HABITAT MANAGEMENT USING *MELINIS MINUTIFLORA* (POACEAE) TO DECREASE THE INFESTATION OF SUGARCANE BY *ELDANA SACCHARINA* (LEPIDOPTERA: PYRALIDAE)

BARKER A L[1,2], CONLONG D E[1,3] and BYRNE M J[2]

[1]*South African Sugarcane Research Institute, Private Bag X02,*
Mount Edgecombe, 4300, South Africa
[2]*School of Animal, Plant and Environmental Sciences,*
University of the Witwatersrand, PO Wits, South Africa
[3]*School of Biological and Conservation Sciences, University of KwaZulu-Natal,*
Private Bag X01, Scottsville, Pietermaritzburg, South Africa
Alistair.Barker@sugar.org.za   Des.Conlong@sugar.org.za   Marcus@gecko.biol.wits.ac.za

Abstract

In field trials planted in the Midlands North and Gingindlovu areas, *Melinis minutiflora* Beauv. was intercropped in various ways with sugarcane in fields bordered by *Cyperus dives* C.B. Cl. to determine whether the presence of this grass reduced *Eldana saccharina* Walker numbers and infestation levels in sugarcane. Results showed *E. saccharina* populations were decreased by up to 50% and *E. saccharina* damage was reduced by up to 57% when compared with control fields. In addition, no competition was recorded between *M. minutiflora* and adjacent sugarcane rows in terms of sugarcane yield loss. Where *M. minutiflora* was planted along field margins, weed biomass was reduced by up to 79%.

These results are discussed in the context of *E. saccharina* population management, field margin weed management and potential economic benefits accrued from using this approach.

Keywords: sugarcane, *Eldana saccharina*, habitat management, *Melinis minutiflora*, economic benefit, *Cyperus dives*

Introduction

Eldana saccharina Walker (Lepidoptera: Pyralidae) is a stem boring insect pest of sugarcane, indigenous to areas of sub-Saharan Africa and found in wetland sedges (Cyperaceae) (Conlong, 1994). This insect was first identified as a pest of sugarcane in South Africa on the Umfolozi Flats, KwaZulu-Natal in the 1940s (Carnegie, 1973). Since then, *E. saccharina* has spread to all sugarcane growing regions along the coast of KwaZulu-Natal (Conlong *et al*, 1988), as well as to inland areas. *E. saccharina* is now regarded as the major pest of sugarcane in all areas of the industry (Keeping and Meyer, 2002). There is thus an urgent need to manage this pest in high population pressure areas to avoid sucrose yield reduction due to high infestations of the stalks by *E. saccharina*, and to retard the spread of this pest into areas where populations are currently low.

Several control methods are in place to manage *E. saccharina* in sugarcane (Leslie, 1994; Keeping and Meyer, 2002; Conlong, 1994). However, other than cultural methods of control and use of resistant varieties, none of the other tested methods was found to be effective. The use of insecticides is not successful because of the cryptic nature of *E. saccharina* (Kasl, 2004). Insecticides do not affect larvae once the larvae have bored into the stalk of the host plant (Jotwani, 1983). Additionally, none of the parasitoids that were released against this pest in South African sugarcane have been able to establish for any length of time (Conlong, 2001).

Recent studies on the management of stem borers have investigated the manipulation of the agro-ecosystem to the advantage of natural enemies, and disadvantage of the pest, to minimise the effect of pests on crops. This management strategy is called a ‘push-pull’ system (Pyke *et al*, 1987), or stimulo-deterrent diversion (Miller and Cowles, 1990). Khan *et al*. (1997) pioneered this approach in maize in Kenya, and van den Berg (2003) is using it to control stem boring maize pests in the Northern Province of South Africa. Kasl (2004) commenced this approach to control *E. saccharina* in South African sugarcane in 2000.

An indigenous grass, *Melinis minutiflora* Beauv. (Poaceae) gives off a strong chemical signal, 4,8-dimethyl-1,3,7-nonatriene, which has been shown to repel maize stem borers and attract their parasitoids (Khan *et al*, 1997). Kasl (2004) found through laboratory trials that this grass has repellent effects on *E. saccharina* adults while the natural host plants, *Cyperus papyrus* L. and *C. dives* C.B. Cl. (Cyperaceae) are attractive to these moths. Kasl (2004) also found that the chemical signal from this grass is attractive to a pupal parasitoid, *Xanthopimpla stemmator* (Thunberg) (Hymenoptera: Ichneumonidae). These laboratory results need to be validated in the field.

This paper presents the results from field trials where *M. minutiflora* was intercropped into fields of sugarcane in order to repel *E. saccharina*. The agricultural and economic benefits of using *M. minutiflora* as a push crop in the stimulo-deterrent diversion strategy to manage *E. saccharina* in sugarcane are discussed.

Materials and Methods

Field sites

Eldana saccharina populations in coastal sugarcane are generally high, whereas in the Midlands area they are low. However, in this latter area, more and more fields are being infested with this borer (Webster *et al*, 2005). Two field sites were thus established to determine the impact of *M. minutiflora* on *E. saccharina* populations, one in a high and one in a low population pressure area.

The high population pressure site is in the Emoyeni region (28°57´S and 31°39´E) on the north coast of Zululand, in rainfed sugarcane. It is bordered on two sides by a stream with *C. dives* growing on the banks. Parallel drainage canals were dug along the length of the field, wide enough apart to accommodate 20 rows of sugarcane. They were kept free of weedy plant material by regular herbicide treatments. Sugarcane (variety N19) was grown in the field for 16 months before harvesting.

The low population pressure site was in the Midlands North area (29°35´S and 30°30´E), located an hour inland from the coast and was irrigated. Irrigation lines were 20 rows apart. The irrigation line margins next to the field were treated once with herbicide at the time of planting. The field site has *C. dives* growing on the banks of a stream running along the bottom edge of the field. Sugarcane (variety N39) was grown in these fields for 18 months before harvesting. Unfortunately, sections of sugarcane in the treatment plots were cut after seven months for use as seed-cane by the farmer.

Site preparation

Chosen fields were divided into 50x50 m blocks at both trial sites. The blocks were numbered, and random numbers were used to choose three treatment plots and three control plots. These were marked out within each field site, using wooden stakes at the corners of each plot. The plots were 50 m in length and 40 rows of sugarcane wide. There was at least one plot length distance between treatment and control plots. Field plots were set up within fields so that irrigation/drainage lines ran along the top and bottom edges of the experimental plots. The plots at both sites thus had three irrigation/drainage lines associated with each of them, two parallel to the rows on each margin and one in the centre.

In the treatment plots, *M. minutiflora* was planted at the same time as sugarcane was planted (Midlands, December 2003; Emoyeni, March 2004), to prevent the shading out of *M. minutiflora* by the bigger sugarcane. Three rows of *M. minutiflora* were planted in each treatment plot, along the drainage/irrigation line on the top and bottom edges and along the central irrigation/drainage line. One *M. minutiflora* seedling (obtained from a Top Crop Nursery, Cramond, in 200 compartment seedling trays) was planted every 50 cm along these lines. The drainage/irrigation lines were wider than the sugarcane inter-rows, allowing *M. minutiflora* planted along these lines to grow more efficiently in the unshaded sunlight. Control plots were not planted with *M. minutiflora*.

Assessment of E. saccharina *populations and damage*

Every fourth row of sugarcane, commencing with the row adjacent to the row of *M. minutiflora* in the treatment plots, or next to the demarcated drainage/irrigation line in the control plots, had a stalk taken every 5m along the length of the row. Ten stalks were thus taken per designated row, and 50 stalks were thus sampled per plot. The stalks were sampled per row, and data collected per row. Surveys were completed in March 2005.

The total number of nodes of each harvested stalk was counted and recorded. Stalks were then split carefully down their length using a short cane knife, to collect any *E. saccharina* life stages. The number of nodes damaged by *E. saccharina* was counted. Any *E. saccharina* pupae and larvae in the stalks were collected and placed in 30ml plastic vials filled with artificial diet prepared for rearing *E. saccharina* (Conlong *et al*, 1988). The perforated lids put on the vials had fine mesh gauze covering the hole in the lid. Collected larvae were reared at the South African Sugarcane Research Institute (SASRI) Insect Unit, at 28^{o}C, 75% relative humidity, until moth or parasitoid emergence.

Natural host plant surveys

To confirm the presence of *E. saccharina* in the respective study areas, *C. dives*, a known preferred host plant of *E. saccharina* (Atkinson, 1980; Kasl, 2004), was surveyed along the banks of the streams that run along part of the perimeter of the field sites. Clumps of sedges were dug from the stream banks and separated into individual rhizomes with associated leaves. The rhizome and compacted leaf stalks were carefully sectioned using a short cane knife and examined for the presence of borings by stalk borer larvae, or for any live larvae still feeding on the plant material. *E. saccharina* life stages present in the stalks were collected and reared on artificial diet as described above, until emergence of moths or parasitoids.

Competition effects of M. minutiflora *on sucrose yield*

A quadrat, 1.0x0.5 m, was placed at three points equally spaced beside the edge sugarcane row adjacent to the *M. minutiflora* row and in the middle row of the treatment plots. Height of sugarcane and number of stalks along the 1m length was recorded. Twelve sugarcane stalks, one every 4 m, were taken from the edge rows of treatment and control plots, i.e. the rows adjacent to the *M. minutiflora* rows in the treatment plots and the rows adjacent to the demarcated drainage/irrigation lines in the control plots. Twelve stalks were similarly taken from the tenth row of each treatment plot midway between the *M. minutiflora* lines. The stalks from each line were kept separate. Sucrose yield analysis was done using standard procedures developed at SASRI to give an indication of the percentage sucrose from the sugarcane. The values of ERC%cane (Estimated Recoverable Crystal as a percentage of total sugarcane) were used in the statistical analysis to determine the difference between plots, and between collection points.

Competition effects of M. minutiflora *on weed biomass*

A quadrat, 1.0x0.5 m, was used to measure biomass of *M. minutiflora* and other weedy species in the *M. minutiflora* rows of the treatment plots, and in the same positions in the weedy margins of the control plots. The quadrat was placed at three collection points equally spaced beside the edge sugarcane row of both the treatment and control plots. The narrow edge of the quadrat was placed against the stalk bases of the adjacent sugarcane row, and the long axis thus stretched away at right angles from the sugarcane row. All the vegetation in it was cut to ground level, and sorted into *M. minutiflora* and 'other plants'. These were placed individually into large 50 kg woven plastic bags, and the vegetation weighed after drying at 80ºC to constant weight.

Cost: benefit analysis

The economic benefit of planting *M. minutiflora* as a push crop in sugarcane was calculated from the cost of planting the grass within a hectare of a sugarcane field, the cost of planting a hectare of sugarcane and a reduction in loss of usable sugar. Expected income per hectare was calculated from an average sugarcane yield of 60 tons per hectare (Anon, 2006), percentage sucrose at 13.7% (personal communication[1]) and the current sugar price taken as R5.00 per kilogram. Income loss from infestation was calculated at 1% nodes damaged (taken from field results) is equal to 1% loss in usable sugar (King, 1989) and expressed in Rands per hectare. Net income is the expected income minus income loss from infestation. Revenue in rands per hectare was calculated by subtracting the cultivation cost of sugarcane and the cultivation cost of *M. minutiflora* per hectare from the net income. The economic benefit is the difference in revenue between treatment and control plots.

Statistical analysis

Differences in levels of infestation by *E. saccharina*, percentage nodes damaged and weed biomass in treatment and control plots were compared using a t-test. Analysis of variance (ANOVA) was used to determine the significance of differences in sugarcane yield between treatment and control plots and between positions within the field plots, edge or middle.

Results

Impact of M. minutiflora *on* E. saccharina *populations and damage in sugarcane*

Results from surveys just prior to harvesting the Emoyeni field trial are summarised in Figure1. Although there were no significant differences in the average number of total nodes of the stalks sampled in the control and treatment plots, the treatment plots had significantly lower *E. saccharina* populations than the control plots (20.7 and 40.0 per 100 stalks

[1] Anil Haripasad, Management Accounting Officer, SASA, email: Anil_Haripasad@sasa.org.za

respectively). Similarly, percentage internodes damaged was significantly lower in the treatment plots compared with the control plots (4.5 and 10.7% respectively) (P=0.001).

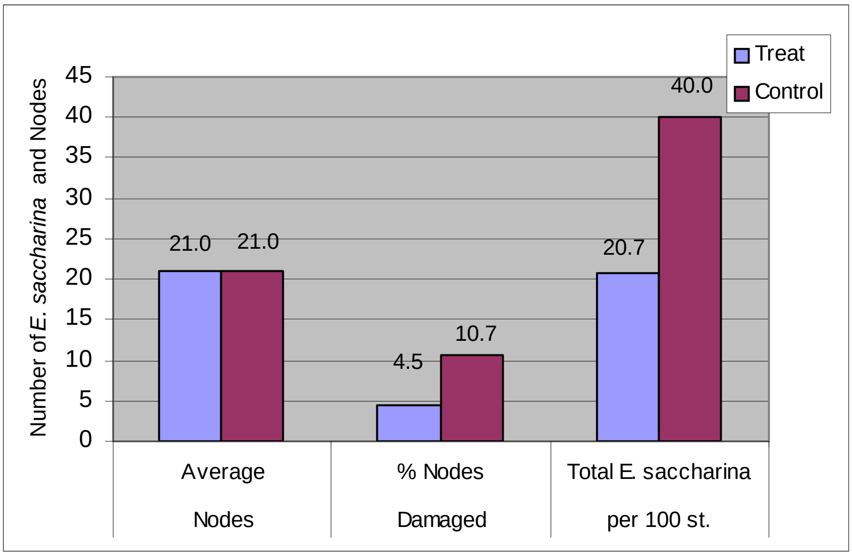

Figure 1. Average number of nodes per stalk, % nodes damaged and the number of *E. saccharina* per 100 stalks in the Emoyeni treatment and control plots. Numbers above columns are mean values (P<0.001).

In the Midlands field trial there was a significant difference in the average number of total nodes of the stalks sampled between the control and treatment plots (P=0.05) (Figure 2). The average number of nodes in the treatment plots was lower (14.8 nodes/stalk) than the control plots (19.0 nodes/stalk). This discrepancy was caused by the farmer harvesting some of the treatment plot sugarcane for seed, before the due harvest date. *E. saccharina* levels were very low at this site, with only one being found in the three control plots. None were recovered in the treatment plots (Figure 2). However, some damage was still recorded, and that in the treatment plots (0.9% nodes damaged) was half that of the control plots (1.5% nodes damaged) (Figure 2).

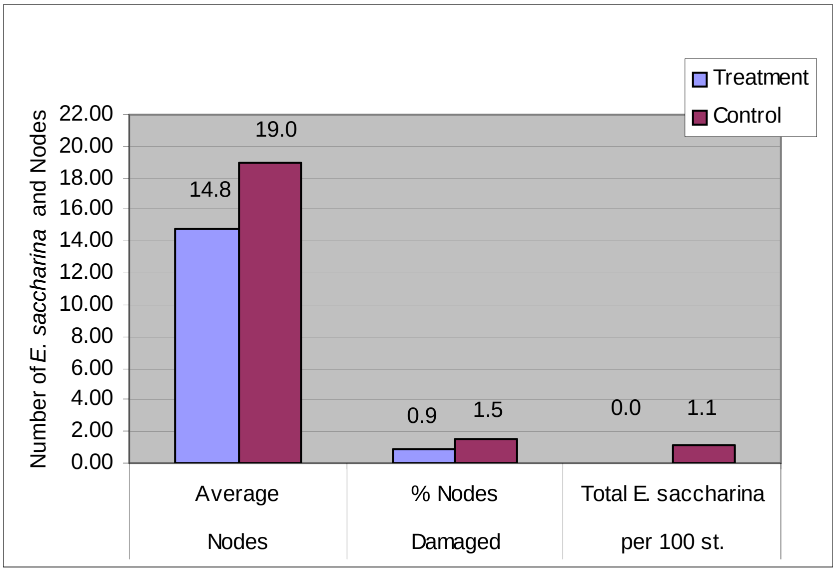

Figure 2. Average number of nodes per stalk, % nodes damaged and *E. saccharina* collected per hundred stalks from treatment and control plots at the low population pressure Midlands field site. Numbers above columns are mean values.

Natural host plant surveys

There were low numbers of *E. saccharina* in *C. dives* at the Midlands field site (Table 1). Higher levels of *E. saccharina* were found in *C. dives* rhizomes at Emoyeni. Damage by borers was similar at both sites (Table 1).

Table 1. Population surveys of *E. saccharina* in *C. dives* at the Emoyeni and Midlands trial sites.

Field sites	Total rhizomes surveyed	% *C. dives* rhizomes bored	No. *E. saccharina* per 100 rhizomes
Emoyeni	216	18.0	9.3
Midlands	162	21.6	1.8

Competition effects of M. minutiflora *on sucrose yield*

There was no significant difference in height and density between the treatment plots and the control plots at the Midlands field site (Table 2). At the Emoyeni field site, the height and density of sugarcane at the edge of the treatment plots was not significantly different from the control plots. However, a significant difference in height was recorded when the middle rows of the treatment plots were compared to the edge rows and the control plots (Table 2). There was no significant difference in density at the Emoyeni field site (Table 2).

Table 2. Height and density of sugarcane between field plots at Emoyeni and Midlands.

Field sites		Control	Treatment	
			Edge	Middle
Emoyeni	Height	2.3a	2.1a	2.8b
	Density	12.3a	14.3a	14.6a
Midlands	Height	3.9a	3.6a	3.7a
	Density	17.3a	13.2a	16.3a

NB: Means in the same row within Emoyeni trial followed by the same letter are not significantly different (P=0.05). Means in the same row within Midlands trial followed by the same letter are not significantly different (P=0.05).

There were no significant differences in sucrose yield (ERC%cane) between control and treatment plots at either field site (Table 3). Similarly, the distance of sugarcane from *M. minutiflora* rows was found to have no significant effect on sucrose yield.

Table 3. Mean ERC%cane differences between field plots at Emoyeni and Midlands.

Field sites		Control	Treatment
Emoyeni	Edge	9.8a	10.3a
	Middle	9.8a	10.3a
Midlands	Edge	6.6b	6.2b
	Middle	5.7b	5.3b

NB: Means within Emoyeni trial followed by the same letter are not significantly different (P=0.05). Means within Midlands trial followed by the same letter are not significantly different (P=0.05).

Competition effects of M. minutiflora *on weed biomass*

A reduction in weed biomass of 79.6%, because of its displacement by *M. minutiflora* in treatment plots, was recorded in the Midlands field trial. This was not the case at Emoyeni, because of the absence of weeds between the rows of the sugarcane fields and in the drainage ditches (Table 4).

Table 4. Impact of *M. minutiflora* on weed biomass in sugarcane at Midlands and Emoyeni.

Field site	Treatment	Total *M. minutiflora* biomass (g/m^2)	Total other weed biomass (g/m^2)	% Weed reduction
Midlands	Treatment	1548	322	79.6
	Control	0	1580	
Emoyeni	Treatment	3560	0	0
	Control	0	0	

Cost:benefit analysis

Planting of *M.minutiflora* as a push crop at the Emoyeni field site was found to reduce the *E. saccharina* level from 10.7 to 4.5% (Table 5). This reduction in infestation resulted in an increase in net income from R30 905 per hectare in the control, to R33 369 per hectare in the treatment where *M. minutiflora* was planted, a net economic benefit of R2464 per hectare when the cost of planting *M. minutiflora* is subtracted. Similarly, planting *M. minutiflora* in the Midlands field site reduced the infestation level from 1.5 to 0.9%, which was calculated as a net economic benefit of R164 per hectare (Table 5).

Table 5. Cost:benefit analysis of planting *Melinis minutiflora* as a push plant against *Eldana saccharina* in sugarcane, calculated for Emoyeni and Midlands trials.

Trial	Cultivation cost of sugarcane (R/ha)	Cost of planting *M. minutiflora* (R/ha)	Gross yield expected (R/ha)	Infestation (% internodes bored)	Yield reduction from infestation (R/ha)	Net yield (R/ha)	Revenue (R/ha)	Benefit (R/ha)
Emoyeni Control	5904	0	41 220	10.7	4411	36 809	30 905	
Treatment	5904	91.94	41 220	4.5	1855	39 365	33 369	2464
Midlands Control	5904	0	41 220	1.5	627	40 593	34 689	
Treatment	5904	91.94	41 220	0.9	371	40 849	34 853	164

NB: An average cane yield of 60 tons per hectare, 13.7% sucrose yield and
a sugar price of R5000 per ton were used in this calculation[2]
1% loss in useable sugar for every 1% internodes bored by the pest insect[3]

[2] Source: Anon (2006); Anil Haripasad, personal comm.
[3] King, 1989

Discussion

Impact of M. minutiflora *on* E. saccharina *populations and damage in sugarcane*

In this study, a significant reduction in percentage damage to sugarcane by *E. saccharina* was found when *M. minutiflora* was intercropped within the sugarcane field at Emoyeni. Additionally, the number of *E. saccharina* larvae in sugarcane was found to be lower in *M. minutiflora* treatment plots when compared with control plots. In the Midlands field, lower percentage damage and number of *E. saccharina* per hundred was shown (Figure 2). Although not significantly different, percentage damage in treatment plots was visibly less than the control plot values. Due to low numbers of *E. saccharina*, significance could not be shown at this field site. Similar results were reported by Khan *et al*. (2001) who showed a significant increase in maize yield with the decrease in damage between *M. minutiflora* treatment and control plots.

These reductions contributed to an increase in usable sugar yield, and thus profitability of a sugarcane farm. For these trials, the use of irrigation/drainage lines meant that no sugarcane rows had to be sacrificed to plant *M. minutiflora*. However, with the benefit gained with lower internodes damaged in fields with this grass, it may even be possible for growers with no irrigation or drainage lines to sacrifice every 20th row of sugarcane to plant *M. minutiflora*.

The economic benefit estimates of lower *E. saccharina* damage of R2464 per hectare in Emoyeni and R164 in the Midlands (Table 5) trial sites are based on industry average data. In irrigated areas such as the Midlands, sugarcane yields are closer to 80 tons/ha. Using this figure in the calculations for the Midlands site, the economic benefit would increase to R249 per hectare. This substantial economic benefit further promotes the potential of *M. minutiflora* as a push crop in a stimulo-deterrent diversion strategy in sugarcane.

Competition effects of M. minutiflora *on sugarcane yield*

The planting of *M. minutiflora* in irrigation/drainage ditches next to sugarcane did not compete with nor impede the growth of sugarcane, as stalk density and height in the Midlands was not significantly different between rows next to *M. minutiflora* and rows in the middle of the treatment and control fields (Table 2). Height of sugarcane at Emoyeni showed a significant difference between middle and edge of treatment plots (Table 2). However, the average number of nodes was the same in treatment and control plots when sugarcane from these fields was surveyed (Figure 1). Sunlight could influence the height of the cane because leaves on the stalks on the more open edges of the field do not extend as far upward to get sunlight, as do stalks in the middle of the field. Sucrose yield, in terms of ERC%cane, was also not significantly different from stalks collected in these same locations. It was evident at the trial sites that *M. minutiflora* is not shade tolerant, as it did not encroach into the adjacent sugarcane row.

Competition effects of M. minutiflora *on weed biomass*

M. minutiflora was shown to reduce other weeds within the field where this grass was planted (Table 4). Khan *et al*. (2001) found that planting an intercrop of *Desmodium uncinatum* Jacq. within a field of maize reduced the negative effect of witchweed, *Striga hermonthica* (Scrophulariaceae), on the yield of maize. This intercrop was also found to repel ovipositing stem borers. Although *D. uncinatum* is a legume and *M. minutiflora* a grass, the latter could also have allelopathic properties similar to the former on other plants. Growers could thus accrue further economic benefits by planting this grass along field margins, which would decrease herbicide applications and also labour costs.

Results of this study show that *M. minitiflora* has a double advantage by reducing *E. saccharina* damage in sugarcane and suppressing weeds at the field margins. It is therefore likely that this grass is a suitable candidate for use by farmers in the control of weedy plant material that competes with sugarcane in the field. *M. minutiflora* is also known as a valuable hay and pasture grass, with well known anti-tick properties, especially when still green (Khan ZR, Overholt WA and Hassanali A (1998). http://www.push-pull.net/PDF%20files/cs-agr-cereal-stemborers.pdf).

Conclusions

Melinis minutiflora intercropped in fields of sugarcane at a spacing of 20 rows, and in irrigation/drainage lines, has a role in reducing *E. saccharina* infestation and lowering damage by *E. saccharina*. This is evident in high and low *E. saccharina* population pressure areas. Wherever it was planted in sunny situations, it outcompeted other plants regarded as weeds in sugarcane fields without encroaching into the sugarcane rows.

Using *M. minutiflora* as a push crop in habitat management strategies on commercial and small-scale farms is affordable, financially feasible and has significant economic benefit. This grass can thus be recommended for use as a component of the agro-ecosystem described in this paper for the management of *E. saccharina* in sugarcane.

REFERENCES

Anon (2006). South African Sugar Industry Directory 2005/2006. External Affairs Division, South African Sugar Association, Mount Edgecombe, South Africa. p38.

Atkinson PR (1980). On the biology, distribution and natural host plants of *Eldana saccharina* Walker (Lepidoptera: Pyralidae). *J Ent Soc Sth Afr* 43: 171-194.

Carnegie AJM (1973). The insect borer - *Eldana saccharina* Walker. *S Afr Sug J* 57: 445-447.

Conlong DE (1994). A review and perspectives for the biological control of the African sugarcane stalkborer *Eldana saccharina* Walker (Lepidoptera, Pyralidae). *Agr Ecosyst Environ* 48: 9-17.

Conlong DE (2001). Biological control of indigenous African stemborers: What do we know? *Insect Sci Appl* 21: 267-274.

Conlong DE, Graham DY and Hastings H (1988). Notes on the natural host surveys and laboratory rearing of *Goniozus natalensis* Gordh (Hymenoptera: Bethylidae) larvae from *Cyperus papyrus* L. in southern Africa. *J Ent Soc Sth Afr* 51: 115-127.

Graham DY and Conlong DE (1988). Improved laboratory rearing of *Eldana saccharina* (Lepidoptera: Pyralidae) and its indigenous parasitoid *Goniozus natalensis* (Hymenoptera: Bethylidae). *Proc S Afr Sug Technol Ass* 62: 116-119.

Jotwani MG (1983). Chemical control of cereal stem-borers. *Insect Sci Appl* 4: 185-189.

Kasl B (2004). Stimulo-deterrent diversion to decrease *Eldana saccharina* Walker (Lepidoptera: Pyralidae) infestation in sugarcane. PhD Thesis, University of the Witwatersrand, South Africa.

Keeping M and Meyer J (2002). Effect of four sources of silicon on resistance of sugarcane varieties to *Eldana saccharina* (Lepidoptera, Pyralidae). *Proc S Afr Sug Technol Ass* 77: 99-103.

Khan ZR, Ampong-Nyarko K, Chiliswa P, Hassanali A, Kimani S, Lwande W, Overholt WA, Pickett PA, Smart LE, Wadhams LJ and Woodstock CM (1997). Intercropping increases parasitism of pests. *Nature* 388: 631-639.

Khan ZR, Pickett JA, Wadhams LKJ and Muyekho F (2001). Habitat management strategies for the control of cereal stemborers and Striga in maize in Kenya, *Insect Sci Appl* 21: 375-380.

King AG (1989). An assessment of the loss in sucrose yield caused by the stalk borer, *Eldana saccharina*, in Swaziland. *Proc S Afr Sug Technol Ass* 63: 197-201.

Leslie GW (1994). Observations on crop damage and larval populations of the pyralid borer *Eldana saccharina* in the sugarcane varieties NCo376 and N11. *Proc S Afr Sug Technol Ass* 68: 12-15.

Miller JR and Cowles RS (1990), Stimulo-deterrent diversion: A concept and its possible application to onion maggot control. *J Chem Ecol* 16: 3197-3212.

Pyke B, Rice M, Sabine G and Zalucki M (1987). The push-pull strategy-behavioural control of *Heliothis*. *Australian Cotton Grower*. May-July. pp 7-9.

Webster TM, Maher GW and Conlong DE (2005). An integrated pest management system for *Eldana saccharina* in the Midlands North region of Kwazulu-Natal. *Proc S Afr Sug Technol Ass* 79: 347-358.