# Chapter 5

# Determining the efficacy of push-pull for the control of *Eldana saccharina* through on-farm trials

## 5.1 Introduction

The South African Sugarcane Research Institute (SASRI) recommends an area-wide integrated pest management (AW-IPM) approach for control of *Eldana saccharina* Walker (Lepidoptera: Pyralidae) (Conlong and Rutherford, 2009; Rutherford and Conlong, 2010). Push-pull is an integral part of IPM recommendations for controlling *E. saccharina,* and is currently being implemented in the Midlands North region (Webster *et al.*, 2005; Webster *et al.*, 2009). The 'push' or repellent plant used is molasses grass (*Melinis minutiflora* P. Beauv (Cyperales: Poaceae)) which has a repellent effect on the egg-laying adults of *E. saccharina* (Kasl, 2004; Barker, 2008) and can also attract the natural enemies of this pest into the crop environment, as was done for maize stem borers in East Africa (Khan *et al.*, 1997a). The pull plants used are Bt maize and indigenous wetland sedges. Bt maize is used as a 'dead-end trap crop', because of the toxic effect on lepidopteran larvae of the cry protein produced by Bt maize plants. Furthermore, older maize plants have been shown to be more attractive than sugarcane to gravid moths (Keeping *et al.*, 2007). The sedge species used as a pull plant are *Cyperus papyrus* L. and *C. dives* Delile (Cyperales: Cyperaceae). These are indigenous to wetlands in KwaZulu-Natal and are the natural host plants of *E. saccharina* (Atkinson, 1980). For a diagram of the push-pull strategy see Figure 4.1 in Chapter 4.

Research trials during the developmental stage of push-pull in sugarcane included laboratory, cage and small field trials managed by scientists and in some cases extension staff (Kasl, 2004; Barker, 2008). No large-scale on-farm trials in which farmers have been given full responsibility for planting and maintaining the push-pull plants have been completed yet. Previous on-farm field trials were limited to small plots (50m x 50m) and were managed by research staff (Kasl, 2004; Barker,

2008). There is thus a need for trials to be carried out on a larger scale on a fully functioning farm and under farmers' own management conditions where variables such as soil type, sugarcane variety, and sugarcane age are not strictly controlled as they are in small plot trials.

These larger on-farm field trials can be used not only to increase the scientific knowledge base of push-pull but also to aid in the further adoption of push-pull by neighbouring farmers. For example, Khan *et al.* (2008b) attributed their successful implementation of push-pull among small-scale maize farmers in Kenya in part to their decision to move from scientist-managed field trials to farmer-managed field trials under farmers' own conditions. Farmers in the Midlands North area have specifically asked for on-farm "proof" that push-pull can contribute to reduce *E. saccharina* damage to sugarcane (Cockburn *et al.* (2012) and Figure 4.7 D, Chapter 4).

Furthermore, although a specific spatial arrangement of push and pull plants has been recommended (Conlong and Rutherford, 2009) its efficacy has not yet been tested in field trials. Several factors that may be encountered in on-farm situations may affect the efficacy of the push-pull strategy. For example, Murlis *et al.* (1992) showed that concentrations of plant volatiles released by plants decrease with distance from the source. A need therefore exists to determine at what distance the effect of *M. minutiflora* on *E. saccharina* diminishes. This information is important in refining push-pull recommendations to farmers on how much *M. minutiflora* is needed to effectively reduce *E. saccharina* damage per unit area of sugarcane. The structure and physical condition of a plant may also influence volatile emission (Randlkofer *et al.*, 2010). A larger plant biomass will presumably result in emission of larger amounts of volatiles. Therefore, how well the *M. minutiflora* seedlings establish and how much plant biomass there is will likely affect how effectively *M. minutiflora* repels *E. saccharina* moths. Since farmers perceive implementation of push-pull as a potential 'hassle' (See Chapter 4), it is important to provide a scientific basis for good management of the repellent plants so that farmers see it as a worthwhile activity.

This study thus has the following three aims:

- to determine the efficacy of push-pull in reducing *E. saccharina* damage and infestation using on-farm trials
- to determine whether the effect of *M. minutiflora* on *E. saccharina* damage levels changes with distance from the grass stands
- to determine whether the biomass of *M. minutiflora* stands has an effect on *E. saccharina* damage levels in sugarcane.

## 5.2 Materials and Methods

### 5.2.1 Field sites

The Midlands North region was chosen for on-farm push-pull trials for two reasons. Firstly, because the Local Pest Disease and Variety Control Committee (LPD&VCC) have been promoting push-pull as part of an IPM approach to managing *E. saccharina* in this area since 2004 (Webster *et al.*, 2005; Webster *et al.*, 2009). The farmers, LPD&VCC manager and extension staff in the region are all committed to implementation of environmentally sustainable farming practices (Maher and Schulz, 2003). Secondly, since the *E. saccharina* infestation levels in the Midlands North are on the increase (Webster *et al.*, 2009), but not yet as high as those in the coastal areas (Goebel *et al.*, 2005), it is seen as a suitable area to initiate implementation of push-pull and IPM as a preventative measure.

Four large-scale or commercial farms, were identified as trial sites for this study. *Eldana saccharina* is currently more of a threat to large-scale than small-scale sugarcane farmers (Way *et al.*, 2003; Goebel *et al.*, 2005), hence large-scale farmers were chosen for this study. Three of the farms were in areas regarded as high risk for *E. saccharina*, and one in a medium risk area (Webster *et al.*, 2009). The farms were identified as suitable field sites based on a combination of four criteria:

1. topography which is suitable for push-pull implementation, i.e. wetland areas which could potentially be used as a 'pull' component and fields with contour banks between fields running parallel to the wetland area for planting of the 'push', *M. minutiflora*.
2. *Eldana saccharina* risk: Host farmers consider *E. saccharina* to be a threat to their sugarcane production and the farm is situated in a medium or high *E. saccharina* risk area determined by the LPD&VCC (Webster *et al.*, 2009).

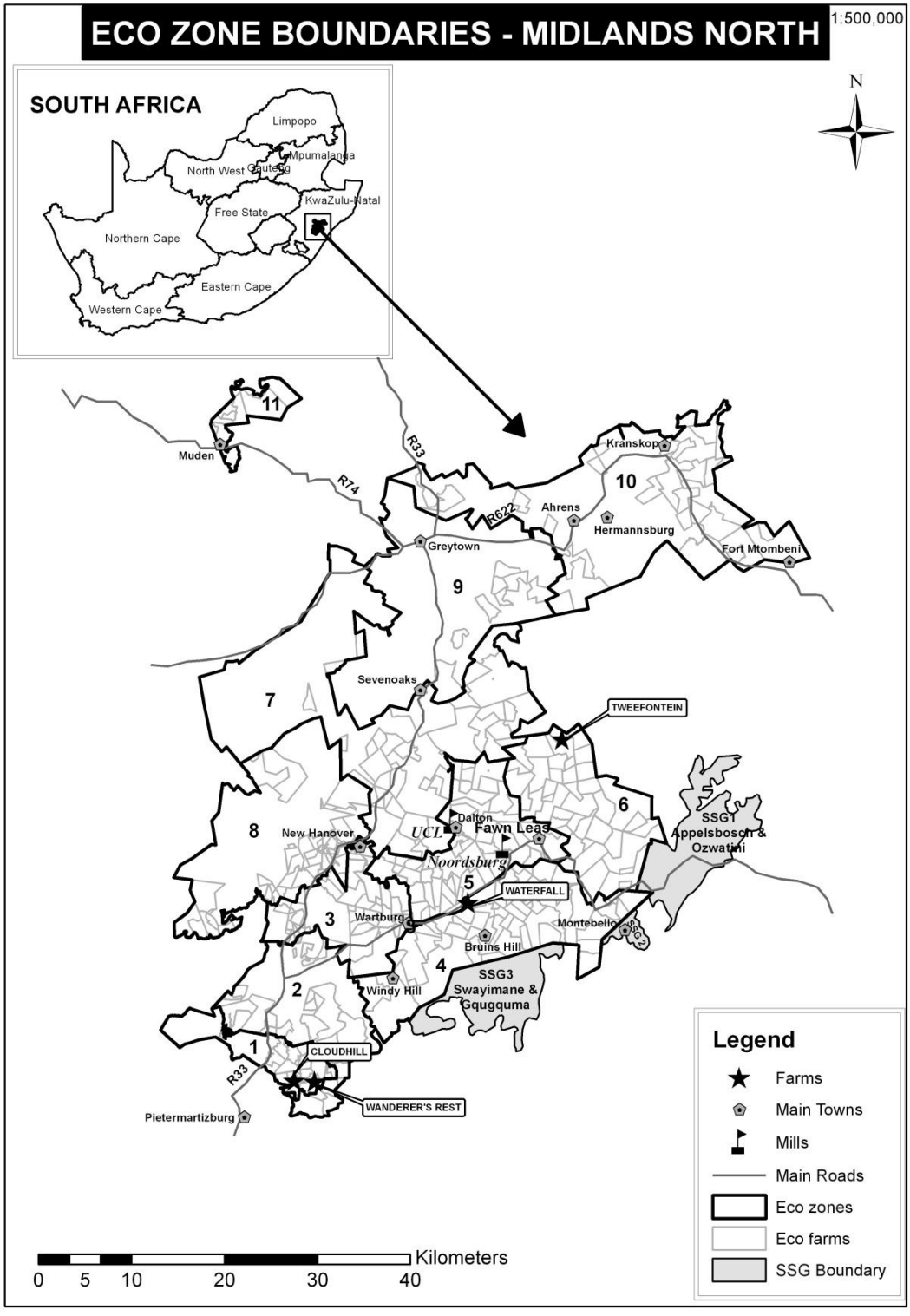



**Figure 5.1.** The Midlands North sugarcane growing region, with push-pull trial farms indicated by stars: Tweefontein, Waterfall, Cloudhill, Wanderer's Rest.

3. the farmer is willing to co-operate and host trials on his farm.
4. the farmer is prepared to provide inputs in the form of his time, labour and preparation and management of sites for planting *M. minutiflora* and Bt maize (herbicides, fertilizers, water and equipment).

The farms chosen as sites for the push-pull trials are listed in Table 5.1 and Figure 5.1 shows the position of the farms within the Midlands North region.

**Table 5.1** Characteristics of farms chosen for push-pull field trial sites.

| | **Cloudhill** | **Wanderer's Rest** | **Tweefontein** | **Waterfall** |
|---|---|---|---|---|
| **GPS co-ordinates** | 29°35'8.93"S 30°27'6.98"E | 29°35'11.84"S 30°28'27.66"E | 29°15'17.20"S 30°44'59.38"E | 29°24'49.34"S 30°38'43.16"E |
| **Ecozone** | 1 | 1 | 6 | 4 |
| **1. Suitability of topography** | good | very good | very good | excellent |
| ***2. E. saccharina* risk category** | high | high | high | medium |
| ***3.* Farmer co-operation** | very good | very good | very good | very good |

## *5.2.2 Layout and preparation of trial sites*

The four farms were visited in November 2010 to plan the layout of the trial areas with the farmers. On each farm, a push-pull treatment and a control area (no push-pull) were designated and each had to include a wetland. Treatment and control areas were along the same watercourse and with similar topological characteristics such as slope and aspect, and were approximately the same size. In two cases, the control areas had to be designated on a neighbouring farm to keep them as similar as possible to the treatment sites (Cloudhill and Wanderer's Rest).

In February and March 2011, Bt maize seed and *M. minutiflora* seedlings were delivered to the farmers for planting, together with a map showing the suggested planting layout for the push-pull treatment areas and instructions on how to plant the material. Plantings were completed at all sites by the end of March 2011. Unfortunately the *M. minutiflora* planting on one of the farms initially chosen as a trial farm was unsuccessful and this farm was removed from the study. An alternative

farm was selected (Cloudhill), which had *M. minutiflora* still growing from a previous field trial (Barker, 2008). The sampling period on Cloudhill was therefore shorter than for the other farms: it was only sampled from October 2011 until April 2012 when the whole area used for the study was harvested. The planting layout for the push-pull treatment area on each farm is shown in Figure 5.2.

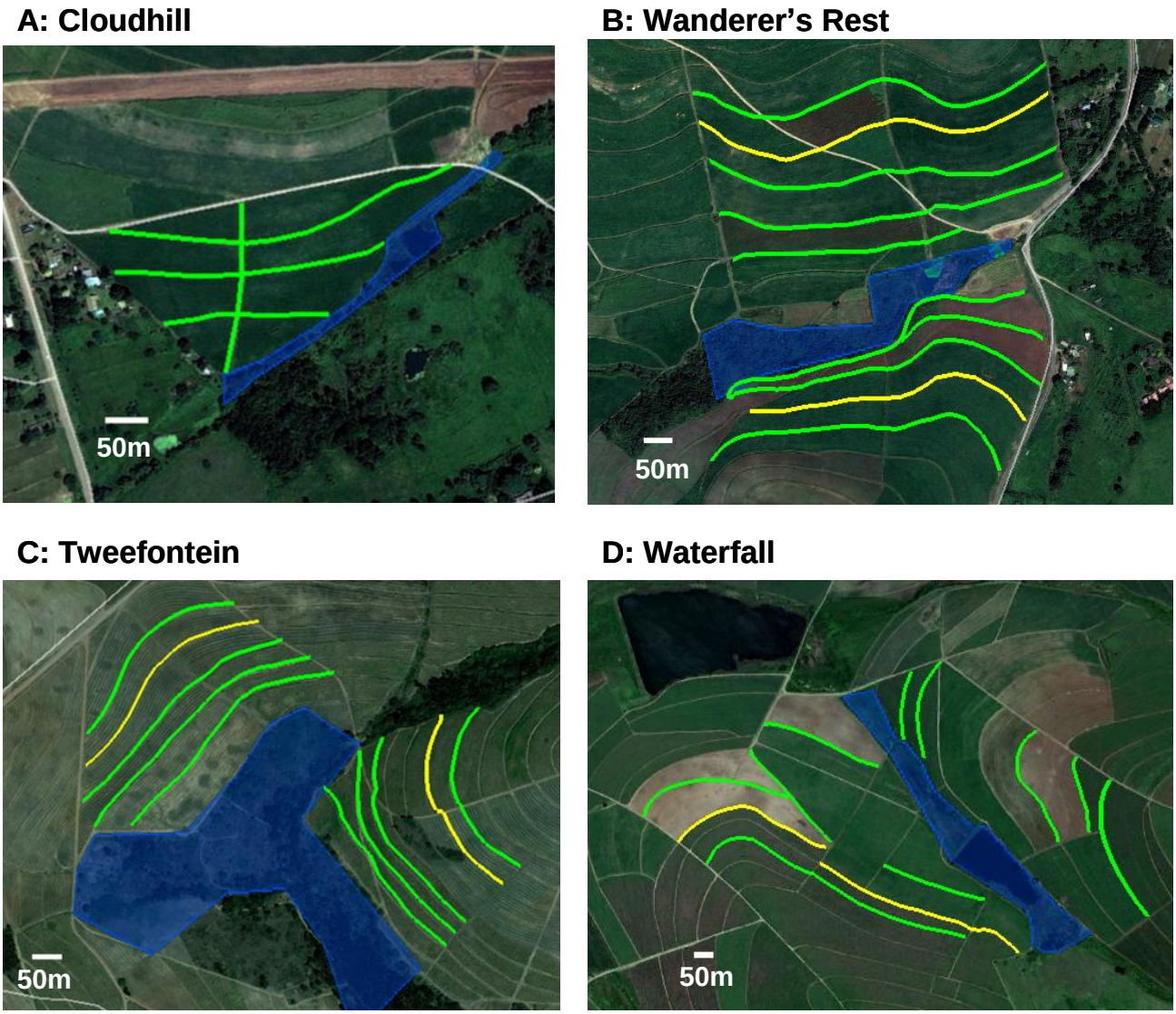



**Figure 5.2.** Spatial arrangement of push-pull treatment areas on trial farms. Yellow lines = Bt maize, green lines = *Melinis minutiflora,* blue areas = wetlands (Note: maps not at equal scales).

To prepare the contour banks between fields for planting of maize and *M. minutiflora*, farmers were asked to spray a 0.5m strip, where the seed and seedlings were to be planted, with glyphosate herbicide. This was done 2-4 weeks before planting to kill any grass or weeds and avoid competition. They then used a ripper to loosen the soil in the strip of the contour bank designated for planting. Some farmers planted the push and pull plants in the centre of the contour bank and others planted them on the edge of the contour banks against the sugarcane. The planting was

done in this way since, in previous studies, it was observed that *M. minutiflora* plants can aid in the suppression of creeping grasses into fields if planted against the edge of the sugarcane field (Barker *et al.*, 2006; Conlong and Campbell, 2010). Some farmers however, wanted to be able to use the contour banks for transport in which case planting in the middle would be more suitable. The *M. minutiflora* seedlings were planted on the first three to four contour banks on either side of the wetland as indicated by the green lines in Figure 5.2. These seedlings were planted one meter apart along the length of the contour banks. A hole was made every one meter and an adsorbent (AQUA-STOR KM) was mixed with water and added into the hole before the seedling was planted, as there was concern that the young seedlings may not establish well due to the dry conditions at the time of planting.

The Bt maize was planted in a single row along one contour bank, at least three sugarcane fields away from the wetlands, on either side of the site (yellow lines in Figure 5.2). The maize seeds were planted 30cm apart along the length of the contour bank as indicated in Figure 5.2, also either on the edge or in the middle. Note that maize was only planted in the first year of the study and not again in the second year. The decision whether or not to plant maize for the second season was left to the farmers and they all decided not to re-plant the maize. All planting was done by hand and where possible, seedlings were watered for the first few weeks by water cart to aid in establishment.

### *5.2.3 Assessment of* E. saccharina *infestation and damage*

Surveys for *E. saccharina* infestation and damage were carried out in the treatment and control areas of the four farms on a 6-weekly basis from April 2011 until July 2012. A total of 11 repeated surveys were completed over 16 months. For each survey, seven panels or fields were surveyed per treatment and control area on each farm i.e. 14 fields per farm. At each sampling date 30 sugarcane stalks were randomly selected from each field, 10 stalks from each of three different rows of sugarcane. Two of the rows were near the outer edge of the field and the third row was the middle row of the field. The rows in each field were counted to determine the middle row. The stalks were selected randomly by walking ten steps along the row and picking a stalk on the tenth step. This was repeated ten times along the row, such that each sample was taken along a 100m length from the start of the row.

Sugarcane stalks were split along their length and the total number of internodes, as well as the number of damaged internodes, was counted and recorded for each stalk (Barker *et al.*, 2006).

Since differences in damage patterns from *E. saccharina* and *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae), a minor pest of sugarcane, are difficult to distinguish the damage recorded included that from both stem borer species. *Eldana saccharina* damage is however much more extensive and destructive than that of *S. calamistis* (Way, 2001; SASRI, 2006). Larvae found in the stalks were collected and placed in labeled 30 ml plastic vials, with a gauze lid, filled with 8ml of artificial rearing diet (Graham and Conlong, 1988; Gillespie, 1993). Larvae were reared in temperature controlled units at the SASRI Insect Rearing Unit, at 28°C, 75% relative humidity until moths emerged and their species identity could be confirmed. Any parasitoids that emerged from larvae or pupae were collected and preserved for identification. Parasitoids were identified by Dr. G.L. Prinsloo at the Agricultural Research Institute (Plant Protection Research Institute, Biosystematics Division). Voucher specimens of parasitoids were stored at the National Insect Collection.

### *5.2.4 Assessment of* M. minutiflora *edge effect and biomass effect*

To determine whether the efficacy of *M. minutiflora* in repelling *E. saccharina* moths decreased with increased distance from the plants, an edge effect analysis was carried out on the damage and infestation data. This was done by comparing the stem borer damage and infestation levels in rows on the edge of the field with rows in the middle of the field, as described in the sampling procedure above (5.2.3).

To determine whether the biomass of *M. minutiflora* had any effect on stem borer damage or infestation levels, the level of plant establishment was determined by measuring the percentage seedling establishment. This was done by determining how many of the seedlings that were planted established successfully, and the plant cover abundance (Mueller-Dombois and Ellenberg, 1974) of the *M. minutiflora* stands on the contour banks. The impact of these measures was then tested against the stem borer damage levels. The percentage seedling establishment was determined towards the end of the sampling activities (in July 2012) by walking the length of the contour banks in which *M. minutiflora* was planted and counting the number of plants established per running meter, and then calculating the % establishment along the entire length of the contour bank. This then allowed a calculation of % *M. minutiflora* plant establishment for a whole field. The cover abundance was estimated using the Braun-Blanquet method for six of the contour banks planted to *M. minutiflora* per farm. In the Braun-Blanquet method, the cover abundance of species in quadrats is estimated by a single assessor using a scale of classes, as shown in Table 5.2 (Mueller-Dombois and Ellenberg, 1974). Twenty quadrats were assessed using the Braun-Blanquet

method per contour bank on four contour banks per farm. The mean cover abundance was calculated by averaging the Braun-Blanquet scores for *M. minutiflora* across all quadrats in a contour bank. If a field had *M. minutiflora* planted on both edges of the field, a sum of the % plant establishment and overall mean cover abundance for both field edges was used for analysis. If a field edge had no *M. minutiflora* planted on it, it was incorporated as such in calculations, to account for an overall lower biomass of *M. minutiflora* for that field (i.e. plant establishment=0%, mean cover abundance=0 for that contour bank).

**Table 5.2.** Braun-Blanquet scale used to determine *M. minutiflora* cover abundance.

| Braun-Blanquet Class[a] | Range of plant cover in quadrat area (%) |
|---|---|
| 5 | 75-100% |
| 4 | 50-75% |
| 3 | 25-50% |
| 2 | 5-25% |
| 1 | 1-5% |
| † | <1 |
| *r* | <<1 |

[a]Class † and r were combined in assessments and for purposes of analysis they were ignored and considered insignificant (Mueller-Dombois and Ellenberg, 1974).

## *5.2.5 Statistical analysis*

Both the number of stem borer larvae infesting the sugarcane and the damage cause by stem borers are used as measurements of *E. saccharina* damage (Leslie, 2009; Keeping *et al.*, 2012). In this study both % stalks infested with stem borers and % damaged internodes were calculated. For statistical analysis however, we used only the data on the incidence of damaged internodes, since the number of stem borers were too low to justify meaningful statistical analyses. The data were tested for normality using the W-test for normality (Shapiro-Wilks) and were found not to be normal. The data were then transformed using either the LOG ($x$+1) or square root functions since a large majority of the data points were zeroes.

As *E. saccharina* is known to preferentially attack older crops (Girling, 1978; Gounou and Schulthess, 2004) and it generally causes more damage in older sugarcane (Way and Goebel, 2003), the age of the sugarcane in the experiments was also taken into account. Since sugarcane is grown on a 24-month cycle in the Midlands North, sugarcane younger than 18 months was

removed from the initial data set. A further refinement of the data set was to remove the samples from the first four surveys since the *M. minutiflora* plants were still young and likely would not have had an effect on the stem borers and damage yet (except at Cloudhill where the grass was already well established from a previous trial). Upon scrutiny of the results from this refined data set, two further sub-samples were identified for more detailed analysis, as shown in Table 5.3. These two sub-samples were selected on the basis that the damage levels were high enough to allow for analysis (damage was too low and/or inconsistent at Waterfall and Wanderer's Rest) and because they coincided with two known moth peaks. *Eldana saccharina* is known to have two moth population peaks or flights in a year: one in November and one in April (Atkinson, 1982). Since the *M. minutiflora* was planted in March 2011 and took a few months to reach maturity, it would only have had an effect on the November 2011 and April 2012 moth peaks.

**Table 5.3** Samples and sub-samples of stem borer incidence and damage data used for statistical analysis, indicating which farms and surveys the data were taken from.

| Sample | Farm | Survey number | Age of sugarcane[a] |
|---|---|---|---|
| 1: Full sampling period | All four farms | 5 - 11 | ≥18 months |
| 2: Sub-sample 1 | Cloudhill | 8 - 9 | ≥18 months |
| 3: Sub-sample 2 | Tweefontein | 7 - 10 | ≥18 months |

[a]Age of sugarcane was calculated for each specific survey date, and only cane 18 months or older was used in the sub-samples

To determine whether push-pull had an effect on *E. saccharina* damage and infestation levels, a restricted maximum likelihood (REML) analysis was carried out. REML analysis is similar to an ANOVA in that it can account for multiple variables which could have an effect on the variable being measured (Piepho *et al.*, 2003), in this case *E. saccharina* damage and infestation. However, the REML analysis is better suited to a farm-based trial as it allows for unbalanced data (Keeping *et al.*, 2012). The other variables included in the analysis, termed "random variables" or "terms" in a REML analysis, were sugarcane variety, sugarcane age, farm or field and survey number (sampling date). The y-variable or response variable used in the REML analysis was LOG (x+1)(% internodes damaged) or square root (% internodes damaged), depending on which transformation provided a better W-statistic in the normality tests (as shown in Table 5.4). The REML analysis was run for all four farms in the full sample and for the two sub-samples from Cloudhill and Tweefontein.

The multiple variables included in the REML analysis were much reduced in the two sub-samples from Cloudhill and Tweefontein, and for this reason these data sets were further analysed to simply test the effect of push-pull (treatment vs. control) on the % internodes damaged, without considering other random variables. Since the data was found to be non-parametric, a Mann-Whitney U-test was used and the medians and the means of the data (% internodes damaged) were reported (Olsen, 2003). Since the data set for this study had so many zeroes, the medians did not have much value in describing the data. For this reason the means were used for describing and reporting differences in % internodes damaged between treatment and control areas.

The Mann-Whitney U-test was used to test edge effects of *M. minutiflora* on % internodes damaged. The data from the two outer sugarcane rows of the field and the data from the middle sugarcane row were compared to determine whether the distance from the *M. minutiflora* plants had any effect on the incidence of damage. Only the data from the push-pull treatment areas in the two sub-samples were used for this analysis. The relationship between *M. minutiflora* biomass and stem borer damage (mean % internodes damaged per field) was analysed using a correlation and presented using scatter plots. As data were found not to fit a normal distribution, the non-parametric Spearman rank-order correlation was carried out to determine whether the relationships were statistically significant or not (Dytham, 2003). The Spearman-rank order correlation computes the test statistic $r_s$, which ranges from -1 to 1. The closer $r_s$ is to -1 or 1, the stronger the relationship between the two variables (Dytham, 2003).

## 5.3 Results

### *5.3.1 Effect of push-pull on stem borer infestation and damage*

#### 5.3.1.1 Stem borer infestation levels

Throughout the survey period, very low numbers of stem borers were collected from sugarcane. The % stalks infested of the full sampling period for each farm and the mean number of stem borers (*E. saccharina* and *S. calamistis*) per 100 stalks are shown in Figure 5.3. The highest number of stem borers was collected at Cloudhill, and they were mostly *E. saccharina*. *Sesamia calamistis* can thus be assumed to have a negligible effect on sugarcane on this farm, since it is known not to be a pest of economic concern in sugarcane (Carnegie, 1974). Waterfall had the lowest stem borer infestation, with only *S. calamistis* and no *E. saccharina* collected from this farm (Figure 5.3). This was consistent with results of previous surveys by LPD&VCC personnel on this farm (Tom Webster, pers. comm., 2012). Wanderer's Rest and Tweefontein had intermediate levels of stem borer infestations, but both had higher numbers of stem borers in the treatment than in the

control areas. This can be ascribed to the varieties and age of the sugarcane on these farms. Overall the stem borer numbers on both of these farms were consistently low, however, in cases where significant numbers were observed, it was either in fields of a sugarcane variety more susceptible to *E. saccharina* (variety N35 on Wanderer's Rest) or in sugarcane which was allowed to mature beyond the recommended age (Tweefontein: sugarcane age up to 28 months).

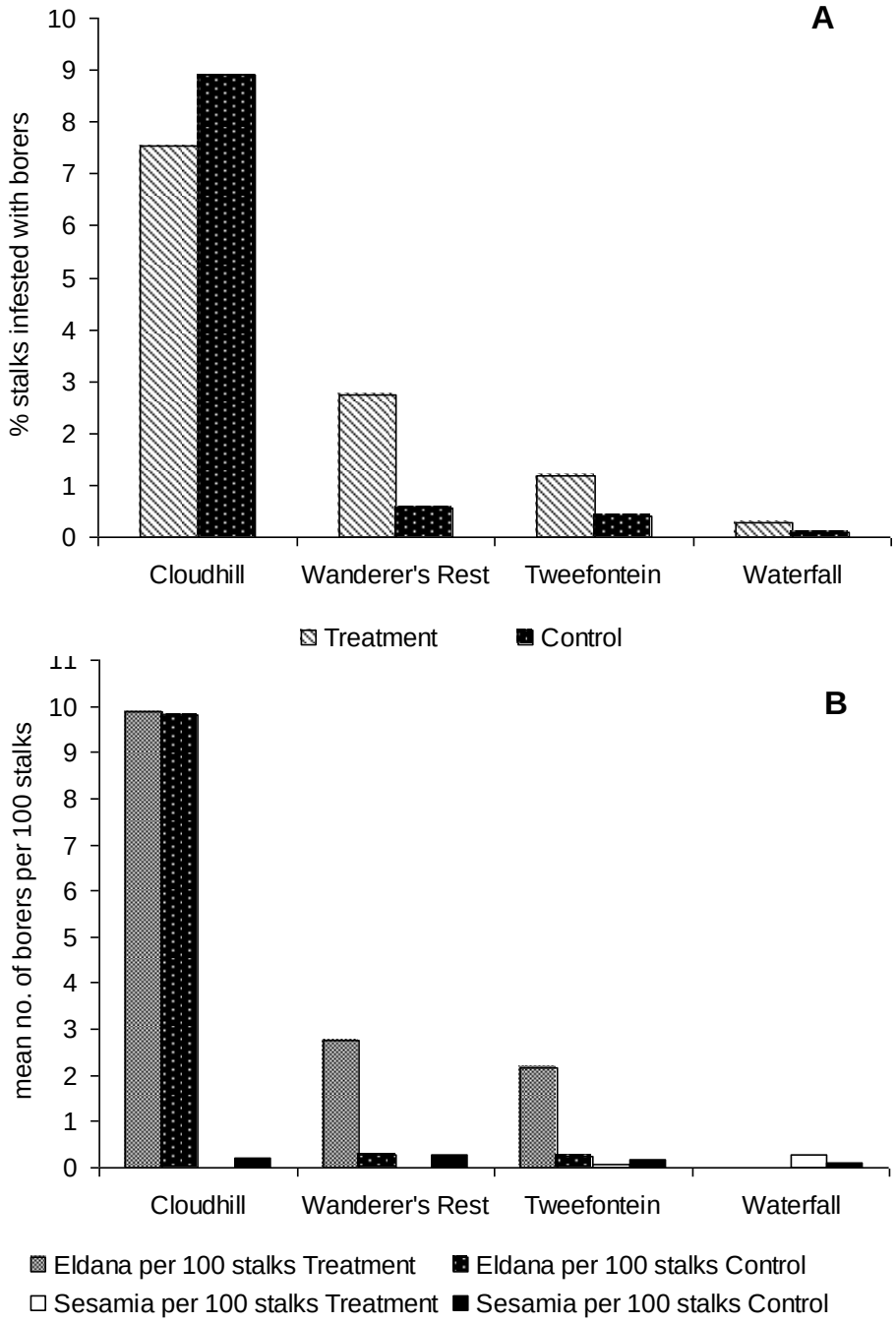



**Figure 5.3.** Mean stem borer infestation levels, for both *Eldana saccharina* and *Sesamia calamistis*, in the push-pull treatment and control areas over the full sampling period on all farms.

The stem borer infestations in the Cloudhill sub-sample showed a higher percentage of stalks infested with stem borers in the control compared to the treatment area (Figure 5.4). The Tweefontein sub-sample, as with the full sampling period data, also showed higher stem borer infestations in the treatment compared to the control area (Figure 5.4).

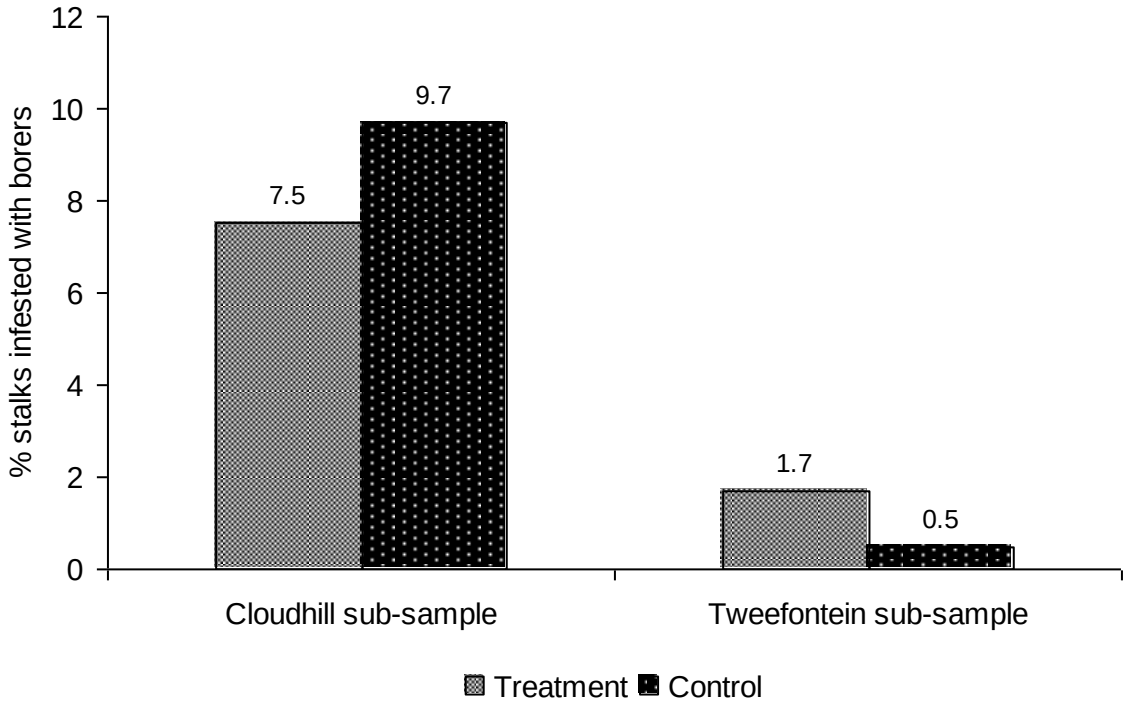



**Figure 5.4.** The incidence of borer infested sugarcane stalks in the push-pull treatment and control areas for sub-samples at Cloudhill (survey 8-9) and Tweefontein (survey 7-10).

### 5.3.1.2 Stem borer damage levels

The percentage internodes damaged for the full sampling period showed inconsistent results across all farms (Figure 5.5). As with the stem borer infestations, damage levels were highest at Cloudhill and lowest at Waterfall. Only at Cloudhill and Tweefontein were stem borer damage levels higher in the control than in the push-pull treatment areas. Stem borer damage measured as % internodes damaged (Figure 5.5 A) was similar to that measured as % stalks damaged (Figure 5.5 B). For this reason, only data on % damaged internodes are presented and discussed further.

Figure 5.6 shows the stem borer damage levels per farm for the Cloudhill and Tweefontein sub-samples using box and whisker plots. These show the medians, quartiles and minimum-maximum ranges of the data since they were analysed using a non-parametric statistical test. The mean value is included in the box and whisker plots since, compared to the median values, it provides a clearer indication of the differences between damage in the treatment and control plots. Stem borer

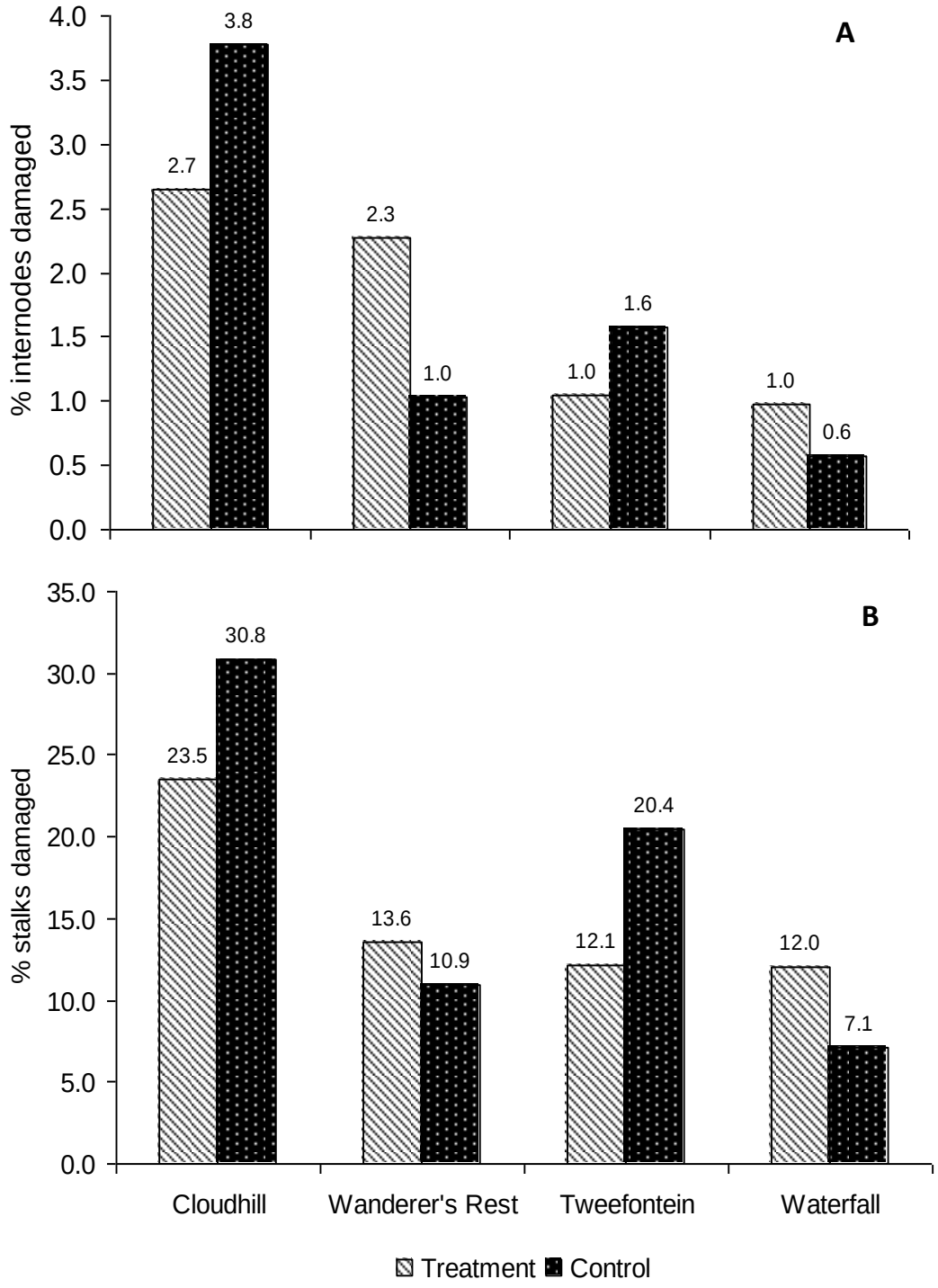



**Figure 5.5.** Stem borer damage levels (A=% internodes damaged, B=% stalks damaged) in the push-pull treatment and control areas for the full sampling period (survey 5-11) on all farms.

damage in treatment and control plots for the Cloudhill and Tweefontein sub-samples was similar to that in the full sample for both farms (Figure 5.7). Mean % damaged internodes was higher in the control than in the treatment areas for the sub-samples of both farms. The range of % internodes

damaged was also larger, indicating higher maximum damage levels in control areas, compared to treatment areas (Figure 5.6). The mean % internodes damaged in the push-pull treatment area on Cloudhill was 1.1% and in the control it was 1.7% (Figure 5.6). At Tweefontein, the mean % damaged internodes in the treatment area was 2.7, compared to 4.1% in the control (Figure 5.6). Damage levels were thus reduced in the presence of *M. minutiflora* at both of these sites.

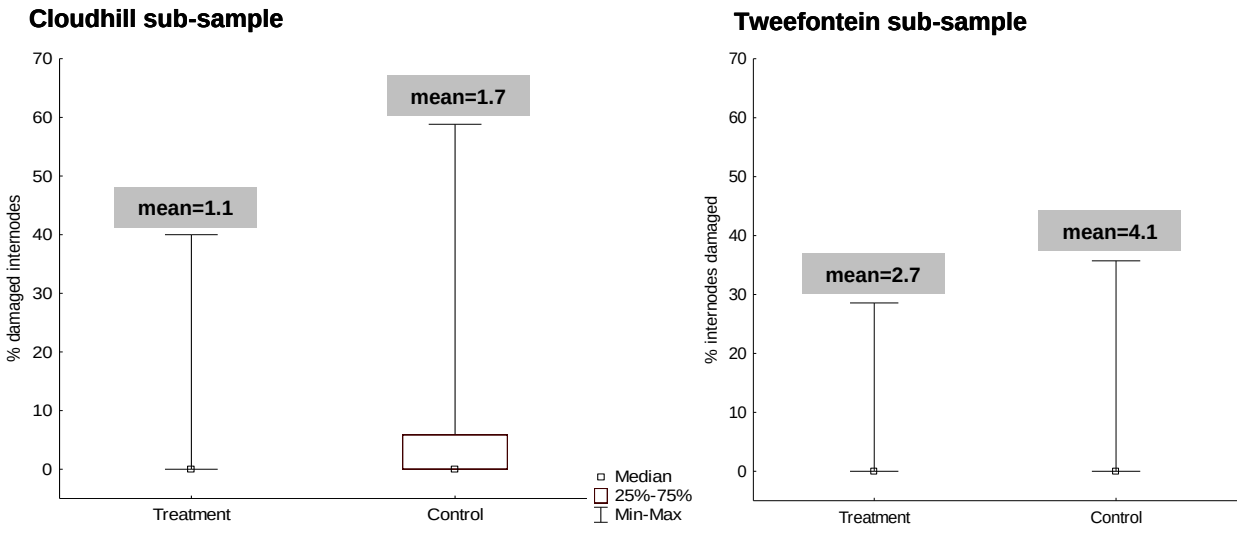



**Figure 5.6.** Box and whisker plots showing % damaged internodes in treatment and control areas for the sub-samples on Cloudhill (survey 8-9) and Tweefontein (survey 7-10). Small squares indicate medians, and means are shown in grey blocks.

The REML analysis to determine the effect of push-pull, in particular *M. minutiflora*, on % internodes damaged revealed no statistically significant effect, for the full or either of the sub-samples (Table 5.4). Waterfall showed a borderline effect at the 0.05 significance level, however since no *E. saccharina* was found on this farm, this damage is ascribed to *S. calamistis*, which is not the target species for push-pull. The *p*-values for Cloudhill and Tweefontein, for both the full and sub-samples, were lower than those for the other sites which indicated that there may be slightly more of an effect of push-pull on damage in these two samples shown by the REML analysis.

These lower *p*-values in the REML analysis prompted further analysis using a Mann-Whitney U test for the sub-samples, which indicated that *M. minutiflora* did have a significant effect on % internodes damaged for the sub-samples at both Cloudhill and Tweefontein (Table 5.5). This result shows that push-pull, in particular the repellent grass *M. minutiflora*, reduced the damage of *E. saccharina* on sugarcane in these two samples.

**Table 5.4** Results of REML analysis to determine effect of push-pull treatment or control[a] on % damaged internodes.

| Sample from which data was taken | *W*-test for normality (*p*<0.001 for all) | Random terms[b] (variance component) | *W*-Statistic and *p*-value |
|---|---|---|---|
| Full sampling period: All farms | % damaged internodes: *W*=0.376<br>LOG(x+1)(% dam. Internodes): *W*=0.456 | Farm (0.0036)<br>Farm-Field (0.012)<br>Variety (0.123) | $W_{1,63} = 0.05$<br>$p = 0.818$ |
| Full sampling period: Cloudhill | % damaged internodes: *W*=0.538<br>SQRT(% dam. internodes): *W*=0.620 | Field (0.164) | $W_{1,13} = 0.88$<br>$p = 0.366$ |
| Full sampling period: Wanderer's Rest | % damaged internodes: *W*=0.324<br>LOG(x+1)(% dam. internodes): *W*=0.403 | Field (0.463)<br>Variety (3.753) | $W_{1,15} = 1.31$<br>$p = 0.270$ |
| Full sampling period: Tweefontein | % damaged internodes: *W*=0.425<br>SQRT(% dam. internodes): *W*=0.472 | Field (0.051)<br>Survey (0.004) | $W_{1,18} = 2.49$<br>$p = 0.132$ |
| Full sampling period: Waterfall | % damaged internodes: *W*=0.316<br>SQRT(% dam. Internodes): *W*=0.353 | None | $W_{1,7} = 5.12$<br>$p = 0.057$ |
| Sub-sample 1: Cloudhill | % dam internodes: *W*=0.526<br>SQRT(% dam. internodes): *W*=0.615 | Field (0.142) | $W_{1,14}=2.26$<br>$p = 0.154$ |
| Sub-sample 2: Tweefontein | % damaged internodes: *W*=0.439<br>SQRT(% dam. internodes): *W*=0.491 | Field (0.083) | $W_{1,16} = 1.31$<br>$p = 0.269$ |

[a]Fixed model = Push-pull treatment/control for all.
[b]Random terms initially included were removed from analysis if the variance components were negative or zero i.e. they made a negligible contribution to describing variability in the data

**Table 5.5** Results of Mann-Whitney U tests to test the effect of the push-pull treatment and control on % internodes damaged in the sub-samples at Cloudhill and Tweefontein.

| Sample: | *U* - statistic | *Z* - statistic (adjusted for ties) | *p*-value |
|---|---|---|---|
| Sub-sample 1: Cloudhill* | 110855 | -2.775 | 0.005 |
| Sub-sample 2: Tweefontein* | 381146 | 4.360 | 0.000 |

**p*-value significant at the 0.01 level

## *5.3.2 Parasitism of stem borers in sugarcane fields*

Three parasitoids were collected during the entire 16-month sampling period none of which were collected from *E. saccharina* (Table 5.6). The parasitoids were all found in control sections of the field trials, and were all Hymenoptera. This represents a parasitism rate of 6.5% for *S. calamistis* (a total of 46 individuals were collected during these surveys), and 0% for *E. saccharina*.

**Table 5.6** Parasitoids collected from sugarcane stem borers in push-pull field trials.

| Date collected | Host stem borer species | Farm and section (treatment or control) | Parasitoid species |
|---|---|---|---|
| 21/05/2012 | *Sesamia calamistis* | Wanderer's Rest (Control) | *Stenobracon* sp. (Hymenoptera: Braconidae) |
| 11/10/2011 | *Sesamia calamistis* | Waterfall (Control) | *Cotesia* sp. probably *sesamiae* (Cameron) (Hymenoptera: Braconidae) |
| 11/10/2011 | *Sesamia calamistis* | Waterfall (Control) | *Cotesia* sp. probably *sesamiae* (Cameron) (Hymenoptera: Braconidae) |

## *5.3.3 Effect of distance from* M. minutiflora *on stem borer damage*

The % internodes damaged was higher in sugarcane rows in the edge of the fields (outer row) compared to those in the centre of the field (inner row) in both the Cloudhill and Tweefontein sub-samples (Figure 5.7). The Mann-Whitney U test showed this difference to be statistically significant for Cloudhill (Table 5.7).

**Table 5.7** Results of Mann-Whitney U tests to test the effect of outer/inner sugarcane row on % internodes damaged for the sub-samples at Cloudhill and Tweefontein.

| Sample | *U* - statistic | *Z* - statistic (adjusted for ties) | *p*-value |
|---|---|---|---|
| Sub-sample 1: Cloudhill* | 8634 | 2.749 | 0.006 |
| Sub-sample 2: Tweefontein | 209813 | -0.037 | 0.970 |

*p=value significant at the 0.01 level

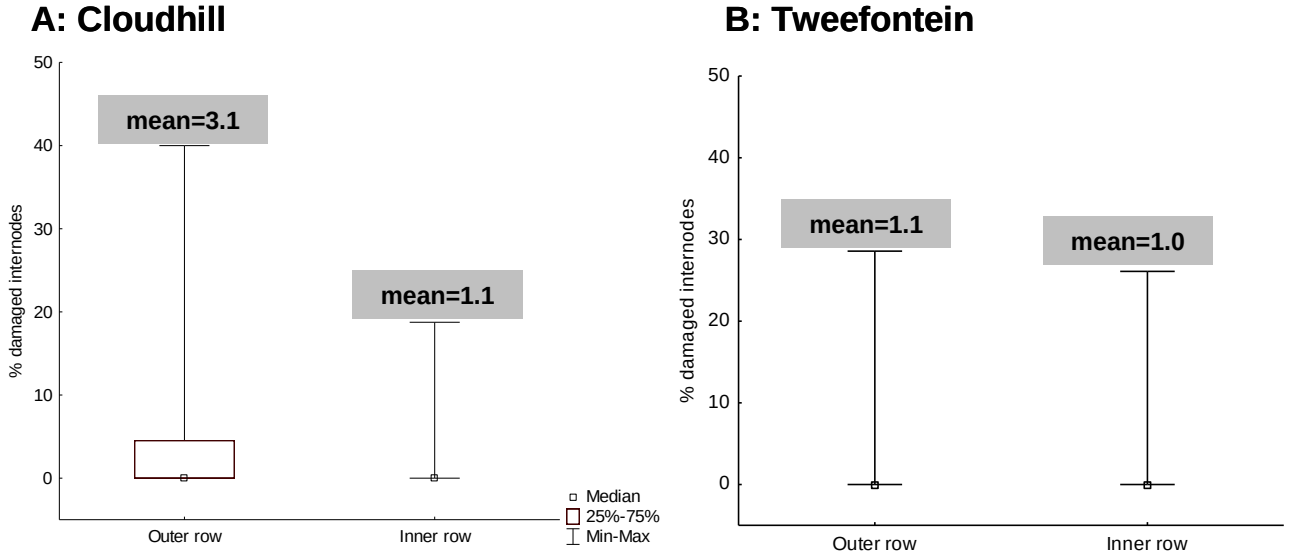



**Figure 5.7** Box and whisker plots of % internodes damaged in outer and inner rows of sugarcane for the sub-samples at Cloudhill (survey 8-9) and Tweefontein (survey 7-10). Small squares indicate medians, and means are shown in grey blocks.

## *5.3.4 Effect of* M. minutiflora *biomass on stem borer damage*

The success of *M. minutiflora* establishment varied across farms (Figure 5.8). The best establishment was at Waterfall, where *M. minutiflora* was watered and fertilised in the first few weeks of planting and was hand weeded for winter weeds. Problems with plant establishment included competition from weedy species (particularly *Cynodon dactylon* L. (Cyperales: Poaceae), mistaken hoeing and herbicide application by farm staff, residual herbicides in the soil from previous applications, dry conditions and poor soil.

There was no significant relationship between the % plant establishment and mean cover abundance of *M. minutiflora* and the % internodes damaged for either the Tweefontein or Cloudhill

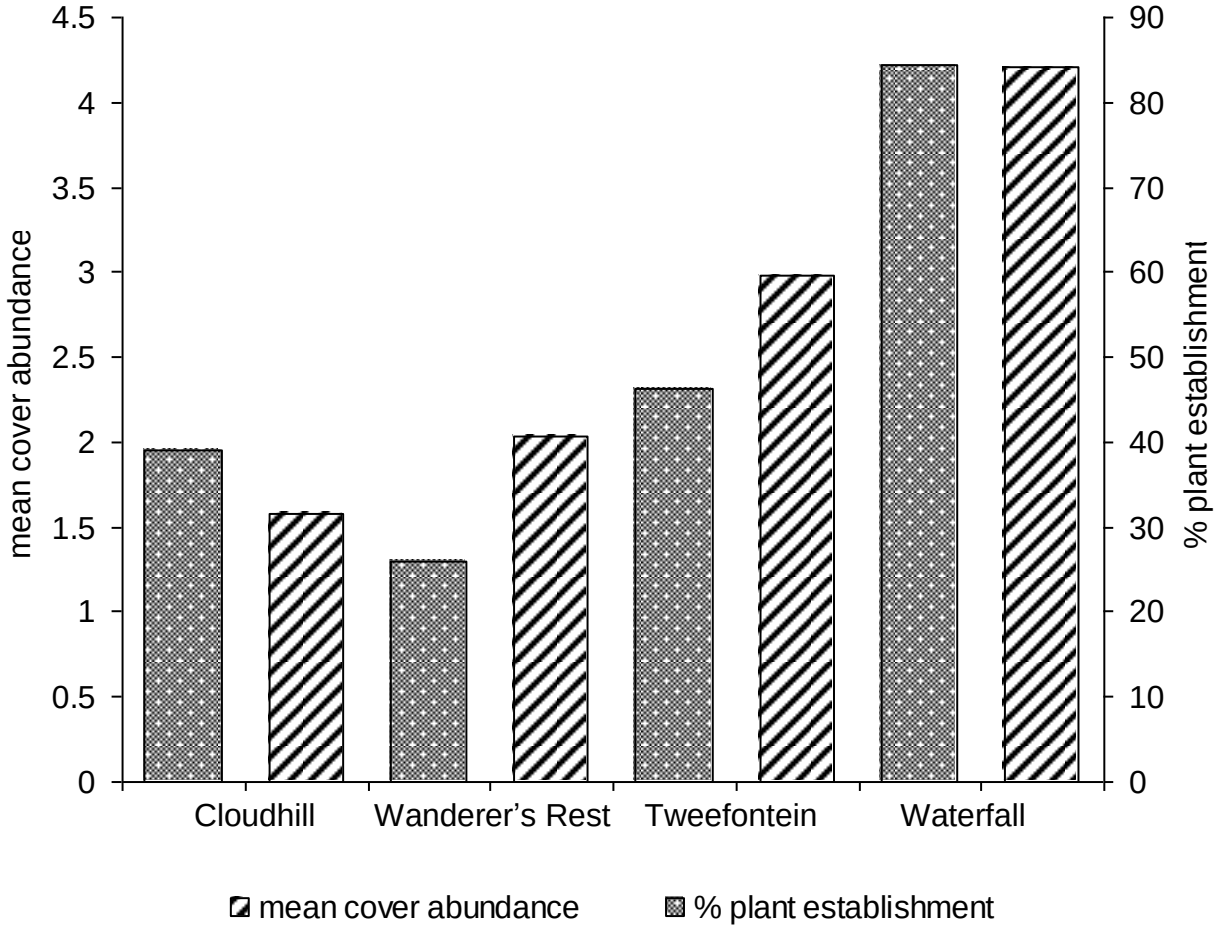



**Figure 5.8** The mean cover abundance (left y-axis) and % plant establishment (right y-axis) of *Melinis minutiflora* on four trial farms.

**Table 5.8** Spearman's rank order correlation showing relationships between mean % internodes damaged and % plant establishment and mean cover abundance of *Melinis minutiflora.*

| **Sample:** | **Spearman's $r_s$** | ***p*-value** |
|---|---|---|
| **Sub-sample 1: Cloudhill:** | | |
| Mean % internodes damaged and % plant establishment | -0.400 | 0.600 |
| Mean % internodes damaged and mean cover abundance | -0.400 | 0.600 |
| **Sub-sample 2: Tweefontein:** | | |
| Mean % internodes damaged and % plant establishment | -0.126 | 0.788 |
| Mean % internodes damaged and mean cover abundance | 0.306 | 0.504 |

sub-samples (Figure 5.9, Table 5.8). The negative values for Spearman's $r_s$ for % plant establishment (-0.400) and mean cover abundance (-0.400) at Cloudhill (Table 5.8) do however indicate that there may be a very small effect of increasing plant establishment and cover abundance on % internodes damaged: as plant establishment and cover abundance increase, % internodes damaged decreases. The data points in the scatter plot for % plant establishment vs. % internodes damaged at Cloudhill (Figure 5.9A) show this slight negative trend.

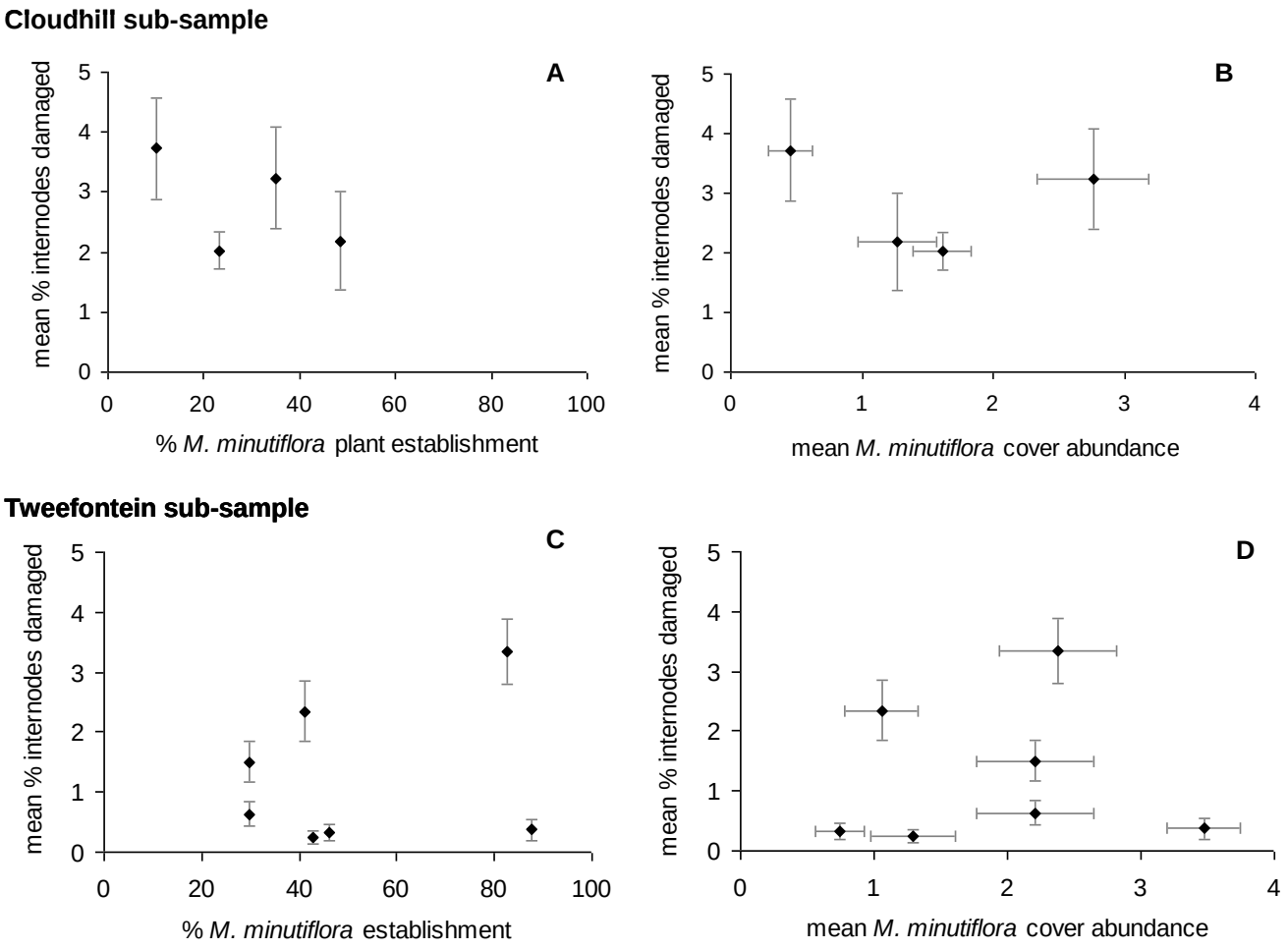



**Figure 5.9.** Scatter plots showing the relationship between mean % internodes damaged and % plant establishment (left) and mean cover abundance (right) for *Melinis minutiflora* at Cloudhill and Tweefontein. Error bars indicate ±standard error of the mean.

## 5.4 Discussion

### 5.4.1 Effect of push-pull on stem borer infestation levels and damage

The infestation and damage of *E. saccharina* and *S. calamistis* on trial farms was generally low, and widely variable (Figure 5.3, 5.5) which made measurement of a push-pull effect on infestation levels and damage difficult. These low stem borer levels are not surprising, as the study area is known to have the lowest *E. saccharina* infestation and damage levels in the South African Sugar industry (Goebel *et al.*, 2005). This is attributed to cooler ambient temperatures at higher altitudes which slow down *E. saccharina* development (Atkinson, 1980). Goebel *et al.* (2005) completed an industry-wide review of LPD&VCC data and reported the levels of stem damage in the Midlands North region as follows: in 2001, 6.3% stems damaged, in 2002, 9.8% and in 2003, 7.6% stems damaged.

The highest % stalks damaged in this study was at Cloudhill in the control (31%, Figure 5.5), and the lowest was at Tweefontein in the treatment area (12%, Figure 5.5) (Waterfall was excluded as there was only *S. calamistis* damage on this farm). These damage levels are higher than the mean levels reported for the Midlands North region as a whole by Goebel *et al.* (2005). This result is ascribed to the fact that the trial farms were selected based on higher *E. saccharina* risk, and so we were working on the farms at the higher end of *E. saccharina* damage range in the Midlands North region (Webster *et al.*, 2009).

Barker *et al.* (2006) completed push-pull field trials in the Midlands North and found very low levels of damage (0.9% mean internodes damaged in treatment and 1.5% mean internodes damaged in control plots). Although damage was reduced by almost half in the push-pull treatment plots, this was found not to be statistically significant. Barker *et al.* (2006) did however demonstrate significant reductions in infestations and damage at a coastal site with higher levels of damage. Barker *et al.* (2006) further demonstrated, using a cost-benefit analysis, that planting *M. minutiflora* to reduce damage in sugarcane had an economic advantage. In addition, in their trials on coastal sugarcane, economic benefits of planting *M. minutiflora* were found to be higher where higher damage levels of *E. saccharina* were recorded (Barker *et al.*, 2006). Since we found similar reductions in damage in our trials (damage reductions by approximately two-thirds in the Tweefontein and Cloudhill sub-samples, Figure 5.6), it can be concluded that farmers who participated in the trials at Tweefontein and Cloudhill gained economic benefit from the reduced damage of *E. saccharina* to sugarcane due to *M. minutiflora*.

Unusually high peaks in numbers of *E. saccharina* were observed in some fields on Wanderer's Rest and Tweefontein. This was ascribed to poor variety choice and old sugarcane. *Eldana saccharina* is known to favour older sugarcane and pest numbers rapidly increase as the crop matures (Carnegie and Smaill, 1980; Way and Goebel, 2003). Differences in susceptibility to *E. saccharina* attack of different sugarcane varieties is also well-known (Goebel *et al.*, 2005; Keeping, 2006) and this information is readily available to farmers (SASRI, 2005). Thus farmers should not expect push-pull to be effective if they do not manage their crops according to recommendations, including choosing *E. saccharina* resistant varieties and not allowing sugarcane to mature beyond 22-24 months in the Midlands North area. Push-pull is being promoted as part of an IPM approach to managing *E. saccharina*, and will be most effective where farmers take an integrated approach to managing their crops for good crop health and reduced pest damage.

Results of the REML analysis showed no significant effect of push-pull on % internodes damaged (Table 5.4). By taking a sub-sample of the data which took into account the fact that the *M. minutiflora* only reached maturity and a significant biomass around six months after planting and that *E. saccharina* has two moth population peaks in the year (Atkinson, 1982), a significant effect of *M. minutiflora* on % internodes damaged was shown (Figure 5.6). The Mann-Whitney U-test showed these reductions due to *M. minutiflora* to be statistically significant (Table 5.5), and the *p*-values in the REML tests at Cloudhill and Tweefontein were lower than those for the full sample and for the other sites, indicating that although effects of push-pull were statistically insignificant, they were slightly more pronounced in these two sub-samples (Table 5.4). The two sub-samples from Cloudhill and Tweefontein take into account the possibility than the *M. minutiflora* could have resulted in a reduction in the numbers of eggs laid in sugarcane by moths flying during the November 2011 and April 2012 peaks. This would have resulted in reduced larval damage 2-3 months after those moth peaks, i.e. between January and July 2012 (Survey 7 to 11). The effect of Bt maize which was planted as a 'pull' would however be excluded from these sub-samples, since it would only have had an effect on the April 2011 moth peak. The window of efficacy for Bt maize as a pull plant is unfortunately very short. Thus the results reported for the Cloudhill and Tweefontein sub-samples are only showing the efficacy of *M. minutiflora* as a repellent, or push, and not of a complete push-pull effect including Bt maize.

The levels of damage reduction due to *M. minutiflora* at Cloudhill and at Tweefontein are similar to those found by Barker *et al.* (2006) in their push-pull field trials. The fact that a statistically significant effect was identified by considering the *E. saccharina* moth biology (Atkinson, 1980) highlights the knowledge-intensive nature of push-pull and IPM for managing this pest. Farmers

should not expect that planting push-pull plants will have a blanket effect of reducing *E. saccharina* infestations and damage across the entire crop on their farm. Rather, it is important that the push-pull plants are planted at the correct time to ensure that they have an effect on egg-laying *E. saccharina* moths when populations peak, and to protect aging sugarcane which is most susceptible to damage. The importance of timing of planting has also been stressed by Barker (2008) and Kasl (2004). In addition, it is important for farmers to recognise that *M. minutiflora* plants take time to establish and may well only start being an effective repellent around six months after planting, as indicated in this study. This does however need to be studied more carefully using methods in chemical ecology.

The approximately two-thirds reduction in *E. saccharina* damage at Tweefontein and Cloudhill is very encouraging. By implementing push-pull within an IPM framework of good crop management, more specifically by planting *M. minutiflora,* and re-establishing wetlands with *E. saccharina*'s indigenous host plants (see Chapter 6), farmers can reduce damage levels due to this pest and maintain them at these low levels. This will be an economic benefit for farmers, as shown by Barker *et al.* (2006), and could reduce the negative effects of insecticide applications on the environment and farm workers, which is an important component of sustainable agriculture (Pretty, 2005). In addition, it supports the aims of SUSFARMS, a sustainable sugarcane farm management system which is being promoted in the South African sugar industry (Maher, 2007).

### *5.4.2 Parasitism of stem borers in sugarcane fields*

No parasitoids were recovered from *E. saccharina*, confirming the lack of parasitism of this species in sugarcane (Conlong, 1990). A rate of 6.5% parasitism was found for *S. calamistis* during this study (3 specimens), and two species were identified: *Stenobracon* sp. and *Cotesia* probably *sesamiae* (G.L. Prinsloo, pers. comm.). All three parasitoids were recovered from stem borers found in control areas of farms, and not treatment areas where *M. minutiflora* was planted. *Melinis minutiflora* is known to attract *C. sesamiae* and increase its host foraging in other cereal cropping systems (Khan *et al.*, 1997a), and one would thus have expected to find more *C. sesamiae* in treatment than in control areas. This was however not the case in this study, and further research is required to determine whether this is true for *C. sesamiae* in the sugarcane agroecosystem as well.

### *5.4.3 Effect of distance from* M. minutiflora *on stem borer damage levels*

The distance of *M. minutiflora* from sugarcane did not have the expected effect on *E. saccharina* damage in the crop (Figure 5.7, Table 5.7). There were higher levels of damage on the outer edges of the fields than in the centre of fields. This is the opposite of what was expected for this part of the trial. The aim was to prove whether increasing distance from the repellent grass, *M. minutiflora* would result in higher levels of damage due to moths not being repelled as much as they would from sugarcane closer to the *M. minutiflora,* and this has not been the case in this sample. Kasl (2004) also found no significant effect of the distance of *M. minutiflora* planted as a barrier on the edge of fields on stem borer damage in sugarcane. This may indicate that the effect of *M. minutiflora* is evenly spread over the field, or it may be that damage levels in these field trials were too low to measure an effect of distance from *M. minutiflora*.

This result may also indicate a 'colonisation' effect, where pest populations move into the field from the edges towards the centre (Cohen and Yuval, 2000). Berry *et al.* (2010) described patterns of *E. saccharina* distribution in newly planted sugarcane fields and concluded that distributions of this pest within a field were a function of both colonisation from the outside and spread within a field which could be from old stubble in the field or in the case of a ratoon crop, from the root stock. It is also known that maize stem borer densities are higher on field edges than in the centre of fields (Van den Berg, 1997). This is most likely also due to pest colonisation of fields from the edges towards the centre, or maybe because moths fly out of fields to mate and then move into fields from the outside and thus more eggs are laid at the margins (Van den Berg, pers. comm.) Another reason for higher *E. saccharina* damage at the field edges could be that *E. saccharina* larvae are attracted to *M. minutiflora* as was reported by Harraca *et al*. (2011). Although adult *E. saccharina* moths are effectively repelled by *M. minutiflora*, the larvae are attracted to it and it could be used as a pull-plant for larvae (Harraca *et al.*, 2011). Stems of *M. minutiflora* are much thinner than those of other host plants used by *E. saccharina*, and other studies have shown it not to support development of stem borers (Khan *et al.*, 1997a). Thus it is possibly a candidate for a "dead-end trap plant" on which larval survival of *E. saccharina* would be very low, as was found for *Pennisetum purpureum* Schumach (Cyperales: Poaceae) when tested on *Chilo partellus* Swinhoe (Lepidoptera: Crambidae) larvae (Khan *et al.*, 2006a).

The effect of vegetation structure and complexity on wind speed and direction plays an important role in the distribution of plant volatiles in the crop environment (Murlis *et al.*, 1992; Randlkofer *et al.*,

2010). In a preliminary study of thrips (Thysanoptera) dispersal in sugarcane, Way *et al.* (2012) reported that the wind speed below the sugarcane canopy is much lower than above, and this could also have an effect on how *E. saccharina* moths respond to the repellent volatiles emitted by *M. minutiflora*. Thus the effectiveness of *M. minutiflora* with increasing distance from the crop needs to be further investigated using chemical ecology and trapping techniques. Field trials should take place in areas with higher levels of *E. saccharina* damage, where measuring such an effect is more likely. For farmers to gain the maximum benefit from *M. minutiflora*, recommendations need to be made on how much *M. minutiflora* needs to be planted per unit area of sugarcane. However, further research is needed to establish the optimum number of *M. minutiflora* plants.

### *5.4.4 Effect of* M. minutiflora *biomass on stem borer damage*

There was no relationship between % internodes damaged and mean cover abundance and % plant establishment of *M. minutiflora* (Table 5.8, Figure 5.9). Slightly larger negative values for Spearman's $r_s$ at Cloudhill (Table 5.8), and trends in the scatter plot (Figure 5.9A) indicated that there might be a small, and non-significant, negative relationship between the variables, but this requires further research. This is needed to confirm that farmers who maintain their *M. minutiflora* plants well, by providing sufficient water and possibly even fertilisers at establishment, and keeping out competitive weedy species, could gain greater benefit from this grass as a repellent to *E. saccharina*. *Melinis minutiflora,* when used as a repellent in the push-pull system should be considered a valuable resource by farmers and should be managed as any other crop. Similar to the question of how distance from *M. minutiflora* can reduce efficacy of *M. minutiflora*, the question of plant biomass needs to be investigated using chemical ecology and further field studies in areas with higher levels of *E. saccharina* damage.

## *5.5* Conclusion and recommendations

Using on-farm field trials has shown that push-pull, in particular the repellent component of this system, *M. minutiflora,* can reduce damage of *E. saccharina* in sugarcane. However, *M. minutiflora* cannot be seen as a 'silver bullet' in controlling *E. saccharina*. On two of the farms used for this study, incidents of poor crop management (i.e. poor variety choice and allowing sugarcane to age beyond recommended limits) resulted in rapid increases in *E. saccharina* numbers. This emphasizes the need for implementing push-pull within an IPM framework where good crop management is practiced.

Selecting a sub-sample for analysis based on known peaks in moth activity also demonstrated the need for a thorough understanding of pest biology by farmers for effective implementation of push-pull and IPM. The results of these trials provide further evidence that push-pull, within an IPM framework, can contribute to the sustainable control of *E. saccharina* in South African sugarcane, and that farmers who are experiencing economic losses due to *E. saccharina* can derive direct economic benefit from planting *M. minutiflora*.

Inconclusive data on the effect of increasing distance from *M. minutiflora* on damage levels in these trials have shown a need for further field trials to investigate this, together with further investigations into the chemical ecology of *M. minutiflora* and *E. saccharina*. Such studies also need to take into consideration how much plant biomass is needed over what area of crop to effectively repel *E. saccharina*.