Ghana, Tanzania and Malawi.

However, there is no convincing evidence for the practical benefits under field conditions (Parker, 1991). Trap crops show a degree of variability in terms of inducing *Striga* seed germination (Rambakudzibga and Mabasa, 1995; Kabambe, 1997). Dogget (1965) showed little benefit in terms of lower *Striga* numbers or greater crop yield from 5 year rotational treatments, involving cotton, velvet bean, millet, sunflower, and mungbean. In most cases, trap crops have been used without knowledge on their effectiveness to germinate *Striga* seed. If a crop which is not efficacious in terms of *Striga* germination is used in rotations, it is not likely to have an impact on *Striga* control. The limitation on the use of trap crops has been lack of knowledge of the most appropriate species to use (Mabasa, 1996).

**2.10.4 Intercropping**

Intercropping, which is growing different crops in the same field during the same cropping season, could be a cheap option for controlling *Striga*. The system requires less financial inputs than some of the method described above. When groundnuts were intercropped with pearl millet (Salle, *et al.*, 1987) and sorghum (Carson, 1989), the emergence of *Striga* hermonthica was reduced. Singh, Ndikawa and Rao (1991) reported that intercropping of sorghum with cowpea, millet or soyabean was effective in increasing the overall land productivity under *Striga* infestation. Alternating stands of sorghum and cowpea within the same row gave the best yield of sorghum and greater reduction of *Striga* (Carsky, Singh and Ndikawa, 1994). Intercropping maize and cowpea in the same row reduced *S. asiatica* in maize (Kabambe, 1997; Kasembe, Chivinge and Mabasa, 1998). In most cases the cereal grain yield is reduced by the intercropping system (Parker, 1991, Kabambe, 1997). The impact of intercropping methods is very variable and the mechanisms for intercropping are not always understood.

### 2.10.5 Resistant/ Tolerant varieties

In host-parasite interactions, the reaction of the host may be described as susceptible, resistant, partially resistant, immune and tolerant (Table 2.1). The terms that describe these reactions were defined by Parker and Riches (1993).

**Table 2.1.** Host-parasite interactions (Adapted from Parker and Riches, 1993)

| Reaction | Parasite response | Host response |
|---|---|---|
| Susceptible | High *Striga* emergence | Low grain yields |
| Tolerance | High *Striga* emergence | High grain yields |
| Partial resistance | Less *Striga* emergence | Slight grain yield reduction or no grain yield reduction |
| Resistance=immunity | No *Striga* emergence | High grain yield |

The term resistance applies to crop varieties showing less attack, usually in terms of numbers of parasite attached or emerged. Partial resistance implies significantly less attack compared with the standard varieties. Immunity is total resistance or no parasitic attachments. The term tolerance refers to the reaction of the varieties that are parasitized to the same extent as susceptible ones but suffer less damage. *Striga* resistance in maize has not yet been found. Furthermore *Striga* tolerance in maize has been rarely reported (Kim *et al*., 1985; 1987).

### 2.10.6 Stimulants and fumigants

The use of ethylene gas at 1 to 2 kg per ha was an important component of the USA control programme for *S. asiatica* (Parker, 1991). Results in Africa have given only about 50% control (Bebawi and Eplee, 1986). This is one of the technologies that would be very expensive for the smallholder farmers. The fumigant with the broadest spectrum of activity and efficacy is methyl bromide (Bromomethane) (Eplee and Langston, 1971). This technology is certainly beyond the reach of farmers. In any event, methyl bromide is being phased out due to the damage it causes to the ozone layer.

### 2.10.7 Biological control

Biological control of *Striga* appears to be feasible to farmers. Insects such as *Smicronyx spp* gave promising results for the control of *Striga* (Eplee and Norris, 1995). It appears more research needs to be done before the smallholder farmers can take advantage of this technology. Although efforts are increasingly aimed at intergrated control of *Striga*, an effective control programme that fits local farming systems, has not yet been developed (Piertese and Verkleij, 1991). Lack of knowledge on how each component works in the intergrated approach has been the major drawback.

## 2.11 Imazapyr Herbicide

Imazapyr is a broad-spectrum herbicide that controls terrestrial annual and perennial grasses and broad leaved herbs, woody species and riparian and emergent aquatic species. It can be used where total vegetation control is desired or in spot applications. Imazapyr is relatively slow acting, does not readily break down in the plant and is therefore particularly good at killing large woody species (American Cyanamid 1986). Caution should be used when applying imazapyr around non-targets species, as it is readily adsorbed through foliage and roots, and therefore, could be injurious by drift, run-off or leaching from the roots of treated plants.

### 2.11.1 Mode of Action

Imazapyr is absorbed quickly through plant tissue and can be taken up by roots. It is translocated in the xylem and phloem to the meristematic tissues, where it inhibits the enzyme acetohydroxy acid synthase, also known as acetolactate synthase (ALS). ALS catalyses the production of three branched-chain aliphatic amino acids, valine, leucine and isoleucine, required for protein synthesis and cell growth. The rate of plant death usually is slow (several weeks), is likely related to the amount of stored amino acids available to the plant. Only plants have ALS and produce these three amino acids, and therefore, imazapyr is low toxicity to animals (including fish and insects). Animals need these three branched chain aliphatic amino acids, but obtain them by eating plants or other animals (American Cyanamid, 1986)

### 2.11.2 Dissipation mechanisms

Imazapyr is degraded in soils primarily by microbial metabolism. It will quickly undergo photodegradation in aqueous solutions (photohydrolisis) but there is little to no photodegradation of imazapyr in the soil, and it is not readily degraded by other chemical processes. Imazapyr does not bind strongly with soil particles, and depending on soil pH, can be neutral or negatively charged. When negatively charged, imazapyr remains available in the environment (Mangels, 1991b).

### 2.12 Imazapyr Resistant (I.R) -Maize technology

The initial testing of the low dose herbicide seed treatment technology made use of the I.R-maize hybrid; PH3245-I.R developed by Pioneer seeds. This hybrid is temperate material and very susceptible to maize diseases prevalent in the tropics. In 1996, the Pioneer hybrid PH3245-I.R was crossed with a CIMMYT maize population namely ZM503 to bring the gene into a tropical maize germplasm background. This resulted in an I.R-synthetic maize population with an African genetic background of more than 75%. This population was then used in the herbicide agronomy work, which started in 1996 (Kanampiu, *et al.*; 2001). Some $S_2$ maize lines with tolerance to drought, low nitrogen and maize streak virus disease resistance were crossed with Pioneer hybrids and advanced to $S_2$, as well as the I.R-synthetic was sent to Kenya. However, the breeding materials were found to be very susceptible to *Exserohilum turcicum* leaf blight and gray leaf spot caused by *Cercospora zeaemaydis*. The synthetic was also found to have low yield potential. At the same time, two inbred lines (CML 202 and CML 204) converted to I.R by the CIMMYT Applied Biotechnology Center in Mexico were also received in Kenya.

### 2.13.1 Breeding Approaches

Four approaches were used to develop I.R maize cultivars (i) advancing the $S_2$ lines received from Harare to $S_6$ under foliar disease pressure and treatment with imazapyr to generate I.R. CMLs and subsequently form hybrids and synthetics, (ii) improving the I.R. synthetic for disease resistance, inbreeding tolerance and high yield, (iii) converting the elite and mid-altitude CMLs and stress tolerant open pollinated varieties to I.R using CML202-IR and CML204-IR as new sources of I.R. in conventional backcrossing breeding method and (iv) developing new I.R. inbred lines by selfing the improved version of the I.R-synthetic (Kanampiu, *et al*., 2001).

### 2.13.2 Germplasm conversion method

Early and intermediate stress tolerant open pollinated varieties and CMLs developed under the Africa maize stress (AMS) and the Southern Africa Drought and low soil fertility projects (SADLF) were crossed with the I.R. single cross CML 202 I.R/CML 204 I.R. The (B.Co) F1 crosses were planted along with the recurrent parents and four weeks after planting or after the first irrigation the plants of the (B.Co) F1 crosses were sprayed with imazapyr (15g a.i per ha) as 25% Arsenal. Higher doses of imazapyr at the early backcrossing stage lead to male sterility of the plants especially when applied close to the tasseling stage. Plants without the I.R gene are killed while the heterozygous ones are severely deformed. At flowering, bulk pollen of the recurrent parents used to pollinate the resistant parents of (B.Co) F1 crosses and vice versa. The (B.C1) F1 crosses along with the recurrent parents were planted to form the (B.C2) F1 using the same procedure. To form the (B.C3) F1 30g imazapyr a.i/ha of herbicide was used. The (B.C3) F1 were recombined twice. However the seeds were coated with imazapyr at 30g a.i per 25kg seed instead of spraying the plants. Using these methods, different types of germplasm (open pollinated varieties, hybrids, late, early) adapted to the mid altitude and lowland ecologies were developed (Diallo, *et al*., 1997). IR-Maize or StrigAway maize technology comprises two main elements – a herbicide-resistant maize seed and imazapyr, a systemic imidazolinone herbicide.

The herbicide-resistant maize is coated with low doses of the herbicide, about 30g imazapyr per 25kg of seed, to control *Striga.* As the StrigAway maize germinates, it absorbs some of the herbicide used in coating it. The germinating maize stimulates *Striga* to germinate and as it attaches to the maize root, it is killed before it can cause any damage. The herbicide that is not absorbed by the maize plant diffuses into the soil and kills *Striga* seeds that have not germinated. The StrigAway seed coating acts at the time of *Striga* attachment to the maize root. *Striga* seed attempting to attach to germinating maize seed is killed and the herbicide prevents the attachment of the *Striga* on the maize plant. The herbicide also kills *Striga* seeds that have not germinated in the soil surrounding the maize seedling. The herbicide imazapyr inhibits the activity of acetolactate synthase, ALS (Garcia-Torres and Lopez- Granados, 1991; Abayo *et al*., 1996). The herbicide works by specifically inhibiting the biosynthesis of branched chain amino acids (Saari *et al*., 1994).

The StrigAway maize technology, therefore, decreases the level of *Striga* in the farm through direct attack activity on the *Striga* plants and seeds. The maize field can virtually be clear of *Striga* throughout the season. The resistance is derived from a naturally occurring gene in maize originally identified by BASF and made available to CIMMYT (Garcia-Torres and Lopez- Granados, 1991; Abayo *et al*., 1996). The technology is available in Kenya and Tanzania and is currently being tried in farmers' fields in Uganda and Ethiopia. In southern Africa, evaluation is being conducted in Malawi, Zambia, Zimbabwe, Lesotho and Swaziland. This is being done through the joint efforts of CIMMYT, African Agricultural Technology Foundation (AATF), BASF, NGOs, agricultural extension, the national agricultural research institutes and seed companies such as Kenya Seed Company and Western Seed Company in Kenya, Tanseed in Tanzania and Nalweyo Seed Company (NASECO) in Uganda. Extensive on-farm testing of ordinary maize and the new hybrid on farmers' fields under *Striga* infestation revealed that the hybrid maize yields were three (3) times those of ordinary maize (Abayo, Ransom, Gressel and Odhiambo, 1996),

### 2.14 Advantages of StrigAway Maize

Apart from its *Striga* control qualities, StrigAway maize has other advantages that include resistance to maize streak virus and *Exerohilum turcicum* (ET), thus reducing the problems that affect maize production. For long-term control of *Striga,* farmers are advised to combine StrigAway maize with other *Striga* management methods, such as uprooting, burning *Striga* plants before flowering, field sanitation, crop rotation, intercropping, organic matter use, improved fallows and push-pull system MBILI planted with groundnut, golden gram, soybean or lablab and *Striga*-tolerant maize germplasm. StrigAway maize is planted and managed in the same way that farmers currently grow their maize. As is recommended with all commercially available maize seed coated with insecticide and fungicide, farmers should wash their hands after handling the maize. They should not handle other seed before they wash off the imazapyr herbicide as this may affect germination of the other crops. StrigAway maize can be intercropped with legumes, but the two must not be planted in the same hole, as the herbicide is likely to affect the legume seed. Instructions on handling of the treated seed should be enclosed with packaged seeds.

StrigAway maize does not have residual effects where it is grown. The amount of herbicide is minuscule and is completely broken down in the soil 2-3 months after planting. This kind of maize can be grown in a field where there is no *Striga* infestation. It will grow and perform just like any other improved maize variety but the farmer will not have the benefit of the seed dressing without the presence of *Striga* (Berner, Ikie and Green, 1997). On-farm testing of seed coating with low doses of Imazapyr gave good *Striga* control resulting in over threefold grain yields compared to the untreated check in a *Striga* infested area (AATF, 2006).

It is necessary to look for the best performing maize lines under stress conditions (drought, low nitrogen, Maize streak virus) besides that of *Striga* as they stand a better chance yielding under smallholder farmers' conditions, and help resource poor farmers by reducing the costs for spraying equipment, herbicides, fertilizers, labor and other inputs. Also there is no possibility of off target application and little chance of damage to sensitive intercrops (AATF, 2006).

### 2.15 Availability of StrigAway Maize

StrigAway hybrid seed is commercially available to farmers in Kenya and Tanzania. In Kenya, the seed is available through Western Seed Company and agro-dealers in the

*Striga* infested areas of western Kenya and in Tanzania through Tanseed International Ltd. New StrigAway maize varieties will be available in future from other seed companies in the region. StrigAway maize is not genetically modified. The technology relies on herbicide resistance that was derived from a naturally occurring gene in maize originally identified by BASF and made available to CIMMYT. Plant breeders at CIMMYT in collaboration with Weizmann Institute of Science, Israel and KARI with funding from Rockefeller Foundation later incorporated the IR-gene into African maize varieties and adapted it for agro-ecological regions in Africa where *Striga* is endemic (Kanampiu, Ransom and Gressel, 2001 ). Research and testing with the technology has shown that fields that are heavily infested with Striga can increase their maize harvest by more than three-fold compared to the checks at an additional cost of less than US$5 per hectare. The technology of IR-maize seed, coated with the herbicide, has been incorporated in several maize varieties adapted to Western Kenya and the East African Community. Several seed companies have started producing the seed on a commercial basis. The first four IR maize hybrid varieties were released in 2005 (AATF, 2006).

# CHAPTER THREE

## EFFICACY OF IMAZAPYR HERBICIDE SEED DRESSING ON IMAZAPYR RESISTANT MAIZE IN THE CONTROL OF WITCHWEED (*Striga asiatica.L.*).

Maize (*Zea mays* L.) is the most widely grown cereal crop in Zimbabwe. It is the staple diet for the generalmjity of households in Zimbabwe. There are several constraints to maize and other cereal production in the smallholder sector ranging from social, economic, physical, political and biological factors. Witchweed is among the many biological constraints that limit maize production in the smallholder sector (Musambasi, 1997). It also parasitizes sorghum, pearl millet, finger millet and other related wild grasses of the gramminae family. *Striga asiatica* is an obligate hemi-parasite because of its direct association with the roots of cereal host plant through a haustorium (Parker and riches 1993).

*Striga* species are a serious problem mainly in communal areas (Page, Sithole and Mguni, 1985) and in a few large commercial scale farms (Chivinge, 1983). Witchweeds are mostly found in low rainfall areas (below 500mm annually) areas where 75 % of the smallholder farmers are located (Mabasa, 1991). Crop yield losses can reach up to 100 per cent depending on the degree of infetstation. Apart from crop losses, infestation by *S. asiatica* also results in farm abandonment and changes in the cropping system as farmers are forced to grow non-host crops in order to maintain the viability of their farms (Musambasi, 1997).

*Striga* species are difficult to control as they cause most of the damage before they emerge from the soil and in addition they emerge after most weeding operations have been completed (Musambasi, 1997). The use of StrigAway maize technology kills the *Striga* before it emerges.

### 3.1 Location

The trial was conducted at Henderson Research Station (Table 3.1).

**Table 3.1 Location and characteristics of the trial site, Henderson Research Station**

| Site | Henderson |
|---|---|
| GPS co-odinates | $17^0$ 34'S $30^0$54'E |
| Natural Region | IIA |
| Rainfall (mm) | 820 |
| Planting period | Summer |

## 3.2 MATERIALS AND METHODS

### 3.2.1 Pot Experiment

A pot experiment was established at Henderson Research Station Mazowe. The size for each pot was as follows; 22.2 cm in diameter and 22.3 cm in depth. About 0.02 g of *S. asiatica* seed was mixed in the top 5 cm of the soil before sowing maize seeds in the pots. Sandy soil was used for the pot trial.

Maize was planted on fifteen December 2010 at two seeds per pot and was thinned to one plant per pot two weeks after emergence (WACE). Three pots represented a plot

(Fig 3.1). Hand pulling of other weeds was carried out from the first emergence of *Striga*, care being taken to avoid pulling out the *Striga*.

Compound D basal fertilizer (7N: $14P_2O_5$: $7K_2O$) and Ammonium Nitrate (33.5 % N) top fertilizer were applied at a rate of 100kg per ha.

**Table 3.2 Treatments used in the experiment**

| **Untreated** | | **Treated** | |
|---|---|---|---|
| 1 | J437-27 | 6 | J437-27 |
| 2 | J437-29 | 7 | J437-29 |
| 3 | J437-30 | 8 | J437-30 |
| 4 | J450-2 | 9 | J450-2 |
| 5 | J450-3 | 10 | J450-3 |

### 3.3 Trial Design

A 2 X 5 factorial design was used and replicated three times with ten treatments per replicate. Three pots represented a plot (fig3.1).


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**Fig 3.1 Layout of pots before planting**

### 3.4 Data collection

#### 3.4.1 Crop Data

Plant and ear heights, were taken when all the internodes had elongated fully. The number of plants showing stem lodging, and ears with open tips were counted just before harvest. Harvested plants and ears were counted at harvest in all plots at all sites.

Anthesis date (AD): Measured as number of days after planting when 50% of the plants shed pollen. Anthesis-silking interval (ASI): Determined by (1) measuring the number of days after planting when 50% of the plants shed pollen (anthesis date, AD) and show silks (silking date, SD) respectively, and (2) calculating ASI = SD – AD. Plant height (PH). Maize biomass and maize stem weight was taken after harvesting. Grain yield was also determined.

### 3.4.2 *Striga* Data

Days to first *Striga* emergence were noted and *Striga asiatica* counts were done at 7-8 weeks after emergence. Counts were taken from the plots after every two weeks until crop senescence. *Striga* dry matter and *Striga* capsule numbers per plant (for pot experiment) and numbers of flowering and non flowering *S. asiatica* plants were recorded.

### 3.4.3 Data Analysis.

Data from individual site was subjected to analysis of variance (ANOVA) according to alpha (0, 1) lattice design (Patterson and Williams, 1976) using fieldbook software (Banziger and Vivek, 2007). The following model was used to quantify the sources of variation:

$Y_{ijk} = \mu + B_i + A_j + T_k + A_j \times T_k + \varepsilon_{ijk}$

Where:

$Y_{ijk}$ = Measurements taken (*Striga* counts, Plant height, *Striga* attachments, Anthesis dates, maize leaf biomass, maize stem weight, maize roots and grain yield)

$\mu$ = overall mean

$B_i$ = $i^{th}$ effect of blocking

$A_j$ = $j^{th}$ the effect of varieties used (j= J437-27, J437-29, J437-30, J450-2, J450-3)

$T_k$ = $k^{th}$ the effect of treatment used (k = no herbicide and herbicide (imazapyr) used)

$AT_{ik}$ = the interaction of the $i^{th}$ imazapyr resistant maize varieties (i=J437-27, J437-29, J437-30, J450-2, J450-3) and $k^{th}$ the herbicide (k=no herbicide and herbicide (imazapyr) used) and;

$\varepsilon_{ijk}$ = residual error

A square root transformation was applied to all *Striga* count data to normalize the data before analysis of variance. Means were separated using Least Significant Difference (LSD) at a confidence level of $p<0.05$.

## 3.5 RESULTS

### 3.5.1 *Striga* Counts

There were significant differences ($P<0.05$) on the *Striga* counts after every two weeks between the treated and the untreated seeds (Table 3.3). During the first week significant differences on the number of *Striga* were noted on the untreated genotypes with J450-3 recording the highest number of *Striga* but it was not significantly different from J437-29 and J437-30 (Table 3.3). J450-2 had the least number of *Striga* but it was also not significantly different from J437-27 (Fig 3.2). The ANOVA tables for all the measured parameters are appended. The number of *Striga* plants in the untreated plots was increasing after every two weeks with total *Striga* count averaging to about 33 *Striga* plants per plot for the untreated treatments. In the herbicide plots *Striga* was suppressed. Table 3.3 shows the comparison in the number of *Striga* counts noted among the untreated genotypes and the treated varieties. The interaction of maize cultivar and imazapyr was not significant at all sampling dates but however imazapyr effects were highly significant in the *Striga* counts.

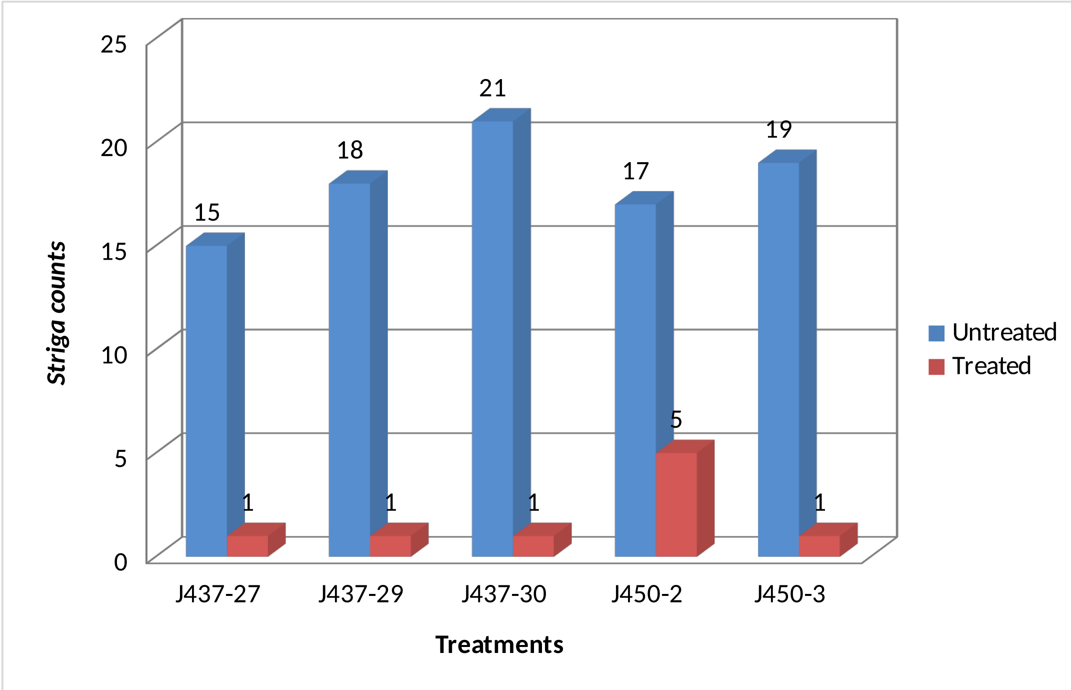


**Fig 3.2 *Striga* Counts at 4 WAE**

At 4WAE, significant differences were noted on the number of *Striga* plants which have emerged with J437-30 recording the highest number of *Striga* counts among the untreated and the treated showing the least number of *Striga* plants which have emerged as shown in fig 3.2.

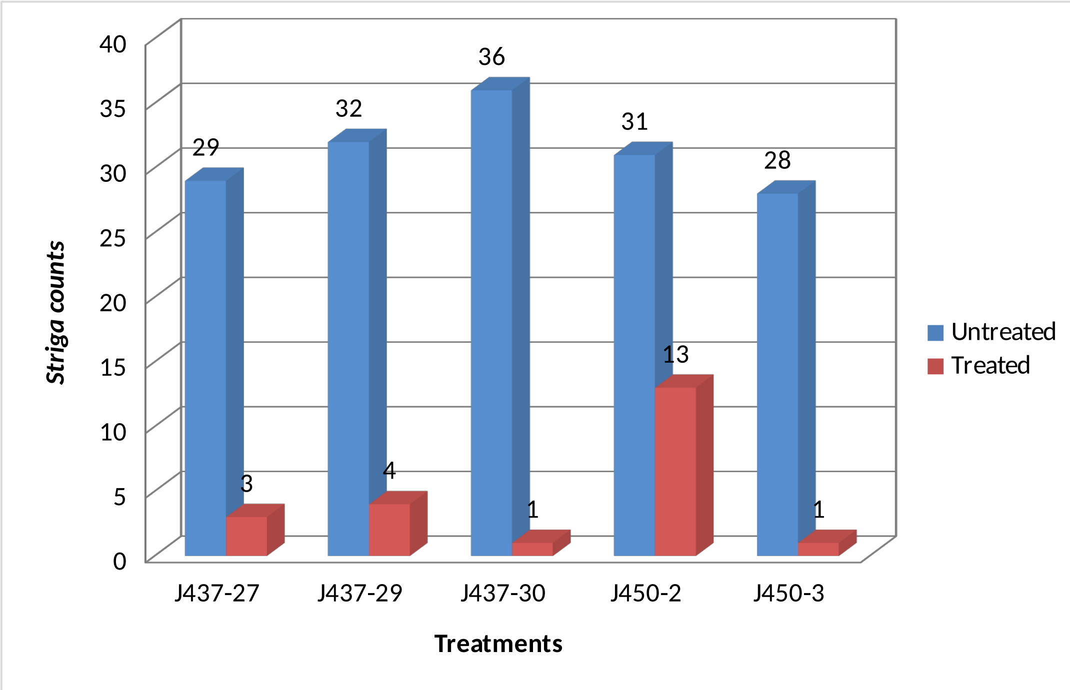


**Fig 3.3 *Striga* Counts at 8 WAE**

At 8 WAE, the same trend for *Striga* counts (fig.3.3) at 4 WAE is exhibited. The *Striga* numbers continue to increase at each maize cultivar for the untreated but for the treated cultivars there is high suppression of the *Striga* numbers by the herbicide. Untreated J437-30 still is exhibiting the highest number of *Striga* plants.

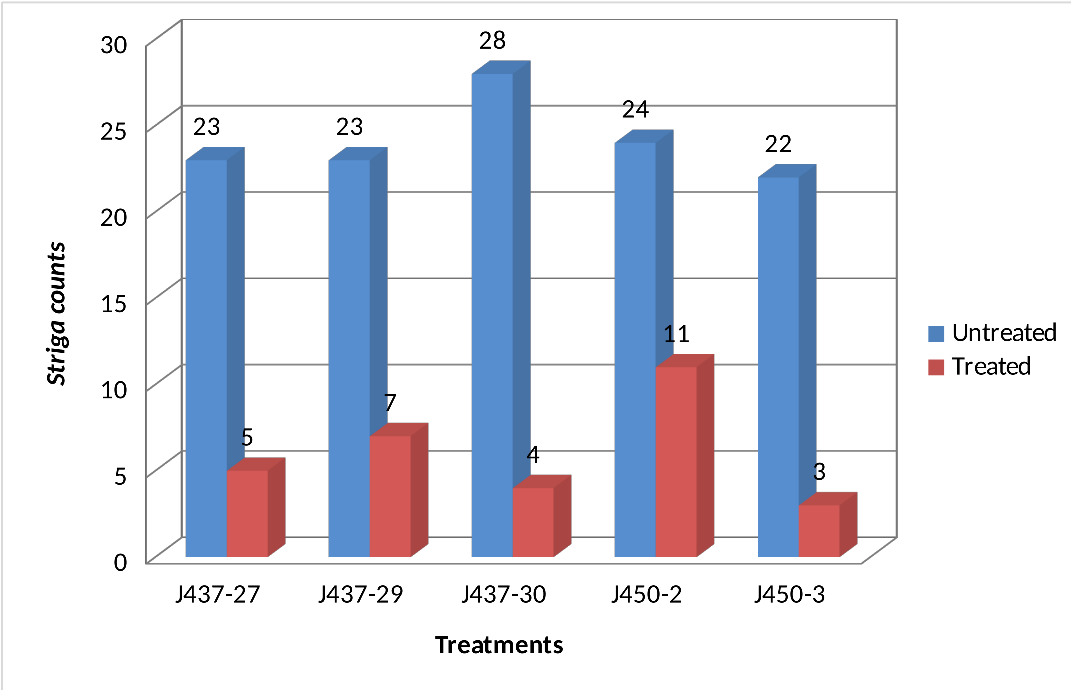


**Fig 3.4 *Striga* Counts at 12 WAE**

There was a general increase in the number of *Striga asiatica* plants at 4 WAE and 8 WAE as shown by the trend of the graphs shown (Fig 3.2 and 3.3). At 12 WAE there was a decline in the number of *Striga* counts as shown in fig 3.4.

**Table 3.3 *Striga asiatica* counts at Henderson Research Station for 2010-2011 seasons (Data transformed using square root) alpha=0.05**

| | Line | 2WAE[1] | 4WAE | 6WAE | 8WAE | 10WAE | 12WAE | Total |
|---|---|---|---|---|---|---|---|---|
| **Untreated** | J437-27 | 9b | 15c | 22b | 29b | 28b | 23b | 53b |
| | J437-29 | 15c | 18c | 25b | 32b | 30b | 23b | 59b |
| | J437-30 | 15c | 21c | 30b | 36b | 31b | 28b | 68b |
| | J450-2 | 9b | 17c | 25b | 31b | 29b | 24b | 56b |
| | J450-3 | 16c | 19c | 24b | 28b | 27b | 22b | 54b |
| **Treated** | J437-27 | 1a | 1a | 1a | 3a | 5a | 5a | 7a |
| | J437-29 | 1a | 1a | 2a | 4a | 6a | 7a | 10a |
| | J437-30 | 1a | 1a | 1a | 1a | 2a | 4a | 5a |
| | J450-2 | 2a | 5ab | 10a | 13a | 13a | 11a | 24a |
| | J450-3 | 1a | 1a | 1a | 1a | 1a | 3a | 3a |
| | LSD | 4.14 | 6.32 | 8.94 | 11.24 | 10.81 | 8.62 | 20.24 |
| | Residual | 8.74 | 25.17 | 42.92 | 53.37 | 47.43 | 4.49 | 183.57 |
| | CV% | 47.41 | 48.02 | 46.42 | 45.29 | 43.77 | 40.54 | 41.08 |

Means followed by the same letter in the same column are not significantly different at $p<0.05$.

WAE[1]= Weeks after emergence

**Fig 3.5 Pots infested with *S. asiatica***

Fig 3.5 shows the suppressive effect of the imazapyr herbicide.

### 3.5.2 *Striga asiatica* emergence and density

*Striga asiatica* germination was first noted at day 34 after infestation. It was generally low with the highest germination recorded in untreated pots with J437-29 and J450-3. However significant differences ($P<0.05$) were observed among the different IR varieties. Varieties J437-29, J450-3 and J437-30 were the first to be infested by *Striga asiatica* (Table 3.4). Treatment differences ($P<0.05$) were noted at 8 week ACE with untreated J437-30 recording the highest number *S. asiatica* counts. However there were no differences in *S. asiatica* density between the treated varieties (Table 3.4). Treatment differences were also apparent at 10, 12 and 14 WACE with treatment 1 supporting the lowest number of *S. asiatica* counts among the untreated entries. The same trend persisted at 16 and 18 WACE. For the treated varieties no *Striga* was noted in the pots emerging (Table 3.4). There were no significant differences between the imazapyr-treated plots. The results showed distinct suppressive effects of the herbicide on *Striga.* (Table 3.4). At 103 DAP the effectiveness of the herbicide was wearing off with time, as *Striga* emergence was building.

**Table 3.4: Means of I.R maize varieties for days to *Striga* emergence, *Striga* weights and *Striga* attachments for Pot Experiment at Henderson Research Station, Mazowe. (Alpha=0.05).**

| | Lines | Number of Days to1st *Striga* emergence after infestation | *Striga* Weights(grams) | *Striga* attachments |
|---|---|---|---|---|
| | J437-27 | 63a | 0.067a | 7a |
| **Untreated** | J437-29 | 24b | 0.100a | 4a |
| | J437-30 | 34b | 0.167a | 9a |
| | J450-2 | 70c | 0.067a | 9a |
| | J450-3 | 24d | 0.233b | 8a |
| | J437-27 | 105e | 0.037c | 0b |
| | J437-29 | 105e | 0.033c | 1b |
| **Treated** | J437-30 | 120e | 0.00c | 2b |
| | J450-2 | 120e | 0.00c | 0b |
| | J450-3 | 120e | 0.00c | 0b |
| LSD | | 14.59 | 0.112 | 6 |
| Residual | | 109.11 | 0.004 | 18.47 |
| CV% | | 128.92 | 83.1 | 101.57 |

Means followed by the same letter in the same column are not significantly different

### 3.5.3 *Striga* Attachments

After pot destructive harvesting at the vegetative stage numbers of *Striga* attachments were counted on each plant. Significant differences were noted between the untreated and the treated varieties at ($P<0.05$). Varieties without the herbicide recorded the highest number of *Striga* attachments as compared to the treated ones (Table 3.4). This shows suppression of the *Striga* by the low dose of imazapyr. On each plant for the untreated varieties there was an average of 7 *Striga* attachments feeding from the host before their emergence.

The result showed that the treated varieties exhibited the highest level of suppression since no seedling of *Striga* was attached to the root while the untreated varieties were the most susceptible.

### 3.5.4 Anthesis Date

Anthesis dates were significantly different ($P<0.05$) among the varieties and also significantly different ($P<0.05$) between the treated and the untreated varieties (Table 3.5).

### 3.5.5 Maize leaf Biomass

Whilst plants were at the vegetative stage, one pot was harvested and the leaves were weighed to get the biomass weight. The treated varieties had highly significant ($P<0.05$) differences in biomass weights (Table 3.5). The average weight of one plant for the treated lines was 0.06g compared to 0.04g for the untreated varieties.

### 3.5.6 Maize Roots

During the pot destructive harvesting, maize roots were cut separately and weighed. Under the herbicide treatment there was significant difference at ($P<0.05$). Analysis of variance for the interaction between varieties x herbicide revealed significant values at ($P<0.05$). Average maize roots weight for treated variety was 18.93 g and for the untreated was 26.03 g (Table 3.5).

### 3.5.7 Maize Stem Weight

Maize stems were also cut separately and weighed and significant differences were noted between the treated and the untreated lines at ($P<0.05$). Average stem weight for the treated varieties was high compared to the one without the herbicide. Stem weight for the treated was 3.53 g compared to the one for the untreated with 2.60 g (Table 3.5).

### 3.5.8 Plant Height at harvest

Mean Squares for entries were not significant. The treated varieties were significant at ($P<0.05$) (Table 3.5). Average plant height for the one with herbicide was 99.33cm and for the untreated were 57.67cm. Plant height for the treated varieties was 63 % greater than the untreated (Table 3.5).

### 3.5.9 Grain Yield

There were significant differences at ($P<0.05$) between the untreated and the treated varieties. (Table 3.5). The treated J437-29 was the one with the highest yield and the one with the lowest yield was the untreated J437-30.

**Table 3.5: Means of I.R maize varieties for Days to anthesis, Maize Biomas, maize stem weight plant height, grain yield and maize roots for Pot Experiment at Henderson Research Station, Mazowe. (Alpha=0.05).**

| | Entry | Days to anthesis | Maize leaf biomass(grams) | Maize stem weight(grams) | Plant height(cm) | Grain yield (grams/pot) | Maize Roots (grams/pot) |
|---|---|---|---|---|---|---|---|
| | **Untreated** | | | | | | |
| | J437-27 | 158.3a | 0.04a | 2a | 65a | 0a | 20a |
| | J4 37-29 | 159a | 0.03a | 4.67b | 66.7a | 0.97a | 41.3b |
| | J437-30 | 148.7b | 0.05a | 2a | 66.7a | 0a | 21a |
| | J450-2 | 164.3c | 0.04a | 2.67c | 31.7b | 0a | 30.7c |
| | J450-3 | 158.3c | 0.04a | 1.67c | 58.3c | 0a | 17.3a |
| | **Treated** | | | | | | |
| | J437-27 | 149d | 0.08b | 3c | 120d | 5.41a | 23.3d |
| | J437-29 | 154d | 0.07b | 2.33c | 91.7e | 11.6a | 13.3e |
| | J437-30 | 149.3d | 0.07b | 5d | 108.3e | 1.91b | 18.3e |
| | J450-2 | 155.3d | 0.04c | 3e | 90e | 2.97b | 11f |
| | J450-3 | 160d | 0.05c | 4.33e | 86.7e | 5.73b | 28.6d |
| LSD | | 6.88 | 0.02 | 1.95 | 25.71 | 8.61 | 16.10 |
| Residual | | 24.26 | 3.301 | 1.95 | 338.68 | 37.96 | 132.989 |
| CV% | | 3.15 | 27.36 | 42.53 | 23.57 | 254.56 | 47.29 |

Means followed by the same letter in the same column are not significantly different

## 3.6 DISCUSSION

### 3.6.1 Suppression of *Striga* plants through herbicide seed dressing

The fact that all the varieties which were treated had the lowest *Striga asiatica* density is probably because the herbicide was effective against the parasitic weed. The herbicide resistance in the maize lines is derived from a naturally occurring gene in maize originally identified by BASF and made available to CIMMYT (Abayo, Ransom, Gressel and Odhiambo, 1996).

The general increase in the number of emerged *S. asiatica* plants from the first date of emergence in all the untreated plots indicates that as the maize plants grew, their roots extended and thus came in contact with an increasing number of viable *Striga* seeds which were stimulated, germinated and attached. The decline after 12WACE for most treatments signaled the onset of senescence and death of the host roots.

The suppression of *Striga* emergence up to 12 weeks was in agreement with previous studies (Abayo *et al*., 1996; Berner *et al*., 1995; Kanampiu *et al*., 2001). Kanampiu *et al*. (2001), also reported on significant yield gains with 30 g ha-1 active ingredient of imazapyr from on-farm trials. The lack of complete control by one method, therefore, necessitates the use of other methods such as using herbicide seed dressings. In this study, yield gains by using imazapyr were, statistically, remarkable. However, yield gains were expected due to delay in emergence of *Striga*. Berner et al. (1995) reported that delaying *Striga* attachment by three weeks (simulated by transplanting maize unto a *Striga*-infected field) gave over 50 and 100% yield gains with resistant and susceptible maize varieties, respectively. The results are important for small-scale farmers in that yield could be improved and *Striga* could be managed simultaneously. Other control measures for possible inclusion in integrated management systems include hand weeding and deliberate efforts to amend or improve fertility. Other practices are cowpea intercropping (Carsky *et al*., 1994; Oswald *et al*., 1998).

The large reductions in *Striga* emergence, particularly numbers flowering are important in reducing seed return to the soil. For practical purposes, the seed-coating method is much easier to perform, and is already a routine seed treatment protocol for insecticides and fungicides by the seed industry. Seed depletion occurs when *Striga* germinates but fails to attach to its host root. This is in agreement with Kanampiu et al. (2001) who showed that *Striga* seeds are almost completely killed in the top 10 cm of soil below treated seed, and by up to 80% at 30 cm depth. The use of imazapyr, therefore, can reduce reproduction of seed of the parasite thereby depleting the soil inoculum in the areas where the parasite is endemic. Analysis showed that the untreated lines had no significant suppressive effect on witchweed. Imazapyr had significant effect on *Striga* emergence. High suppression of witchweed emergence observed with imazapyr is of great significance to management of *Striga* by small scale farmers in Zimbabwe as most of the control options such as fertilizer use, rotations with trap crops, resistant varieties or hand pulling do not offer complete control particularly in the same season. Therefore imazapyr herbicide has an important role to improve yields as well reduce amount of seed return to the soil. Yield gains from imazapyr herbicide are expected not only due to *Striga* suppression but also due to delay in emergence of *Striga*. The damaging effects of *Striga* are more pronounced before emergence (Parker 1992, Parker and Riches 1993). Berner *et al*, (1995) also reported that delaying *S. asiatica* emergence gave high yield gains in maize. Further delayed or decreased emergence is that seed return to the soil is reduced hence lessening the drudgery associated with hand pulling.

### 3.6.2 *Striga* attachments

Varieties without the herbicide recorded the highest number of *Striga* attachments as compared to the treated ones (Table 3.4). This shows suppression of the *Striga* by the low dose of imazapyr. On each plant for the untreated varieties there was an average of 7 *Striga* attachments feeding from the host before their emergence. The result showed that the treated varieties exhibited the highest level of resistance since no seedling of *Striga* was attached to the root while the untreated varieties were the most susceptible. Average maize roots for treated variety was 18.93g and for the untreated it was 26.03g implying that there were a lot of *Striga* attachments on the untreated side giving it a higher root density (Table 3.4). Berner *et al.* (1995) reported that delaying *Striga* attachment by three weeks gave over 50 to 100% yield gains with resistant and susceptible maize varieties under *S. asiatica* infection, respectively.

Heavier stem implies that there were more nutrients being channeled to the plant and the one with lesser stem weight implies that the *Striga* was feeding from the host hence lesser nutrients being channeled to the plant. Most of the nutrients were being taken up by the *Striga*. The stem biomass is a good indicator of the impact of *Striga* on maize. It could be used as a selection tool for *Striga* tolerance in maize.

The greater difference between the treated (99.33cm) and the untreated (57.67cm) implies that those plants infested by *Striga* will have stunted growth because the *Striga* will be feeding from the host.

Treated lines J437-27, J450-2 and J450-3 recorded not even a single *Striga* attachment even though there was no significant difference noted among the lines. J437-29 was the one with the highest maize stem weight both from the untreated and treated lines exhibiting tolerant levels to the *Striga asiatica*. Among the untreated lines J437-29 was the only one which recorded grain yield. The other untreated lines could not even record a single grain.

### 3.7 Conclusion

The results in this experiment showed the suppressive effects of the imazapyr herbicide seed dressing on maize in the control of *Striga asiatica*. This is evidenced by the delay in the *Striga* emergence and the lower number of *Striga* counts noted in the treated lines. Basing on the results I can recommend the use of imazapyr seed dressing on maize in the control *Striga asiatica*.

# CHAPTER FOUR

# THE EVALUATION OF CIMMYT IMAZAPYR RESISTANT MAIZE HYBRIDS FOR AGRONOMIC PERFPRMANCE CIMMYT-Harare and Muzarabani

For the sites CIMMYT-Harare and Muzarabani we were trying to answer questions frequently asked like, "Can the StrigAway maize be grown in a field not infested with *Striga*?" The experiment of evaluating the CIMMYT imazapyr resistant maize hybrids has shown that the hybrids will grow and perform just like any other improved maize variety but the farmer will not have the benefit of the seed dressing without the presence of *Striga.* Most Zimbabwean soils are deficient in N. The cost of N fertilizer has increased beyond most peasant farmers purchasing capacity. The result is low maize yields and household food deficits due to low application of N. Promoting genotypes which have high potential only in high N environments and perform poorly in low N environments will not help the peasant farmers.

Maize Streak virus is one of biotic stresses which is transmitted through the *Ciccadulina mbila* of leafhoppers. It causes economic damage to both lowland tropical and mid altitude environments, especially in drought conditions. Infected plants show white streaks running along the leaf and the plant is stunted. Heavy infestation may result in no ear production and eventual death. This disease has become very important in Zimbabwe due to conditions of continuous maize production cycle especially off season under irrigation on both small holder and commercial scale, hence the need for development of varieties that are tolerant to this disease. This is the only economic solution towards achieving high maize yields in disease-prone environments.

### 4.1 Study Objective

To determine yield, agronomic characteristics and resistance to ear rot disease caused by *Sternocapella maydis* and maize streak virus disease.

### 4.2 Hypotheses

There are some lines with high yield and resistance to ear rot and maize streak virus among the selected hybrids.

### 4.3 Location

Trials were conducted at CIMMYT-Harare and Muzarabani (Table 4.1).

**Table 4.1 Location and characteristics of the trial sites at CIMMYT-Harare and Muzarabani**

| Site | Harare (CIMMYT) | Muzarabani |
|---|---|---|
| GPS co-odinates 31.17$^0$E | 17.80$^0$S 31.05$^0$E | 16.33$^0$S |
| Natural Region | IIA | IV |
| Rainfall (mm) | 610 | 420 |
| Planting period | Summer | Summer |

### 4.4 MATERIALS AND METHODS

Field trials were conducted at Muzarabani and CIMMYT. Five imazapyr resistannt three-way maize hybrids were coated with imazapyr. A solution of 10 g imazapyr and 150 ml water was prepared. Some 30 ml of imazapyr solution were applied to 1500 g of seed and mixed thoroughly. The treated seeds were placed into packets and labeled 'TREATED' in red. The hybrids treated were J437-27, J437-29, J437-30, J450-2, and J450-3.The same five I.R three way maize hybrids were used but not treated with imazapyr (Table 3.2).

Site 1 main disease of concern was Maize Streak Virus (MSV). A six-point disease scale (0=immune to 5=highly susceptible) was used to classify attack whether it was immune, resistant, tolerant, susceptible, very susceptible and highly susceptible. Classification was based on percentage of leaf area covered by chlorotic lesions in infected plants based on the protocol described by Soto et al., (1982).

Site 2 trial was planted in managed low soil nitrogen blocks during the same season with site 1. The low nitrogen (Low N) fields had been depleted of nitrogen by growing unfertilized, non-leguminous crops for several seasons, removing crop biomass after each season. According to soil analysis performed by the Soil Chemistry Section, Department of AREX Zimbabwe, the recommended fertilizer requirements were 400 kg/ha (NPK) basal and 400kg/ha (AN) top dressing. No Nitrogen fertilizer was applied in the field.

### 4.5 Trial Design

Alpha lattice design was used and the gross plot size was four rows with 4.5 m length. The net plot was the two center rows with the outside two rows acting as the guard rows. The plant spacing was 90 cm interrow×30 cm intrarow.

### 4.6 Data collection

#### 4.6.1 Crop Data

Data was collected in trials during the summer of 2010/11 season and in all plots at all sites. During the growth period, disease severity scores were recorded for the following diseases: northern leaf blight (*Exserohilum turcicum*), common rust (*Puccinia maydis*), and gray leaf spot (*Cercospora zeae maydis)* on a 1-5 rating scale.

Ear rot (ER): Percentage of rotten ears. Ears per plant (EPP): Counted as number of ears with at least one fully developed grain divided by the number of harvested plants. Grain yield (GY): Shelled grain weight per plot adjusted to 12.5% grain moisture and converted to tons per hectare. Grain moisture (MOI): Percent water content of grain as measured at harvest. Grain texture (GTX): rated on a scale from 1 (=flint) to 5 (=dent). Grey leaf spot (GLS): Score of grey leaf spot (*Cercospora zeae maydis)* symptoms rated on a scale from 1 (= no infection) to 5 (=severely diseased). Northern leaf blight (ET): Score of the severity of northern leaf blight (*Exserohilum turcicum)* symptoms rated on a scale from 1 (=, no infection) to 5 (=severely diseased). Stem lodging (SL): Measured as a percentage of plants that show stem lodging, i.e. those stems that are broken below the ear.

The main disease of concern was Maize streak virus which has had 100% crop loss recorded on highly susceptible crops depending on timing and extent of infection. It is characterized by development of chrolotic spots and streaks in longitudinal lines on leaves. Plant height and days to anthesis were also recorded.

### 4.6.2 Data Analysis.

Data from individual sites was subjected to analysis of variance (ANOVA) according to alpha (0,1) lattice design (Patterson and Williams, 1976) using field book software (Banziger and Vivek, 2007). A square root transformation was applied to all *Striga* count data to normalize the data before analysis of variance. Means were separated using Least Significant Difference (LSD) at a confidence level of $p<0.05$.

The following model was used to quantify the sources of variation:

$$Y_{ijk} = \mu + B_i + A_j + T_k + A_j \times T_k + \varepsilon_{ijk}$$

Where:

$Y_{ijk}$ = Measurements taken (Anthesis dates, plant height, maize streak virus score, silking days, lodging, senescence days, grey leaf spot score, *Puccinia maydis* score, ear rot score, grain yield)

$\mu$ = overall mean

$B_i$ = $i^{th}$ the effect of blocking

$A_j$ = $j^{th}$ the effect of varieties used (j= J437-27, J437-29, J437-30, J450-2, J450-3)

$T_k$ = $k^{th}$ the effect of treatment used, (k= no herbicide and herbicide (imazapyr) used)

$AT_{ik}$ = the interaction of the $i^{th}$ imazapyr resistant maize varieties (i=J437-27, J437-29, J437-30, J450-2, J450-3) and $k^{th}$ the herbicide (k= no herbicide and herbicide (imazapyr) used) and;

$\varepsilon_{ijk}$ = residual error

## 4.7 RESULTS CIMMYT-HARARE

### 4.7.1 Maize streak virus disease

There was highly significant difference in response to MSV inoculation (Table4.2). The line J450-2 had the highest MSV score and the line J437-30 had the lowest MSV score (Table 4.1). However imazapyr x maize cultivar indicated that there was no interaction.

**Fig 4.1 Maize plant infested by Maize Streak Virus disease**

### 4.7.2 Anthesis Date (AD)

Measured as number of days after planting when 50 % of the plants shed pollen. It showed earliness of maturity. There were significant difference noted on the days to anthesis for the herbicide treatments at $P<0.05$ (Table 4.3). The treated varieties had the highest number of days to anthesis with an average of 75 days and the lowest being recorded to the untreated treatments with an average of 74 days to anthesis. Anthesis dates and silking dates are important for pollination synchronization. Under low N conditions anthesis dates were highly significant at ($P<0.05$) (Table 4.3).

### 4.7.3 Grain Yield

Analysis of variance showed highly significant mean squares ($P<0.05$) among the varieties (Table 4.2, Appendix 5). The best performing hybrid was J450-3 and J437-29 with an average yields of 7t/ha while the lowest yielder among the hybrids recorded was J437-30 with an average yield of 5.8t/ha. No significant differences were detected for herbicide use on maize yield.

In both site 1 and site 2 there was no significant differences on yield. Site 2 had lower yields which were noted as compared to site 1. The highest yield for site 2 was 3t/ha which was J450-3 as compared to the 7 t for site 1. The performances of the genotypes were not significantly different under the same environments indicating that they are not genetically different. The use of imazapyr gave no significant ($P > 0.05$) yield differences.

### 4.7.4 Grey Leaf Spot

Score of grey leaf spot (*Cercospora zeae maydis)* symptoms rated on a scale from 1 (=clean, no infection) to 5 (=severely diseased fig 4.2). There was significant difference among the varieties ($P<0.05$). Treatment 3 (J437-30) had the highest score meaning to say it had a lesser resistance to GLS as indicated in Table 4.2. The hybrid J437-29 was the one which recorded the least score implying a greater percentage of its resistance to the disease.

**Fig 4.2 Maize plant infected by Grey Leaf Spot (*Cercospora zeae-maydis*)**

### 4.7.5 Common Rust (PS)

Score of the severity for common rust (*Puccinia maydis)* symptoms rated on a scale from 1 (=, no infection) to 5 (= severely diseased). There was significant difference among the varieties ($P<0.05$). Treatment 3 (J437-30) had the highest score implying that it is lesser resistant to common rust and the one with the lowest score of 2.58 was treatment 1(J437-27) meaning to say it has got degree of resistance to the *puccinia maydis*.

Under low nitrogen (site 2) there was siginificance difference among the varieties (P<0.05). J450-3 was the one with the highest score of 3.2 with the least recording a score of 2.5 that is J437-29 (Table 4.3).

**4.7.6 Lodging**

There was significant difference between the untreated and the treated varieties at (P<0.05) but no significance difference was shown between the varieties.

**4.7.7 Silking Date and Senescence**

There were no significant differences between the genotypes for silking dates (Table 4.2). J437-30's silking date was earliest of all the hybrids with a mean of 76.00 days while J437-29 took the longest time with a mean silking date of 80 days (Table 4.2).

**Table 4.2 Means of the I.R. maize lines for the agronomic characteristics At CIMMYT- Harare Site 1 during the 2010-2011 season. (Alpha=0.05).**

| Line | Anthesis(days) | Maize streak virus(score) | Grey leaf spot(score) | *Puccinia maydis*(Score) | EarRot(score) | Grain yield (t/ha) |
|---|---|---|---|---|---|---|
| **Untreated** | | | | | | |
| J437-27 | 73.7a | 2.7ab | 2.3abcd | 2.7ab | 4bc | 7.36ab |
| J437-29 | 75.3ab | 3a | 2.5bcd | 2.8abc | 2.7ab | 7.5ab |
| J437-30 | 74.3ab | 2.7a | 2.8cd | 3bcd | 22ab | 7.5ab |
| J450-2 | 74.7ab | 3.2c | 2.2abc | 3bcd | 1.3a | 6.5ab |
| J450-3 | 73.3a | 2.8ab | 2.5bcd | 2.8abc | 1.2a | 7.5ab |
| **Treated** | | | | | | |
| J437-27 | 76b | 2.3a | 2.3abcd | 2.5a | 2.8ab | 6.6b |
| J437-29 | 76.3b | 3a | 1.7a | 3bcd | 0.8a | 6.7b |
| J437-30 | 74.3ab | 2.2a | 3d | 3.2cd | 2.3ab | 6.0ab |
| J450-2 | 75ab | 3.3bc | 2.5bcd | 3bcd | 1.2a | 6.0ab |
| J450-3 | 76b | 2.7ab | 2.5bcd | 3.2cd | 3ab | 7.3b |
| GRAND MEAN | 74.89 | 2.79 | 2.43 | 2.92 | 2.13 | 6.7 |
| LSD | 1.37 | 0.47 | 0.5 | 0.34 | 1.69 | 0.99 |
| Residual | 0.96 | 0.11 | 0.13 | 0.06 | 1.47 | 1.34 |
| CV% | 1.3 | 12.07 | 15.03 | 8.33 | 43.33 | 7.29 |

Means followed by a different letter in the same column are significantly different by Duncan's Multiple-Range Test (P < 0.05).

**Table 4.3 Means of the I.R. maize lines for the agronomic characteristics At CIMMYT- Harare under Low N Site 2 during the 2010-2011 season. (Alpha=0.05)**

| Line | Anthesis(days) | Silking date(days) | *Puccinia maydis*(Score) | Senescence(days) | lodging (Score) | Grain yield(t/ha) |
|---|---|---|---|---|---|---|
| **Untreated** | | | | | | |
| J437-27 | 75abc | 78.3bc | 2.8ab | 30ab | 4.73ab | 2.267a |
| J437-29 | 75.7abc | 79.3abc | 2.7ab | 28.3ab | 4.3ab | 2.894a |
| J437-30 | 73.3c | 76c | 2.7ab | 26.7ab | 5.1ab | 2.941a |
| J450-2 | 75.7abc | 78bc | 2.8ab | 26.7ab | 3.9ab | 3.83a |
| J450-3 | 74.3bc | 77bc | 3ab | 33.3a | 2.03ab | 3.189a |
| **Treated** | | | | | | |
| J437-27 | 76.3ab | 78.7ab | 2.7ab | 30ab | 0.5b | 2.845a |
| J437-29 | 77a | 80ab | 2.5b | 25b | 2.37ab | 3.056a |
| J437-30 | 74.3bc | 76.3c | 2.7ab | 25b | 2.77ab | 2.967a |
| J450-2 | 76.7a | 79.3abc | 3ab | 30ab | 2.6ab | 2.107a |
| J450-3 | 76.7a | 78.3bc | 3.2a | 31.7ab | 3.07ab | 2.897a |
| GRAND MEAN | 75.59 | 78.21 | 2.78 | 28.33 | 3.79 | 2.821 |
| LSD | 1.75 | 2.72 | 0.46 | 5.09 | 4.64 | 2.195 |
| Residual | 0.74 | 1.78 | 0.05 | 6.25 | 5.20 | 1.164 |
| CV% | 1.14 | 1.71 | 8.18 | 8.82 | 60.14 | 38.237 |

Means followed by a different letter in the same column are significantly different by Duncan's Multiple-Range Test ($P < 0.05$).

## 4.8 RESULTS MUZARABANI

### 4.8.1 Ear Rot (ER)

Fig 4.3 shows some of the varieties which were affected by cob rot.There was statistically difference on the varieties on ear rot at $P<0.01$ with treated J450-2 recording the highest score of 2.67 and treated J437-29 having the least score (Table 4.4). This implies that treated J450-2 was the one which was severely attacked by ear rot and treated J437-29 was resistant to the ear rot.

**Fig 4.3 Cobs infected by ear rot (*Sternocapella maydis*)**

### 4.8.2 Grain Yield

Maize grain yield were significantly different among the hybrids at ($P<0.001$). However J450-3 had a higher yield with the least obtained from treated J437-29 with a yield of 4.5t/ha (Table 4.4). Only treatments that reduced *S. asiatica* density had a good yield. Generally the maize lines produced good yields under low N.

**Table 4.4 Means of the I.R. maize varieties for the agronomic characteristics at Muzarabani. (Alpha=0.05)**

| | Lines | Plant height(cm) | Ear height(cm) | Ear rot(Score) | Grain yield(t/ha) |
|---|---|---|---|---|---|
| | J437-27 | 230.0bc | 91.7ab | 1.00ab | 5.5abcd |
| | J437-29 | 233.3bc | 100.0ab | 0.33a | 5.5abc |
| **Untreated** | J437-30 | 245.0ab | 96.7ab | 1.00a | 5.5a |
| | J450-2 | 206.7b | 88.3ab | 1.67ab | 5.5cd |
| | J450-3 | 221.7bc | 98.3ab | 0.67ab | 5.5bcd |
| | J437-27 | 225.0bc | 88.3ab | 1.67ab | 5abcd |
| | J437-29 | 215.0b | 95.0ab | 0.0ab | 4.5abc |
| **Treated** | J437-30 | 233.3ab | 96.7a | 1.33ab | 5.9ab |
| | J450-2 | 270.0bc | 128.3a | 2.67ab | 7abc |
| | J450-3 | 225.0bc | 91.7ab | 0.67ab | 6.5de |
| | Grand mean | 225.8 | 93.8 | 0.90 | 5.5 |
| | LSD (5%) | 37.19 | 18.78 | 1.74 | 2.133 |
| | CV (%) | 9.8 | 11.4 | 73.1 | 11.3 |

Means followed by a different letter in the same column are significantly different by Duncan's Multiple-Range Test ($P < 0.05$).

## 4.9 DISCUSSION

### 4.9.1 Maize Streak virus Disease

There was highly significant difference in response to MSV inoculation. This is probably because of different generations at which the varieties were at the time of the evaluation. J450-2 had the highest MSV score showing that it had least resistance to MSV and J437-30 had the lowest MSV score of indicating near immunity status of the hybrid. The method that was used to introduce the disease (which was releasing infected leafhoppers onto the experimental sweet corn plants) might also have affected uniformity in infecting all the hybrids in each plot at approximately the same period. The activity of leafhoppers can be affected by weather conditions prevailing, particularly wind speed and direction. As a result, other plants could have been infected earlier or later than others which could have contributed to different responses of plants to infection.

### 4.9.2 Anthesis Dates

Anthesis dates and silking dates are important for pollination synchronization. Early flowering cultivars are essential where the growing season is short. The flowering period is the most sensitive stage yet it is the period during which yield formation for grain crops occurs.

### 4.9.3 Grain Yield

The untreated cultivars produced relatively appreciable grain yield in the trial inspite of the moderate *Striga* infestations. The high grain yields which were obtained under the untreated varieties were also due to the fact that the *Striga* in the field was not evenly spread to such an extent that some of the untreated varieties were planted in some areas where there was no *Striga* infestation at all hence varieties can perform well and gave a better grain yield.

In the field at Muzarabani there was less *Striga* which emerged compared to the one for pot experiment throughout the season because when maize was sown on the flat *S.asiatica* seeds were deep in the soil and not brought to the surface hence were not able to attack their hosts until later in the season (Worsham, 1987).

## 4.10 Conclusion

In this experiment results have showed that lines J450-2 and J450-3 performed better than J437-27, J437-29 and J437-30 and can be recommended for further screening in the field trials.

# CHAPTER FIVE

## 5.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS

### 5.1 General Conclusions

The studies have shown that imazapyr seed dressings can suppress *S. asiatica* emergence by up to 12 weeks. The treated hybrids supported fewer *Striga* plants and produced better yield under *Striga* infestation than the untreated hybrids. The untreated supported large number of *Striga* plants and even produced no yield under infestation.

Results in this report have shown the merits of using the immazapyr herbicide together with the I.R maize varieties. The results therefore suggest that the use of immazapyr herbicide can suppresses *Striga* emergence, and also has a seed depletion role in integrated management of *Striga.*

Consequently the high yielding and well adapted IR maize varieties that support the reduced number of *Striga* plants contribute significantly to our effort to eradicate the *Striga* menace on-farm in areas where the parasite is endemic. Use of I.R maize hybrids treated with imazapyr can deplete the reservoir of *Striga* seeds in the soil. Farmers who no longer lose their maize to *Striga* can be expected to put more input into weeding and apply some fertilizer. They will certainly see the benefit of buying coated seed each season. Maize imports can be reduced and the cost of distribution be cut down.

Overall the results for grain yields and disease infection at CIMMYT-Harare and Muzarabani showed that the lines J450-2 and J450-3 have the best potential and are recommended for further screening in field trials. At Muzarabani Maize grain yield were significantly different among the hybrids at ($P<0.05$). However J450-3 had a higher yield with the least obtained from treated J437-29 with a yield of 4.5t/ha.

## 5.2 Recommendations

i. There is need for further research to be carried out under *Striga* hot spot areas in Zimbabwe.

ii. Future researchers are encouraged to work on the residual effect of the imazapyr herbicide on different soil types found in Zimbabwe.

iii. Work should also be carried out on the adoption of herbicide use in Zimbabwe.

iv. There is need for further realistic crop yield losses and to identify those regions and crops that are most severely affected.

v. It is necessary to determine the extent of the variability in *Striga* populations to develop effective breeding programme.

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# APPENDICES

**Appendix 1 Mean Square Values for Anthesis Date (AD), Days to *Striga* Emergence (DSE), Grain Yield (GYG) and Maize Biomass (MB) at Henderson Research Station**

| Source | df | Mean Squares Henderson Research Station | | | |
|---|---|---|---|---|---|
| | | AD | DSE | GYG | MB |
| Rep | 2 | $0.633^{ns}$ | $171.033^{ns}$ | $201.892^{*}$ | $0.002^{**}$ |
| FAC A | 4 | $118.117^{**}$ | $361.917^{**}$ | $25.900^{ns}$ | $0.000^{ns}$ |
| FAC B | 1 | $132.300^{*}$ | $2000.833^{***}$ | $213.173^{*}$ | $0.004^{***}$ |
| FAC A x FAC B | 4 | $40.550^{ns}$ | $361.917^{**}$ | $17.091^{ns}$ | $0.000^{ns}$ |
| Residual | 18 | 26.596 | 74.885 | 46.711 | 0.000 |
| Grand mean | | 155.63 | 8.167 | 2.859 | 0.052 |
| $R^2$ | | 0.6161 | 0.7953 | 0.4841 | 0.7195 |
| CV% | | 3.31 | 106.0 | 239.1 | 28.20 |

*Significant at P<0.05, **Significant at P<0.01, ***Significant at P<0.001, ns Not Significant

**Appendix 2: Mean Square values for Maize Roots (MR), Maize Stem Weight (MSW), Plant Height (PH), *Striga* Attachments (SA) and *Striga* Weights (SW) at Henderson Research Station.**

| Source | df | Mean Squares Henderson Research Station | | | | |
|---|---|---|---|---|---|---|
| | | MR | MSW | PH | SA | SW |
| Rep | 2 | $624.100^{**}$ | $4.633^{*}$ | $727.500^{ns}$ | $22.800^{ns}$ | $0.007^{ns}$ |
| FAC A | 4 | $52.667^{ns}$ | $1.133^{ns}$ | $938.333^{ns}$ | $6.500^{ns}$ | 0.006 |
| FAC B | 1 | $381.633^{*}$ | $6.533^{*}$ | $13020.833^{***}$ | $346.800^{***}$ | $0.095^{***}$ |
| FAC A x FAC B | 4 | $398.633^{**}$ | $6.867^{**}$ | $341.667^{ns}$ | $7.800^{ns}$ | $0.011^{ns}$ |
| Residual | 18 | 86.026 | 1.337 | 378.426 | 11.244 | 0.004 |

| | | | | | |
|---|---|---|---|---|---|
| Grand mean | 22.500 | 3.067 | 78.500 | 4.00 | 0.070 |
| $R^2$ | 0.6893 | 0.6651 | 0.7421 | 0.6896 | 0.7303 |
| CV% | 41.22 | 37.71 | 24.78 | 83.83 | 85.57 |

*Significant at P<0.05, **Significant at P<0.01, ***Significant at P<0.001, ns Not Significant

**Appendix 3: *Striga* Counts at 2, 4 and 6 weeks after emergence (WAE)**

| Source | df | Mean Squares Henderson Research Station | | |
|---|---|---|---|---|
| | | 2WAE | 4WAE | 6WAE |
| Rep | 2 | 8.133$^{ns}$ | 22.033$^{ns}$ | 24.233$^{ns}$ |
| FAC A | 4 | 15.133$^{ns}$ | 11.383$^{ns}$ | 36.883$^{ns}$ |
| FAC B | 1 | 986.133$^{***}$ | 1952.133$^{***}$ | 3763.200$^{***}$ |
| FAC A x FAC B | 4 | 20.133$^{ns}$ | 15.717$^{ns}$ | 36.617$^{ns}$ |
| Residual | 18 | 7.911 | 18.404 | 36.789 |
| Grand mean | | 5.933 | 8.933 | 13.067 |
| $R^2$ | | 0.8893 | 0.8640 | 0.8611 |
| CV% | | 47.40 | 48.02 | 46.42 |

*Significant at P<0.05, **Significant at P<0.01, ***Significant at P<0.001, ns Not Significant

**Appendix 4: *Striga* Counts 8, 10, 12 weeks after emergence (WAE) and Total *Striga* Count**

| Source | df | Mean Squares Henderson Research Station | | | |
|---|---|---|---|---|---|
| | | 8WAE | 10WAE | 12WAE | Total *Striga* Count |
| Rep | 2 | 6.533$^{ns}$ | 3.633$^{ns}$ | 10.133$^{ns}$ | 66.033$^{ns}$ |
| FAC A | 4 | 45.667$^{ns}$ | 44.467$^{ns}$ | 21.133$^{ns}$ | 126.550$^{ns}$ |
| FAC B | 1 | 5360.333$^{***}$ | 4392.300$^{***}$ | 2520.833$^{***}$ | 18204.033$^{***}$ |
| FAC A x FAC B | 4 | 57.533$^{ns}$ | 53.133$^{ns}$ | 24.333$^{ns}$ | 182.617$^{ns}$ |
| Residual | 18 | 58.126 | 53.856 | 34.244 | 188.589 |
| Grand mean | | 16.833 | 16.767 | 14.433 | 33.433 |

| | | | | |
|---|---|---|---|---|
| $R^2$ | 0.8649 | 0.8317 | 0.8154 | 0.8522 |
| CV% | 45.29 | 43.77 | 40.54 | 41.08 |

*Significant at P<0.05, **Significant at P<0.01, ***Significant at P<0.001, ns Not Significant

**Appendix 5 ANOVA results for Maize Streak Virus (MSV), Anthesis Date(AD), Grain Yield(GYG), Ear Rot(ER), Grey Leaf Spot(GLS), and *Puccinia maydis* (PS) for the IR Maize Varieties at CIMMYT Harare during the 2010/2011 season**

| Source | df | Mean Squares Harare Site 1 | | | | | |
|---|---|---|---|---|---|---|---|
| | | AD | GYG | MSV | ER | GLS | PS |
| Rep | 2 | 5.700$^{*}$ | 1.318$^{ns}$ | 0.808$^{**}$ | 1.233 | 0.358$^{ns}$ | 0.033ns |
| FAC A | 4 | 1.833$^{ns}$ | 9.079$^{***}$ | 0.721$^{***}$ | 4.333$^{*}$ | 0.571$^{*}$ | 0.229$^{*}$ |
| FAC B | 1 | 12.033$^{**}$ | 2.330$^{ns}$ | 0.208$^{ns}$ | 0.133 | 0.033$^{ns}$ | 0.075$^{ns}$ |
| FAC A x FAC B | 4 | 2.117$^{*}$ | 1.571$^{ns}$ | 0.104$^{ns}$ | 3.800$^{*}$ | 0.304$^{ns}$ | 0.054$^{ns}$ |
| Residual | 18 | 1.181 | 0.974 | 0.123 | 1.96 | 0.118 | 0.070 |
| Grand mean | | 74.900 | 6.768 | 2.783 | 2.333 | 2.433 | 2.917 |
| $R^2$ | | 0.6496 | 0.7307 | 0.6981 | 0.6200 | 0.6675 | 0.5016 |
| CV% | | 1.45 | 7.29 | 12.61 | 46.88 | 14.09 | 9.10 |

*Significant at P<0.05, **Significant at P<0.01, ***Significant at P<0.001, ns Not Significant

**Appendix 6 ANOVA results for Anthesis date(AD), Grain Yield (GYG), Puccinia maydis (PS), Root lodging (RL), Silking date (SD) and Senescence (SEN) for I.R maize varieties under low N at CIMMYT Harare during the 2010/2011 season**

| Source | df | Mean Squares Harare Site 2 | | | | | |
|---|---|---|---|---|---|---|---|
| | | AD | GYG | PS | RL | SD | SEN |
| Rep | 2 | 1.200$^{ns}$ | 0.293$^{ns}$ | 0.075$^{ns}$ | 15.445$^{*}$ | 1.633$^{ns}$ | 5.833ns |
| FAC A | 4 | 5.917$^{***}$ | 0.228$^{ns}$ | 0.242$^{**}$ | 1.951$^{ns}$ | 10.283$^{**}$ | 42.917$^{**}$ |
| FAC B | 1 | 14.700$^{***}$ | 0.469$^{ns}$ | 0.2215$^{ns}$ | 23.056$^{*}$ | 4.800$^{ns}$ | 3.333$^{ns}$ |
| FAC A x FAC B | 4 | 0.450$^{ns}$ | 1.164$^{ns}$ | 0.042$^{ns}$ | 5.434$^{ns}$ | 0.383$^{ns}$ | 9.583$^{ns}$ |
| Residual | 18 | 0.830 | 1.353 | 0.056 | 3.557 | 2.041 | 6.759 |
| Grand mean | | 75.500 | 2.899 | 2.800 | 3.137 | 78.133 | 28.667 |
| $R^2$ | | 0.7403 | 0.2138 | 0.5580 | 0.5660 | 0.5800 | 0.6490 |
| CV% | | 1.21 | 40.12 | 8.49 | 60.13 | 1.83 | 9.07 |

*Significant at P<0.05, **Significant at P<0.01, ***Significant at P<0.001, ns Not Significant

**Appendix 7 Mean Squares for Grain Yield (GYG), Husk Cover (HC), Ear Rot and Ear Height for Muzarabani**

| Source | df | Mean Squares Muzarabani | | | |
|---|---|---|---|---|---|
| | | Grain Yield | Husk Cover | Ear Rot | Ear Height |
| Rep | 2 | 1.694$^{ns}$ | 5.233$^{ns}$ | 1900$^{ns}$ | 173.333$^{ns}$ |
| FAC A | 4 | 8.943$^{***}$ | 4.697$^{*}$ | 0.383$^{ns}$ | 13.750$^{ns}$ |
| FAC B | 1 | 0.013$^{ns}$ | 1.200$^{ns}$ | 1.633$^{ns}$ | 367.500$^{ns}$ |
| FAC A x FAC B | 4 | 1.623$^{*}$ | 0.700$^{ns}$ | 1.217$^{ns}$ | 7.083$^{ns}$ |
| Residual | 18 | 0.542 | 1.530 | 0.937 | 90.926 |

*Significant at P<0.05, **Significant at P<0.01, ***Significant at P<0.001, ns Not Significant

**Appendix 8: Scale used to rate the Diseases**

1. northern leaf blight (*Exserohilum turcicum*)1 (= no infection) to 5 (= severely diseased).

2. common rust (*Puccinia maydis*) 1 (= no infection) to 5 (= severely diseased).

3. grey leaf spot (*Cercospora zeae maydis)* 1 (= no infection) to 5 (= severely diseased).

4. Maize Streak Virus A six-point disease scale 0(=immune) to 5(=highly susceptible) was used to classify infection whether it was immune, resistant, tolerant, susceptible, very susceptible and highly susceptible.

Classification was based on leaf area covered by chlorotic lesions in infected plants