# IPM for Eldana Control



An Integrated Pest Management (IPM) approach for the control of the stalk borer Eldana saccharina Walker (Lepidoptera: Pyralidae)



SOUTH AFRICAN SUGARCANE RESEARCH INSTITUTE

# Foreword

This book represents far more than a collection of best management practices for eldana control. Rather, it has been written for those who wish to get a deeper insight into the mechanisms that govern the interactions between eldana, the sugarcane crop and the various practices recommended for control of this pest. For this purpose, it has been necessary to include a high level of technical detail, and to draw on several other SASRI publications to describe the complex interactions at play.

A separate publication is available for those requiring a quick reference guide on best management practices for eldana control.

## About the author

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# Introduction

ntegrated pest management (IPM) is a broadbased approach that integrates practices for economic control of pests. IPM aims to suppress pest populations below the economic injury level or economic threshold (ET). The UN's Food and Agriculture Organisation defines IPM as "the careful consideration of all available pest control techniques and subsequent integration of measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human health and the environment".

IPM emphasises the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms. However, it does not exclude the use of pesticides.

There will never be a "quick fix" single solution to the eldana problem. The emphasis of IPM is on control, not eradication. Wiping out the entire eldana population would be impossible due to it being an indigenous insect with several wild host plants. Any attempt to do so would be expensive, unsafe and almost certainly unsuccessful.

With the above in mind, the approach in this book focuses on best management practices which reduce



plant stress – thereby reducing the potential for eldana damage. The various sections describe and explain how these best management practices can be integrated into an IPM programme for eldana control. When applied as an entire package, in an area-wide approach, eldana damage can be reduced to such an extent that a return to longer cropping cycles becomes possible.



The IPM approach described here is structured along the lines of the adjacent graph, beginning with a section on habitat management, followed by sections dealing with the plough-out of the old ratoon, preparing for the re-plant, variety choice, crop nutrition, the use of agrochemicals and harvesting. While each individual input is of benefit, the greatest gain to be made is through positive interactions between multiple inputs.

In following this approach, the grower will become aware that best management practices for sugarcane production contribute significantly to eldana IPM, simply by ensuring that the crop is healthy and stress is minimised.



The combined effect of multiple inputs is far greater than the sum of individual inputs.



# About eldana

This chapter is an overview of the pest from its origin and adaptation to sugarcane to its economical implications for the South African sugar industry. The biology of eldana is also discussed as well as other common borer species affecting the industry.

# About eldana



#### History of eldana

lthough recorded in sugarcane in Sierra Leone in 1865, it was not until 1939 that a severe infestation of eldana was found during harvesting of two year old sugarcane (variety POJ2725) on the Umfolozi Flats. A more general survey suggested that the infestation was limited to this region at that time; no infestations were found to the north as far as Hluhluwe, which at this time was the northern limit of commercially grown sugarcane, nor to the south at the Empangeni and Felixton sugar mills. At first it was thought that the insect had immigrated, or been brought in with chewing-cane from Mozambique, but specimens of the moth were caught as far south as Mount Edgecombe (without larval infestations). It was concluded that the insect was indigenous and widespread, in some other host plant, although at that time it had infested sugarcane only at Umfolozi.

The outbreak lasted some 10-13 years. The most severely infested variety was POJ2725. In contrast, the variety Co281 was remarkably resistant. It is not clear when and why the infestation dissipated, but it was still present at low incidence in 1950, and probably disappeared about 1953. The policy of leaving no stand-over sugarcane and a gradual change of variety to resistant Co281 probably hastened its population decline.

The insect reappeared in 1970 at Hluhluwe, in fields of the susceptible variety NCo376 which had replaced Co281 due to the latter succumbing to RSD. Further infestations were found at Empangeni and in Swaziland during 1972, and at Mtunzini and Amatikulu in 1973. In 1974 it was again detected on the Umfolozi Flats after an apparent absence of twenty years. In 1975 the



Outbreak history of *Eldana saccharina* in South Africa and Swaziland.

first infestation of cane south of the Tugela River was recorded. From this time onwards, eldana has spread throughout the industry.

#### Adaptation to new hosts

Many insect pests such as eldana are relatively poor dispersers. When generation time is short relative to their host plants, and strong selective pressures are imposed by plant defences (that vary between potential host plant species), such insects can develop populations adapted to a new host. A host shift through adaptation can occur if gene flow among populations is too weak to counteract the forces of selection.

Disturbance of the natural habitat of the insect is most likely the root cause of the outbreaks at Umfolozi. It may

be significant that outbreaks began in the vicinity of Lake St. Lucia and the Umfolozi estuary, which together constituted a very large area containing natural host plants. Since the 1930s there have been several drainage schemes on the Umfolozi flats which have changed the courses of the Umfolozi and Msunduzi rivers, altered their estuaries and reduced the abundance of natural host plants of eldana. During the 1970s there was also extensive development at Richards Bay, involving reclamation of marshland for the harbour, industry and residential areas. These disturbances, as well as the planting of sugarcane into drainage schemes, have contributed to the adaptation of eldana to sugarcane and its subsequent spread.



A possible mechanism for eldana adaptation to sugarcane.



A stand of *Cyperus papyrus*, a natural host of eldana found in wetland areas.



Sugarcane planted into a former wetland. 'Wet feet' also causes plant stress and increases the risk of eldana damage.

#### Subsequent infestations

The presence of eldana on the North Coast became significant in 1978. The predominance of the variety NCo376, an advanced age at harvest for carry-over cane, soil water stress, excessive applied nitrogen and other complex factors were all likely causes of this situation. Various changes in agronomic practices were soon adopted to minimise the impacts of eldana on sugarcane yield and quality. The most effective strategy to control eldana was to reduce the age at harvest; where 65% of the area under cane harvested each season was the standard for setting the average age at harvest in the 1970s, the percentage area harvested was soon increased to 80-90% of the area under cane. In addition the variety N12 tended to replace NCo376 because of its greater resistance to eldana.

The damage to yield and quality of sugarcane by eldana was only partially offset by changes in agronomic practices adopted as control measures. The net outcome was that costs increased as a result of increased areas to be ratooned and revenue declined due to poorer cane quality and reduced annualised yields.



Month and Crop Age

Example of accumulating eldana damage in a sugarcane crop carried over during a drought period.

#### **Biology of eldana**

The mating systems of most species of moths conform to a general pattern in which pair formation follows female signalling and male searching. Females emit long-distance pheromone signals for particular periods of the day or night. Males search persistently for such females via an extremely acute sensitivity to their species-specific pheromone. However, several species do not conform to the stereotyped model. Eldana is one of these "non-conventional species".

Eldana moths emerge after sunset, with males emerging slightly before the females. Males emit a complex blended pheromone from wing and abdominal glands which attracts other males into loose aggregations called 'leks'. This has the effect of increasing the pheromone emission rate at a particular location thus becoming more attractive to females. Males usually display in groups of 3–6 moths on leaves of the upper sugarcane canopy.

Furthermore, eldana is a 'hearing' moth that can produce and detect ultrasonic pulses. In addition to pheromones, ultrasound is employed in the mating system and may function to maintain distance between males in a lek. It may also serve to orientate females that have entered the lek in choosing a specific mate. This could be due to acoustic signals being more directional (their source is more locatable at close range) than pheromones.

This unusual system, especially for Lepidoptera, is viewed as an evolutionary response to an aggregated larval food resource. The natural host plants of eldana are sedges (Cyperaceae) found in wetland areas, and such vegetation tends to be highly clumped. This renders searching for mates relatively low in risk and energy expenditure. Consequently, females assume the searching role in locating the aggregation of adult males at the larval food resource.

Most eggs are laid in concealed positions on dry leaf material and stalks within three days of mating. After about a week the eggs hatch and the minute first stage larvae emerge. These larvae may disperse over short distances by 'ballooning' on silk threads after climbing to the canopy. At this stage it is vulnerable to predation. A tiny larva will then feed initially as a scavenger on the outside of the stalk, but protected by leaf sheaths, for 10 to 15 days. Surviving larvae bore into the stalk, where they spend the remainder of their larval period feeding on the internal tissues of the sugarcane stalk.

On maturing, the larva spins a cocoon and pupates, either in the hollow stalk or on the outside, frequently behind a leaf sheath. From the pupa, the adult moth emerges. Breeding is continuous, but there are two peaks in moth numbers around April and November.



Life cycle of eldana.

**Economic implications** 

Eldana larvae feed extensively inside sugarcane stalks. In addition, stalk tissue surrounding borings is infected by a fungus (*Fusarium*) which is beneficial to the insect. The combination of borer and fungal infection causes a severe loss in cane quality which extends beyond the internode being bored.

Eldana damage causes inferior cane quality due to loss of sucrose and an increase in fibre. To a lesser extent yield (tc/ha) is also negatively affected. It has been found that anything between 1 and 4% of recoverable value (RV) can be lost for every 1% of internodes bored (%IB). For illustrative purposes, a figure of 1.5% RV loss for every 1%IB is used.

For example, a crop sustaining 16.5%IB at harvest will be decreased in RV yield by around a quarter ( $16.5 \times 1.5 = 25\%$ ). If the final yield with damage was found to be 7.5 tRV/ha, then in the absence of eldana damage 10 tRV/ha would have been attained (a loss of 2.5 tRV/ha from 10 tRV/ha = 25\%). Using the 2014 RV price of R3300/tRV this would equate to a loss of R8250/ha.

With a harvested area of 271 000 hectares/annum sustaining damage of on average 3% internodes bored, the total direct loss to cane growers across the whole industry is in the region of R 344 000 000/annum.



Eldana larva in a damaged stalk. Red discolouration is caused by *Fusarium* fungus.

Estimated mean losses per hectare harvested by P&D area (%IB are means for the period 2002/03-2011/12) (loss Rands/ha = 0.015 x %IB at harvest x tRV/ha x R3300).

PD&VCC area	Average yield tRV/ha (adjusted)	Average age at harvest (mo)	Average age at survey (mo)	Average % IB in sur- veys	#Estimated Average %IB at harvest	(loss) Rands/ ha harvested
Malelane/Komati	11.9	13.5	11.0	1.52	2.0	(1180)
Pongola	11.1	14.1	11.7	0.61	1.0	(550)
Umfolosi	10.4	12.6	10.5	0.28	0.4	(200)
Felixton	8.2	13.0	11.1	0.99	1.5	(610)
Amatikulu	7.7	14.0	11.4	2.30	4.0	(1520)
Entumeni	7.7	19.0	13.4	1.69	3.3	(1260)
Maidstone	7.6	15.0	13.5	3.74	5.0	(1880)
Gledhow	7.0	14.8	12.4	3.33	5.0	(1730)
Darnall	7.4	14.3	11.6	2.82	5.0	(1830)
Eston	11.1	25.0	16.2	1.64	3.8	(2090)
Noodsberg/UCL	10.4	23.5	19.0	0.64	1.0	(520)
Sezela	8.8	17.7	14.8	2.24	3.8	(1660)
Umzimkulu	9.0	19.1	14.1	1.80	3.2	(1430)
# %IB at harvest estimated based on a linear projected mean rate of increase for the interval between average age at survey and age at harvest.					3.0	(1270)

#### **Indirect losses**

Indirect losses due to reduced cropping duration far exceed direct losses. Research has shown that the optimal physiological and economic harvest age for sugarcane along the eastern coastal areas of South Africa is greater than 18 months, and prior to the mid-1970s this was the recommended practice for these regions.

The adjacent table estimates the annualised gain in R/ha that would be realised in moving from a 12 month cycle to 18 months on the North Coast under normal rainfall conditions and in the absence of eldana.

#### **Total losses**

Across the mill areas most affected by eldana induced early harvesting (Felixton, Amatikulu, Maidstone, Gledhow, Darnall) the average age at harvesting is currently around 13 months on the coast and 16 months in the hinterland. An increase to between 16 and 20 months could be worth around R4000/ha/ annum over approximately 100,000 hectares = R400m/annum. Added to this the estimated direct loss of R344m gives a total annual loss of around R744m. An estimation of annualised gain in revenue attainable in moving from a 12 month cycle to an 18 month cycle in the absence of eldana. (MyCanesim model using an Estimated Rooting Depth of 0.5m and clay content of 10% on the North Coast).

Age of crop (months)	Tonnes RV/ha
12	5.76
18	10.8
Annualised yield	7.2 tRV/ha/annum
gain/annum	1.44
%tRV increase/annum	#25%
Value of RV gain (no eldana)	R 4752/ha/annum
*Value of reduced inputs to 18 month cycle (replant, fertiliser, herbicide, ripener programmes etc)	R 3200/ha/annum
Total gain	R 7952/ha/annum

\*Assuming replant costs (inclusive of crop and creeping grass eradication, lime, gypsum, green manuring, calmasil, seedcane etc) of R30,000/ha and 10% replant of area harvested. Ratooning costs are estimated at R6,600/ ratoon/ha.

#MyCanesim simulates an annualised yield increase of on average 36% in moving from 12 months to 18 months at harvest on the North Coast.

A management factor of 0.7 is then applied (0.7 X 36% = 25%).

#### **Optimal age at harvest**

An investigation into the optimal age at harvest in the different regions was conducted using RV yield data from variety and plant breeding trials harvested between 2000 and 2013.



#### Eldana damage in carry-over cane

**Northern irrigated region.** RV yields generally peak at around 15 months of age. Thereafter there is a steep decrease in RV yields which is most likely associated with increased lodging and/or flowering in older crops. Accumulated damage due to eldana may also be a factor given that most irrigated varieties tend to be eldana susceptible. Growers are therefore urged to make eldana IPM integral to their farming system in order to maximise profitability.

**Coastal region.** Under good growing conditions RV yields tend to peak around 15 to 16 months of age, followed by a decline thereafter. The decline in RV yields after 16 months is due to eldana damage accumulation in the absence of a full IPM programme. Under full IPM, harvesting between 15 and 21 months (average 18 months) should be possible in most years. Growers are therefore urged to make eldana IPM integral to their farming system in order to maximise profitability.

**Inland regions.** RV yields generally peak at around 22 months of age. This is slightly younger than the traditional 24-month harvesting age usually adhered to. This younger harvest age may be linked to the use of newer, quicker growing varieties that reach maturity faster than N12. Additionally, lodging of some crops older than 22 months of age in the Midlands may also contribute to RV yield declines. Harvesting at 22 months will reduce eldana damage at harvest compared to the current Midlands average of 24.5 months.

Uncontrolled eldana can completely negate the advantages of a longer cropping cycle. Eldana populations can increase rapidly in sugarcane older than 12 months. In a series of six trials conducted on the North Coast, %IB increased from around 3% at 12 months to three and nine-fold at 18 months under conditions of normal and low rainfall respectively, in the absence of control measures. The following table estimates the losses incurred in these trials under normal rainfall and low rainfall (70% of normal) scenarios during the carry-over summer.

Estimations of annualised gain (loss) for scenarios where final eldana damage remains relatively low, and where eldana damage increases greatly during carry-over. These simulations are based on data from trials where no eldana control measures were applied.

Age of crop (months)	Normal rainfall	Low rainfall	
	tRV/ha	tRV/ha	
12	5.5*	5.5	
18	10.8	9.29	
Final %IB at 18 month harvest	9	27	
Loss calculation	0.015 x 9 x 10.8 = 1.46 tRV/ha	0.015 x 27 x 9.29 = 3.76 tRV/ha	
Actual Yield 18 months	9.34 tRV/ha	5.53 tRV/ha	
Annualised yield	6.23 tRV/ha/annum	3.69 tRV/ha/annum	
gain (loss)/annum	0.73	(1.81)	
Value of RV gain (loss)	R 2409/ha/annum	(R 5973/ha/annum)	
Value of reduced inputs to 18 month cycle	R 3200/ha/annum	R 3200/ha/annum	
Total gain (loss)	R 5609/ha/annum	(R 2773/ha/annum)	

\*MyCanesim modelled yield of 5.76 tRV/ha reduced by damage of 3%IB to 5.5 tRV/ha.

Under a low rainfall scenario (above-right) increased eldana damage completely negates any gains that might have been made from cane aging. Under the normal rainfall scenario an 18 month cycle remains more profitable than a 12 month cycle when final eldana damage (9%IB) is relatively low. The aim of IPM, therefore, is to restrict eldana damage to low levels such that profitability is maintained.

#### **Other borer species**

Since eldana underwent a "habitat switch" from wetlands to sugarcane, it is possible that the same could happen with other borer species. Stem borers are known to shift between cultivated crop species. For example *Busseola fusca* and *Chilo partellus* (both well-known maize stem borers) have become significant pests of sugarcane in NE Africa. Both of these are important pests of maize in South Africa and are also present within natural habitats. Both species pose potential biosecurity threats to sugarcane. *Chilo partellus* in particular is increasingly being recorded in sugarcane in South Africa.

#### Chilo partellus

Since the appearance of the spotted maize stem borer *Chilo partellus* on the African continent in 1932, it has continuously expanded its distribution in the warm, low-altitude regions of eastern and southern Africa. *Chilo partellus* is now expanding into cooler high altitude regions where it is displacing the indigenous *Busseola fusca*. The life cycle of *Chilo partellus* is three weeks shorter than that of *Busseola fusca*, which gives it a competitive advantage because of its higher potential rate of increase.



Chilo partellus.

*Chilo partellus* larvae feed in leaf whorls of several large grasses, causing characteristic scars and shot holes. They later feed at the growing point, which may be killed forming a characteristic 'dead-heart', especially in young plants. Older larvae tunnel extensively in upper stems. *Chilo partellus* is increasingly being found in sugarcane.

#### Chilo sacchariphagus

In 1999, the spotted sugarcane stem borer *Chilo sacchariphagus* was identified from bored stalks at two sugarcane estates in northern Mozambique. Larvae are identical in appearance to *Chilo partellus*. *Chilo sacchariphagus* is a major sugarcane pest in SE Asia, (its area of origin) and the Indian Ocean Islands of Mauritius, Madagascar and Reunion. Since, its natural host plants are *Saccharum* and related species, this insect poses a significant biosecurity risk to all southern African sugarcane industries.

SASRI has a biosecurity programme which is engaged in several initiatives to ensure that the South



African sugar industry remains vigilant to the possible invasion of the crop by insect pests and plant diseases. One such initiative is aimed at averting the spread of *Chilo sacchariphagus* to South Africa and involves developing a robust incursion strategy. Training workshops on survey methodology and monitoring systems are held regularly, and awareness campaigns make use of articles and posters in several languages. Stakeholders are advised to freeze any unidentified larvae from sugarcane and to send them to SASRI via the Extension Specialist or P&D Officer as soon as possible after collection for DNA based identification.



Spotted sugarcane stem borer *Chilo sacchariphagus.* 



Shot holes on sugarcane leaf caused by *Chilo* sacchariphagus.

Example of the type of materials produced by BIOSECURITY ALERT SASRI for awareness campaigns around the stem borers Chilo sacchariphagus and Chilo partellus. The Chilo stalk borer poses a real threat

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# Eldana risk factors

This chapter deals with the various factors associated with increased risk of eldana damage. An appreciation of these factors will assist in developing the various components of an IPM strategy against eldana.

# Eldana risk factors

#### Water stress

roughts occur regularly in South Africa. Drought may be defined as receiving rainfall of less than 80% of the long-term mean. Severe drought may be defined as rainfall of less than 70% of the long-term mean. Severe droughts occur with an approximate frequency of one year out of six, and dry spells are also quite common. A stressed sugarcane crop is more susceptible to eldana damage. Peaks in eldana damage occur during the periodic droughts that the industry experiences.

The probability of receiving low rainfall is roughly two to three times higher during an El Niño summer compared with other summers (see SASRI Information Sheet 11.6 El Niño and Drought).

Usually, the North Coast and Zululand regions are worst affected by El Niño. The Midlands is affected early in the rainy season in contrast to the South Coast, which is affected later. Mpumalanga seems to be least affected. Generally, February rainfall is worst affected by El Niño.

The SASRI WeatherWeb provides links to up-todate seasonal climate forecasts and also for the latest rainfall and other weather data. See: www.sugar.org.za/sasri.



#### **Estimating water stress**

Rainfall typically shows very high spatial variability, which makes accurate prediction at farm level almost impossible. However, growers can identify fields that are more prone to water stress and eldana damage using soil survey information.

Soil is the reservoir from which the crop obtains the water and nutrients it needs. Available water capacity (AWC) is the amount of water contained in the soil between field capacity (FC) (where the soil is moist and water in the soil pores is held against gravity but not saturated) and permanent wilting point (PWP) (where plants are so severely water-stressed



Annual rainfall is shown for a weather station on the North Coast as a % of the mean for the period 1978 to 2013. Severe drought (less than 70% of LTM) occurred in six years during this 36 year period.

that they do not recover from wilting within a 24 hour period). The AWC therefore represents the amount of soil water available for crop uptake. This quantity of soil water is expressed per metre of soil depth. This information can be obtained from soil sample laboratory results which include field capacity, permanent wilting point and available water capacity estimates.

Soils differ in depth and therefore their ability to store water. Effective rooting depth (ERD) is taken into account to convert available water capacity (AWC) to total available water (TAW). Total available water can be calculated on the farm using AWC provided the ERD of a field is known. The effective rooting depth represents the soil depth in which 85 to 90% of all plant roots are found.

If an obstruction occurs within the soil profile then the effective rooting depth is reduced from its potential to the depth of the obstruction. The obstruction may be due to physical factors (for example, a compacted layer) or a chemical factor (such as the presence of aluminium toxicity in acid soils). TAW can be used as an indicator of eldana damage risk; the lower the TAW, the greater the risk of high eldana infestation and damage. Refer to the table on page 16. An example for a Hutton (Farningham) soil sample submitted to the laboratory for water retention determination:

#### **Results:**

Field Capacity (FC) = 28.0%

Permanent Wilting Point (PWP) = 12.0%

To calculate Available Water Capacity (AWC):

AWC = FC - PWP = 28.0% - 12.0% = 16.0%

Conversion: 16.0% x (1000 mm/m ÷ 100%) = 160 mm/m

To calculate Total Available Water (TAW):

Effective Rooting Depth (ERD) = 0.9 m

TAW = AWC x ERD = 160 mm/m x 0.9 m = 144 mm

However, if ERD is reduced e.g. to 0.3 m, due to high subsoil acid saturation:

TAW = AWC x ERD =  $160 \text{ mm/m} \times 0.3 \text{ m} = 48 \text{ mm}$ 



Distribution of sugarcane roots to a depth of 4 m in a red loamy sand (left) and roots restricted largely to the top 0.4 m in a red sandy clay loam with a compacted subsurface layer (right).

Typical total available water (TAW), effective rooting depth (ERD) and available water capacity (AWC) values for soil forms commonly found in the South African sugar industry.

Soil form	Clay %	ОМ	AWC (mm/m)	ERD (m)	TAW (mm)	Risk of water stress and eldana damage
Sterkspruit	0-15	Low	+/- 80	0.4	+/- 30	
Wasbank	0-15	Low	+/- 90	0.4	+/- 35	
Mispah	6-35	Low to moderate	+/- 80	0.5	+/- 40	
Westleigh	0-35	Low	+/- 100	0.5	+/- 50	
Kroonstad	6-15	Low	+/- 80	0.7	+/- 55	
Katspruit	6-15	Low to moderate	+/-140	0.4	+/- 55	
Glenrosa	6-35	Low	+/- 100	0.6	+/- 60	HIGH
Estcourt	15-35	Low	+/- 100	0.6	+/- 60	
Milkwood	15-35	Moderate	+/- 120	0.5	+/- 60	
Nomanci	<35	High	+/- 120	0.6	+/- 70	
Longlands	6-35	Low	+/- 90	0.8	+/- 70	
Valsrivier	35-55	Low	+/-120	0.6	+/- 70	
Tambankulu	15-35	Moderate	+/- 120	0.6	+/- 70	
Swartland	>15	Low to Moderate	+/- 110	0.7	+/- 75	
Cartref	6-35	Low	+/- 100	0.8	+/- 80	
Fernwood	0-6	Very low	+/- 70	1.2	+/- 85	
Rensburg	>40	Moderate	+/- 140	0.6	+/- 85	
Willowbrook	15-35	Moderate	+/- 120	0.7	+/- 85	MODEPATE
Oakleaf	6-15	Low to modeate	+/- 90	1.0	+/- 90	MODERATE
Shepstone	6-15	Low	+/- 100	1.0	+/- 100	
Clovelly	6-15	Low	+/- 90	1.1	+/-100	
Arcadia	>50	Moderate	+/- 140	0.7	+/- 100	
Dundee	5-10	Very low	+/- 90	1.2	+/-110	
Bonheim	>35	Moderate to high	+/- 130	0.9	+/- 115	
Hutton (Clansthal)	6-15	Low	+/- 100	1.2	+/- 120	
Мауо	15-35	Moderate	+/- 140	0.9	+/- 125	
Kranskop	35	High	+/- 140	1.0	+/- 140	
Lusiki	35-55	High	+/- 120	1.2	+/- 145	LOW
Sweetwater	35-55	High	+/- 120	1.2	+/- 145	
Champagne	20	Very high	+/- 160	0.9	+/- 145	
Hutton (Farningham)	35-55	High	+/- 160	0.9	+/- 145	
Inanda	15-55	High	+/- 140	1.1	+/- 155	
Shortlands	>35	Moderate	+/- 140	1.2	+/-170	
Griffin (Farmhill)	>55	High	+/- 180	1.0	+/- 180	

Note: The table above illustrates examples only; variability exists within soil forms. For the calculation of total available water, see example on page 15.

### Clay content and organic matter

Clay and organic matter contents are positively associated with soil water holding capacity (AWC). These two factors have been related to eldana damage across a range of soils. Sugarcane on soil of below 15% clay and below 1.5% organic matter has an increased risk of eldana damage (see adjacent graphs).

Clay soils tend to have smaller pores but a higher total pore volume compared to sandy soils. Therefore clay soils have more pore space to store water.

Both clay and organic matter content affect the bulk density of a soil. High bulk density soils tend to be low in clay and organic matter. The bulk density of a soil (expressed as the dry mass of the soil in a known volume) describes how closely the soil particles are packed together. The closer the particles are packed, the higher the bulk density.

#### **Bulk density**

The bulk densities (volume weights) of soil samples taken from several field trials have been related to eldana damage at harvest. Sugarcane on soil with a volume weight above 1.4 g/mL has an increased risk of eldana damage.

Bulk density is an important physical property of the soil that has an impact on effectiveness of heat conductance, water-related soil properties and crop growth.

High soil bulk densities lead to:

• increased conductance of heat to other areas in soils and therefore faster evaporation of water from the surface,



Eldana damage related to clay%. Sugarcane on soil below 15% clay has an increased risk of eldana damage.



Eldana damage related to organic matter%. Sugarcane on soil below 1.5%OM has an increased risk of eldana damage.



Eldana damage related to soil sample bulk density. Sugarcane on soil with a volume weight above 1.4 g/mL has an increased risk of eldana damage.

- reduced water holding capacity and
- root growth impediment.

These factors in turn increase plant stress and the risk of eldana damage.

#### Compaction

Soil compaction (very high bulk densities) can greatly reduce the ability of roots to penetrate to depth. During drought, compaction limits access to water in subsoils, thereby increasing eldana risk. Compaction is the result of a closer arrangement of soil particles due to external forces (mechanical aids) and it can occur at and near the soil surface, or in deeper layers of the soil.

Traffic on wet sandier soils with little organic matter will result in compaction to greater depths compared to dry clayey soils with much organic matter. Grey soils are the most susceptible to compaction, with black soils the least susceptible and red soils, intermediate.



Tyre tracks left from an on-farm mechanical aid, resulting in compaction of soil.

Subsurface compaction (between depths of 20 to 45 cm) in the form of a plough pan has a severe effect on rooting depth and water infiltration limitation.

Compaction from traffic occurs mostly within a depth of 20 cm from the soil surface resulting in less space between soil particles for water storage and root development.

Soil compaction in the sugar industry occurs mainly at the soil surface to a depth of between 15 to 25 cm depending on the soil type, clay content and water content at the time of compaction.



Effects of compaction: reduced porosity, increased bulk density and shallow rooting.

#### Soil acidity

In the past, soil acidity has been confined mainly to high altitude areas (such as the Midlands). More recently, an industry survey of soil fertility trends indicated that non-irrigated sandy soils in particular have become more acidic over the past two decades.

Soil samples taken below the plough layer reveal that severe subsoil acidity is a widespread problem in the rainfed areas, and not surprisingly, in many of the soils sampled, little or no evidence of rooting was apparent at depths of greater than 30 to 40 cm.

Decreased yields of crops growing on soils with subsoil acidity are due largely to two factors. Firstly, a major consequence of subsoil acidity in terms of crop growth is an increased susceptibility to water stress. A lack of roots in the subsoil means that once topsoil water reserves are diminished, the crop is unable to access water in the subsoil. This will lead to an increased eldana risk.

The massive differences in available water for deep-rooted and shallow-rooted crops in a sandy loam soil are illustrated above.

Secondly, excessive subsoil acidity reduces the ability of the crop to access nutrient reserves in the subsoil. In particular, nitrate, calcium, magnesium, potassium and silicon uptake is limited due to the negative effects of acidity on both root growth and on the ability of roots to take up nutrients.

### The major causes of subsoil acidity

Removal of calcium and magnesium from the soil by the crop contributes towards acidification. Microbial oxidation of nitrogen fertilisers (nitrification) is a major factor increasing acidity levels. With each successive ratoon, acidity levels build up due to repeated removal of calcium and magnesium, and repeated application of nitrogen fertilisers.



An illustration of the effect of restricted rooting depth on water availability and the time duration a crop can escape drought stress.

Soil acidification produced by nitrification will only be permanent if the nitrate is lost from the system (e.g. by nitrate leaching beyond the root zone) effectively leaving the H<sup>+</sup> ions produced behind.

$$(NH_4)_2SO_4 + 4O_2 \rightarrow 4H^+ + 2NO_3^- + 2H_2O_5 + SO_4^{-2-}$$
  
 $(NH_2)_2CO_5 + 4O_2 \rightarrow 2H^+ + 2NO_3^- + CO_2^- + H_2O_2^-$   
 $NH_4NO_3^- + 2O_2 \rightarrow 2H^+ + 2NO_3^- + H_2O_2^-$ 

 $HNO_3$  is leached to the subsoil where  $H^+$  can displace  $Ca^{2+}$ ,  $Mg^{2+}$  and  $K^+$  from cation exchange sites. Further leaching of Ca, Mg, K and nitrate from the soil leads to acidity.

Soil acidification can also lead to the release of toxic aluminium (Al<sup>3+</sup>) ions from aluminium containing clay minerals.

e.g.  $Al_2Si_2O_5(OH)_4 + 8H^+ \rightarrow 2Al^{3+} + H_2O + 2H_4SiO_4$ kaolinite toxic leached or polymerised

Al<sup>3+</sup> is the largest contributor to acid saturation index (Al<sup>3+</sup>+H<sup>+</sup>, as a percentage of total exchangeable cations). Acid saturation of 20% is considered a threshold limit above which it becomes the most important growth and yield limiting factor for sugarcane crops in acid soils (water pH  $\leq$  5.5).

Al<sup>3+</sup> further displaces Ca<sup>2+</sup>, Mg<sup>2+</sup> and K<sup>+</sup> from cation exchange sites and because Ca and Mg are depleted, Al toxicity is compounded. The degree to which plant roots are affected by Al toxicity depends on the relationship between the quantity of exchangeable Al and the



quantity of exchangeable bases, rather than on the level of exchangeable Al alone. With Ca and Mg depletion, even low concentrations of Al rapidly inhibit root elongation by damaging the root cell walls and membranes, and interrupting various cellular processes. Acid subsoils act as a 'chemical barrier' to root growth, restricting water and nutrient availability.

With reduced rooting capacity, plants become far more susceptible to drought. Eldana thrive under drought conditions, and serious eldana damage can occur under these circumstances.

#### Silicon availability

Silicon (Si) is widely known to reduce plant stress, as well as to protect the plant against a wide range of pests and diseases. In the case of sugarcane, a growing body of evidence has shown that Si reduces eldana damage, in three main ways:

- Si is deposited in sugarcane stalk cell walls, making them harder for the eldana larvae to chew through. This means that the larvae spend a longer time outside the plant – trying to chew their way in – and are more susceptible to desiccation, predators and/or insecticide application.
- Si helps the sugarcane plant to reduce water loss and therefore to withstand dry periods for longer. Improved drought tolerance helps to reduce eldana infestation, as eldana thrives in drought-stressed cane.
- Sufficient Si is vital to ensure that the plant's own natural defence and signalling mechanisms work optimally.

Sufficient levels of plant-available Si are therefore critical in the battle against eldana.

Silicon can be lost from soils by weathering. The silicate clays, in particular, lose silica which is then leached and lost to the system. A general feature of soils low in clay is that they are also low in plant-available silicon.

The extractable silicon (Si) contents of soil samples taken from several field trials have been related to eldana damage at harvest. Sugarcane on soil with less than 15 mg/L extractable Si has an increased risk of eldana damage.



Eldana damage related to extractable silicon in the soil (0.01M CaCl<sub>2</sub>). Sugarcane on soil with less than 15 mg/L extractable Si has an increased risk of eldana damage.



Relationship between leaf silicon content and extractable soil silicon for sugarcane growing on 30 fields at various localities in the South African industry (CNC - Critical Nutrient Concentration). From the literature, the leaf silicon Critical Nutrient Concentration (CNC), resulting in 90% of maximum growth under nonstressed conditions, has been determined to be about 0.5%. For risk of eldana damage, 0.75% of Si in the leaf is considered a critical value. Leaf silicon content is closely correlated with silicon content at the site of attack by eldana, in the stalk.

The adjacent graph shows the relationship between extractable soil Si and leaf Si. Despite adequate levels in some soils, Si taken up by the plant can still be limited. For soil analyses, 15 mg/L extractable Si is considered a critical value.

The rainfed areas are characterised by low average leaf silicon contents and low soil pHs. A large proportion of samples are found to be Si deficient (in terms of eldana risk <0.75%) suggesting that Si deficiency is increasing eldana risk, and in many cases may also be limiting yield.

Factors which limit Si availability in lowpH soils include losses in available Si due to precipitation of unavailable iron (Fe) and Al silicates and to bonding with Fe and Al sesquioxides. Therefore, in low pH soils where a high level of soluble Al is present, and in soils high in sesquioxides, it is highly likely that most of the soluble Si has already been removed. As a result, very little remains for plant uptake. The adjacent graph shows how little extractable Si is present at acid saturations above zero.

#### Nitrogen

The natural Cyperus host plants of eldana are much higher in nitrogen (N) than sugarcane. Eldana is N-limited in sugarcane stalks where there is an excess of carbohydrates (sugar) rather than protein and amino acids. Excessive N use under conditions of water stress can greatly increase the survival and reduce the generation time of eldana. This appears to be due to increased storage of amino acids in the stalk under drought conditions which may be exacerbated by sub-optimal K, Ca and Si nutrition.



Results of a survey linking average leaf Si content with soil pH by region. (Horizontal dotted line indicates eldana risk threshold of 0.75% leaf Si).



The presence of  $Al^{3+}$  in soil is associated with low 0.01M  $CaCl_2$  extractable soil silicon content ( $CaCl_2$  extractable Si is a good indicator of plant available Si).





Extractable silicon in several soil forms of differing clay contents. Caution: The above figure illustrates examples only; considerable variability can exist within soil forms.

In the absence of stress, and where K, Ca and Si are adequately supplied, there may be little direct effect of excess N on eldana.

Although not as significant as some of the other eldana risk factors, leaf N contents have been linked with levels of eldana damage in trials. From this data it appears that an increased risk of eldana damage is likely when leaf sample N content exceeds 2.1%. High leaf N has also been associated with increased rust, thrips and yellow sugarcane aphid damage.

#### **Eldana in the Midlands**

In the early 1980s eldana was restricted to a narrow coastal belt coinciding with the 16°C isotherm for the winter month of July. At the time it was thought that this represented a thermal barrier to the inland spread of the insect. However, since 1998 eldana has invaded the Midlands and continues to spread.

This may in part be due to increasing winter temperatures, but a more significant driver appears to be the adaptive evolution of the insect to tolerate colder conditions. Recent research has shown that the Midlands eldana population has tolerance to temperatures 4°C lower than that of the coastal Umfolozi population.

Much of the eldana prone sandy soils in the Midlands are closer to the coast and at lower altitude. Coupled with this was a limited diversity of varieties, predominantly N12 (intermediate), and N16 (susceptible), with lesser areas of N31 (intermediate) and N37 (intermediate), which increased the rate of eldana spread.

Midlands soils are characterised by widespread acidity. Many of the higher clay, higher organic matter soils with good TAW values would appear to be of lower eldana risk (Champagne, Inanda, Kranskop, Lusiki, Magwa and Sweetwater, see table on page 16). However, the presence of aluminium toxicity and low silicon availability negates these factors. These soils (and Hutton, Clovelly and Griffin forms) also tend to fix phosphorus. The same absorptive sites in the soil also fix silicon further increasing eldana risk.

Soils with high organic matter content are able to mineralise about 60 to 100 kg N per ha per annum. The mineralised N is mainly available to the plant after a dry spell is broken by sufficient rains. Cane crops going into their second year following a particularly dry winter are likely to suffer from this effect which could significantly increase eldana population growth during summer.

#### Nematodes

Damage to roots caused by plant parasitic nematodes increases the likelihood of water stress which increases the eldana risk. The presence of nematodes is a widespread problem throughout the SA sugar industry, especially in sandy soils. The estimated cost to our industry is in the region of R 500 million per annum.

Damage to the shoot-roots of sugarcane by ectoparasitic nematodes affects the uptake of water thus increasing the likelihood of water stress which increases the risk of eldana damage.

Poor root systems that result from nematode infestation lead to a reduction in yield of the affected crop as well as a reduction in the number of high yielding ratoons from one planting, severely affecting profitability.



Differences in root growth between nematicide treated (left) and untreated plants (right).



#### Irrigation and drainage

Eldana risk is increased by any form of plant stress. Whilst eldana levels are on average low under irrigation as compared to rainfed cane, high levels of infestation can be experienced where irrigation scheduling is sub-optimal. In the past, irrigation design philosophy ensured that irrigation systems were designed to meet peak crop water requirements to maximise crop yields whilst limiting water deficit stress. This strategy, however, has lent itself to excessive applications of water which also stresses the crop by causing anaerobic soil conditions through water-logging. Indeed, during periods of water supply restriction, yields often increase in the absence of over-irrigation.



Without waterlogging, roots can exploit soil water and nutrient reserves (left). Roots cannot develop where a surplus of water excludes oxygen (right).



#### **Salinity**

Soils with poor drainage characteristics (prone to waterlogged anaerobic conditions) also tend to be prone to salinity. Sugarcane is regarded as a relatively salt sensitive plant. Salinity induces water stress which is evident in cane by premature wilting, scorching of the leaves, restricted growth and increased eldana risk.

Under irrigated conditions, salinisation is caused by poor water management, i.e. inadequate drainage coupled with excess irrigation, which results in a rise in the level of the water table. Salts dissolved in the ground water reach the soil surface by capillary movement, causing small patches of saline-sodic soil which grow in size as the subsurface water accumulates around them.

Such 'brak' development usually takes many years to manifest itself after irrigation has begun, as was the case in the Pongola Irrigation



The effect of salinity on cane growth is similar to that of severe drought.

#### EC values above 200 mS/m are likely to affect cane growth as follows:

EC (mS/m)	Categorisation	Effect on sugarcane crop
0 - 200	Non-saline	None
200 - 400	Slightly saline	Slight
400 - 600	Moderately saline	50% decrease in crop yield
600	Highly saline	Stools are killed

Scheme where serious problems only appeared after about 40 years of cane production. Severe drought can also cause salts to move to the soil surface.

Salinity is measured as electrical conductivity (EC) using an electrical conductivity metre, usually in a saturated paste extract, and recorded in milli-Siemens per metre (mS/m).

Whilst high EC can indicate that there is a salinity problem, there are three different forms of salinity:

- **Saline** soils have a high salt content in the soil water which restricts plant growth. Calcium and magnesium ions predominate over sodium, and pH is less than 8.5. Soil structure is not affected (clay is not dispersed), which means that soluble salts can be leached with water through the soil profile.
- **Saline-sodic** soils are in transition between salinity and sodicity. Their pH remains less than 8.5. They have developed a high concentration of sodium (that would normally cause clay dispersion), but this is counteracted by high concentrations of calcium and magnesium. The net result might be weaker aggregates. If calcium and magnesium salts continue to be leached out, the soil particles begin to disperse. Such soils increasingly become poorly aerated, permeability is affected and the ability of roots to penetrate to depth is reduced.
- Sodic soils have a low overall salt content but a high level of exchangeable sodium (Na) attached to the clay particles. Hydrogen ions are inactivated by exchange adsorption in place of Na<sup>+</sup> which results in an increase in the OH<sup>-</sup> ion concentration and increased soil pH to more than 8.5, a characteristic of these soils.

clay micelle  $Na + H_2O \ll clay$  micelle  $Na + Na^+ + OH^-$ 

In the presence of sodium and with depletion of calcium and magnesium, soil structure breaks down due to swelling and dispersion of the clay. These soils are poorly aerated, permeability is affected and the ability of roots to penetrate to depth is reduced.

The sodium adsorption ratio (SAR) of the soil saturation extract (proportion of Na to Ca + Mg) is used as an index of sodicity. Different soil forms vary in their sensitivity to sodium and for this reason, soils have been assigned critical SARs based on the content and type of clay present. When the SAR determined by the laboratory is greater than the critical value into which that soil is grouped, the soil is considered sodic.

Different soil forms vary in their sensitivity to sodium and on this basis are assigned critical SAR values. The majority of soil forms associated with high eldana risk (see table on page 16) belong to the SAR 6 category.

Critica	al SAR 6	Critical	SAR 10	Critical SAR 15	
Generally poorly drained, highly dispersed grey soils derived mainly from Dwyka tillite, Vryheid sediments and sandy alluvium.		Mainly slowly swelling clays dolerite, Pieter Vryheid shales, and heavy	r draining black associated with rmaritzburg and Swazi basic rocks y alluvium.	Mainly well drained, non- dispersive soils associated with Recent Sands and other parent materials in upland positions.	
Estcourt	Kroonstad	Arcadia	Milkwood	Champagne	Griffin
Glenrosa	Swartland	Rensburg	Tambankulu	Inanda	Hutton
Katspruit	Valsrivier	Bonheim	Willowbrook	Cartref	Oakleaf
Longlands	Wasbank	Мауо		Clovelly	Shepstone
Mispah	Westleigh			Dundee	Shortlands
				Fernwood	

#### Soil fertility reports

SASRI provides a detailed analysis report with a wealth of information for every soil sample submitted for analysis. Many farmers do not make full use of this report, possibly because they may not understand how to interpret the information provided. To help with this, a poster is available from SASRI which provides explanations for each section of the report.



#### Herbicide residues

Sugarcane growers often only use a few selected herbicides, re-applied annually to the same fields. Herbicides such as hexazinone, diuron and metribuzin are long-term soil residual products that are used extensively in preemergent and early post-emergent treatments. Certain fields in the industry may have been treated with these products regularly for up to 40 years. This practice has raised the question of possible accumulated phytotoxic effects from continuous exposure of sugarcane to them.

The half-life of metribuzin in soil is between 30 and 60 days (the time it takes for 50% of the chemical to degrade or breakdown) while hexazinone and diuron have half-lives that can be as long as 180 days. In the latter case, after 180 days, half of what was applied will remain. After 360 days, 50% of the original amount will have decreased by half again, suggesting that 25% could remain and carry-over into the following year.

Half-lives are only an indicative guide since they vary with soil type. Among other factors, higher soil temperatures, greater soil moisture, and inputs of organic matter leading to higher microbial activity tend to accelerate degradation; dry and cold conditions tend to lengthen degradation. Dry or drought conditions are the main factors in causing herbicide residues to persist longer than normal.

Numerous field phytotoxicity trials have shown that single applications of hexazinone + diuron can reduce sugarcane yields by an average of 4%, while metribuzin + diuron can cause a 2% loss of yield. Although the main mode of action for these herbicides is to inhibit photosynthesis in the leaves, other effects are possible, e.g. diuron has been shown to directly affect root growth and can increase susceptibility to root rot pathogens. Herbicide residues therefore have the potential to increase the risk of eldana damage by increasing plant stress.

#### Persistence in the soil of some selected herbicide active ingredients.

Soil persistence is short term (max. 3 months)	Persistence can be up to 6 months	Under conditions unfavourable to decomposition, residues could accumulate with repeated use
2,4D	acetochlor	amicarbazone
glyphosate	alachlor	atrazine
МСРА	ametryn	diuron
sulcotrione	EPTC	hexazinone
	chlorimuron-ethyl	isoxaflutole
	halosulfuron	pendimethalin
	mesotrione	sulfentrazone
	s-metolachlor	
	metribuzin	imazapyr*
	terbuthylazine	tebuthiuron*

\*imazapyr and tebuthiuron in particular can persist for more than 12 months under conditions unfavourable for breakdown.

#### Summary of eldana risk factors

Critical thresholds or conditions indicating increased risk of high eldana damage				
Total Available Water	Less than 80 mm			
Organic Matter	Less than 1.5%			
Clay	Less than 15%			
Bulk Density (Volume weight)	Greater than 1.4 g/mL			
Silicon	Less than 15 mg/L in soil and less than 0.75% in leaf samples			
Nitrogen	Greater than 2.1% in leaf samples			
	Nematodes: Presence of a pathogenic community			
	Aluminium toxicity: Presence of Al <sup>3+</sup> in topsoil and/or subsoil			
Poor root development	Compaction: Increased volume weight of undisturbed cores			
	Salinity/Sodicity and poor drainage			
	Possibility of herbicide residue build-up			



# Habitat management

The implementation of Push-Pull technology has proven to be an effective way of managing eldana as well as other stalk borers. This technology involves intercropping plants which are more palatable to the borers thus driving them away from the cane.

he fear of predation can influence behaviour in animals. Ecologists at the Yellowstone National Park (Wyoming, US) noticed the impact of fear on the behaviour of elk after the re-introduction of grey wolves. The greatest impact that the predators had on their prey was not by killing, but rather by being scary. Through the eyes of an elk, the landscape is overlaid with a mental map of risk, which has become known as a 'landscape of fear'.

Predators can influence how successfully their potential victims feed and breed, without a single kill. Their mere presence, their scent on the wind or the sound of their calls, creates a constant state of anxiety in their prey. Elk more than doubled the time they spent on watch. They also moved away from open grassland into woodland that offered more protection, but less suitable food. As a consequence, their numbers declined.

A landscape of fear is not only applicable to mammalian predator-prey relationships, but also to arthropods.

Yale University researchers released spiders into cages of grasshoppers. However, the spiders didn't eat the grasshoppers because their mouthparts had been glued shut. Despite this, the grasshoppers were stressed, and their metabolism increased by more than 40 percent whilst their reproductive rates declined. So for insects too, the fear of predation can influence behaviour.

#### **Push-Pull**

The Push-Pull technology, developed by Kenya's International Centre of Insect Physiology and Ecology (ICIPE) and Britain's Rothamsted Research, influences the behaviour of the maize borers *Chilo partellus* and *Busseola fusca*.

The technique involves intercropping Melinis (molasses) grass (*Melinis minutiflora*) with maize as a "push" plant. Melinis has the unusual property of being able to continually emit a volatile scent blend (SOS volatiles) that summons natural enemies of insect herbivores even though it is not damaged.



A Push-Pull system for sugarcane.





An eldana larva in giant watergrass (*Cyperus dives*), a useful pull plant.

#### Examples of natural enemies of eldana

The pupal parasitoid *Xanthopimpla stemmator*, and the larval parasitoid *Goniozus natalensis*.



These same scents act as a signal to the borer moths in adjacent crops that parasitisation of their offspring is likely and that movement away from the area (the "push" effect) would be advantageous to them. In effect, Melinis creates an insect version of a landscape of fear.

To further improve the system researchers included Napier grass (*Pennisetum purpureum*). Scents from this grass attract ("pull") *Chilo* and *Busseola* moths and encourage them to lay eggs in the grass instead of in the maize. Certain varieties of Napier grass were chosen for this because they also produce a gummy substance that traps the



Bt maize mode of action.

newly hatched larvae as they attempt to bore in, so that only a few survive to adulthood.

For sugarcane, a Push-Pull system has been designed that makes use of Melinis as a 'push' plant and combines it with Bt maize (a dead-end trap crop) and natural hosts of eldana as 'pull' plants.

Eldana prefers wetland sedges (*Cyperus dives* and *Cyperus papyrus*) to sugarcane. Eldana is controlled in sedges by its natural enemies (creates a population 'sink'). Field trials and growers' experiences have shown that well-managed cane adjacent to sedges growing in wetlands has lower infestations of eldana than cane which is not adjacent to sedges.

### Additional benefits of habitat management

Wetland sedges may also serve to slow the development of resistance to insecticides in eldana. The mechanism behind this is similar to that of the refugia strategy used to combat the emergence of pest resistance to the *Bacillus thuringiensis* (Bt) insecticidal bacterial toxin engineered into genetically modified pest resistant crops.

In preventing the development of resistance to insecticides, the panel below-left would represent the sprayed crop and the one below-right would represent unsprayed wetland sedges. The few survivors of insecticidal treatment are more likely to mate with moths from the unsprayed sedges. These matings would be more likely to take place in the sedges when Melinis is placed in cane breaks further reducing damage to sugarcane.

Similarly, the presence of alternative host plants may prevent the adaptation of eldana to the resistance mechanisms of newly released resistant sugarcane varieties. Adaptation to sugarcane resistance mechanisms can be prevented if a full IPM approach is adopted such that eldana numbers in the cane are kept low, and the majority of mating and egg laying takes place in the wetland sedges.

### Summary of habitat management benefits

- Push–Pull reduces eldana damage to sugarcane.
- It is effective against *Chilo partellus* and *Busseola fusca* which both pose biosecurity threats to sugarcane.
- Push–Pull is likely to reduce the development of resistance to insecticides and the adaptation of eldana to the resistance mechanisms of newly released resistant varieties.



The refugia strategy for the prevention of resistance development to the Bt toxin in GM crops.



#### Practical guidelines for implementing Push-Pull on a sugarcane farm

#### **Push plant**

### Molasses Grass (Melinis minutiflora)

Melinis is an indigenous African grass. It is a nutritious and highly-palatable fodder and has the additional benefit of acting as a tick-repellent for livestock which consume it. Melinis grows best in well-drained soils and in a sunny position. It is not a particularly competitive grass and does not pose the risk of becoming a weedy species. It is not a host plant for any sugarcane pests and it shades out creeping grass weeds.



#### **Pull plants**



Bt maize (Zea mays)

The word 'Bt maize' refers to a group of maize cultivars which have been genetically modified to include a 'tox gene' which comes from the bacterium *Bacillus thuringiensis* (an insect pathogen) hence 'Bt'. This gene is expressed in the maize plant as a protein which is toxic to most lepidopteran larvae killing them within a few days of feeding initiation.



Giant sedge (Cyperus dives)

This is an indigenous obligate wetland plant which grows in marshy wetlands, drains and the margins of water bodies. It grows best in soil which is wet almost year-round. It is very similar to *Cyperus latifolius* in appearance, but has a very sharpedged leaf and a paler green colour overall. It is more common in lower altitude coastal areas, whereas *C. latifolius* is dominant in cooler inland areas. It is a natural host plant of eldana.



Papyrus (Cyperus papyrus)

Papyrus is also an obligate wetland plant which grows in standing or slow-flowing water and in marshy wetlands. Papyrus dies back when frosted but re-grows in the spring. It takes 2-3 years to establish after which the clump size increases quickly. It is a natural host plant of eldana.
### Site choice and layout

- Ideally choose a site which is adjacent to a wetland or watercourse where sedges can be planted or promoted as a pull, and Melinis as a push.
- Plant Melinis on contours moving up the slope from the watercourse (start at least 20 m or one contour above watercourse) all the way to the top of the slope. Do not plant Melinis directly adjacent to wetlands!
- Bt maize can be planted on every fourth contour going up the slope (instead of Melinis). If there is no watercourse, plant 2-3 rows of Bt maize as a border on the lower edge of the field. Bt maize can also be planted in blocks or as a green manure.
- Plant clumps of sedges in former wetlands, watercourses, drains and along the edges of dams and streams. Where wetlands have long been established to cane it is not necessary to plant a continuous stand of sedges in place of sugarcane. Spaced clumps can be established without giving up too much cane area.

### Planting

### Land preparation:

- Contours should be treated with glyphosate herbicide before planting to kill off weeds and reduce competition. This is especially important for creeping grasses such as Cynodon; young Melinis plants do not establish well in the presence of such highly competitive grasses. Once established, Melinis is effective in suppressing Cynodon.
- Choose position of seedlings/seed and loosen soil using a 1-tyne ripper. If available, use a crumble-buster to soften soil.
- Hoe furrows along loosened soil for planting seeds/seedlings.
- Plant Melinis by hand and Bt maize by hand or maize-planter.



Melinis planted in the centre of a contour.



Melinis seedlings planted in well-prepared soil, 1 m apart.



Bt maize plants planted in the centre of a contour bank, 30 cm apart – note no competitive weeds.



Melinis planted on the edge of a contour adjacent to cane: note how it acts as a barrier to weeds.

### Spacing and positioning:

- Melinis and maize can either be planted in the centre of the contour or on the edge (at least 0.5 m from the last cane row): centre of contour is better for contours used as roads, and also reduces the chance of damage when spraying herbicides on edge of cane. Edge of contour (a minimum of 0.5 m away from cane) is better to aid in suppression of creeping grasses into sugarcane, however plants are more likely to be affected by herbicide residues and over spraying if planted on the edge.
- Melinis plugs: plant 1 m apart in good soils or 0.5 m apart on poorer soils.
- Bt maize seed: plant 15 cm apart.

### Timing

- Eldana moth numbers reach a peak twice a year: in March/April and again in October/November. Bt maize should be planted 3 months before the March/May peak.
- Due the threat of mosaic, maize should not be planted before the beginning of January.
- Maize seed should always be treated with a suitable insecticide to reduce the threat of aphids and mosaic.
- Melinis should be planted from August-January and then maintained. Unless damaged by fire, herbicides or heavy frost, Melinis should persist for many years. It can handle light grazing and mowing. Note that Melinis may take up to 6 months, depending on conditions, to reach sufficient size and biomass to have an effect on eldana. It should not be unnecessarily mowed.
- Bt maize and Melinis may require some water at time of planting.

# Maintenance & adjustments to crop management

- **Burning.** Melinis can be mowed before burning. It is quite sensitive to fires, but re-grows in spring if conditions are favourable.
- Herbicide residues. Maize and Melinis seedlings will not do well if planted on contours with high amounts of herbicide residues or where herbicide over-spray occurs.



Peaks in eldana moth populations and in egg-laying occur in Spring and Autumn.

- Weed control. Growers who usually use a lot of herbicides to keep edges of cane fields free of weeds will have to adjust this practice in Push-Pull fields. Melinis can help to suppress creeping grasses.
- **Mowing.** Melinis can be mowed once a season (not lower than 20 cm off the ground), preferably just before harvesting of adjacent cane.
- **Management.** Keep Melinis free of weeds and consider applying fertiliser at planting to ensure good establishment. Successful establishment is the key to healthy and effective Melinis.
- Use of contours. If contours are used as roads for management or transport purposes, it is recommended that Melinis be planted in the middle of the contour. Contours planted with Bt maize cannot be used as roads.
- Awareness. Growers should make their staff aware of Push-Pull plants to avoid accidental removal or spraying. Markers at the edge of contours can be helpful.

### **Propagating Melinis**

- Contact SASRI for Bt maize and Melinis sources.
- Take cuttings from vegetative tips of Melinis (do not use flowering tips). NB: sterilise secateurs in diluted (1:10) household bleach before cutting pieces of stem material.
- The cuttings should have four nodes. Trim the leaves to reduce transpirational demand. Dip the lower end of the cutting into the fungicide Difenozim (1.5 ml per litre of water) to prevent rotting. Bury the lowest node in Mgeni sand or vermiculite. Ensure adequate water, sunlight and good drainage.

 Sedges should be propagated by taking clumps from growers who have it growing in their wetlands. Plants should be dug out with roots/rhizomes intact and can then be split into plantlets and trimmed back. It is best to mark the position in which the sedges are planted for easy monitoring, especially in large wetlands. To speed up establishment, cuttings can also be placed in bags to ensure good root establishment before planting out into wetlands.



Melinis plantlets propagated from four node cuttings.

### Wetland management for Push-Pull

Using Push-Pull for eldana control can help to focus growers' efforts in rehabilitating their wetlands. The benefits of wetlands can be shared across farm boundaries. Growers are encouraged to work together in area-wide IPM programmes when restoring their wetlands.

Alien invasive plants (AIPs) commonly colonise disturbed wetlands due to favourable, moist conditions and can radically alter wetland habitat and functioning. Such plants need to be sprayed using the correct herbicides or mechanically eradicated in order to make space for indigenous plants including natural hosts of eldana. See SASRI Information Sheet 10.3 Alien Plant Control: Legislation and Guidelines for control & SASRI Information Sheet 10.7 Alien Plant Control: Methods and Registered Chemicals.

The Conservation of Agricultural Resources Act states: "Cane should also not be cultivated within the flood area of a watercourse or within 10 m horizontally outside the flood area of a watercourse."



Planting sedges in bags to allow for new root establishment before planting them out into wetlands increases the rate of successful establishment. The bagged plants must be kept moist at all times.



Well managed riparian zone with buffer. Riverine trees provide perching positions for insectivorous bats.

### Broad recommendations for managing wetlands to optimise them as habitat for eldana

- Sedges grow in moist soils prioritise these areas for AIP clearing and establishment of sedges.
- Key sedge species to establish for eldana habitat: *Cyperus dives* (giant sedge) and *Cyperus papyrus* (papyrus). *Cyperus latifolius* can provide habitat as well, but is less favoured than the other two.
- Use source material from natural sedge populations on the farm/neighbouring farms.
- Sedges can be transplanted: dig up rhizomes, split them, trim growth (leave about 30 cm) and re-plant clumped together in wet areas. Transplanted sedges take 2-3 years to establish. They are fire and frost tolerant.

- Look out for 'wet spots' in sugarcane fields where a clump of sedges (e.g. papyrus) can be established. It is not necessary to plant a continuous stand of sedges in place of sugarcane. Spaced clumps can be established without giving up too much cane area.
- Establish a 1-2 m buffer zone of natural vegetation alongside drains/riparian wetland areas. Ideally maintain indigenous vegetation in these buffer zones.
- Burning: reduce burning frequency and intensity. i.e. try to burn once every 2-3 years. When burning, try to do a cool and/or patchy burn in wetland areas. Remember: too frequent burning favours AIPs.
- Ideally, all wetland areas should be restored to their natural state; however this is often not economically viable. By managing wetlands with an emphasis on an eldana habitat, one can take small achievable steps towards improving wetland management on a farm.

### A tool for wetland management for Push-Pull

Refer to the Mondi Wetlands Programme website: www.wetland.org.za for a wealth of information on wetland management, including the following schematic.



### Wetland Action Plan for Push - Pull

### Bats: A natural form of pest control

Any insect that flies at night must deal with echo-locating insectivorous bats. Many insects have 'ears' sensitive to ultrasonic frequencies. The evolution of ultrasonically sensitive ears in moths (tympanate moths) has had an important secondary effect; the evolution of ultrasonic communication systems used in courtship and mating behaviours by many moth species, including eldana.

Insectivorous bats can eat about a third of their own body weight in insects every night and in many parts of the world organic growers install bat boxes throughout their farms to encourage this natural form of pest control. Through habitat enhancement and the provision of roosting sites it is possible to encourage greater habitation of bats in and around areas where their 'pest control services' are most needed. Indeed, insectivorous bats roosting in natural habitats have been shown to prefer foraging above nearby sugarcane. Eldana has been shown to be predated through DNA analysis of bat faecal pellets.

From a tympanate moth's perspective, bats give away their presence with the ultrasonic pulses that they use to probe the environment. Analogous to the wolf-elk predator-prey interaction, the impact of insectivorous bats may have as much to do with influencing moth behaviour as with killing them. Animals reduce courtship behaviour under conditions of high predation risk, thus trading off investment in reproduction relative to the threat of predation. Even animals with simple nervous systems need to distinguish between opportunities for mating and threats from predators.

The presence of echo-locating bats seems likely to interfere with the mating system of eldana which could be disrupted by:

- inhibition of lek formation due to decreased moth movement in the presence of an echo-locating predator,
- reduced ultrasonic sexual display behaviour within leks, which could be detected by bats.

Both mating disruption and predation are likely to occur. Perhaps the most effective way for a bat to slip close to tympanate prey is to cease echo-locating altogether and detect prey by passive hearing. Some bats use a special technique called 'gleaning' to pluck insects off leaves. For example, these bats will perch on branches and listen for the sounds of insect movement or ultrasonic sexual display before attacking. Gleaning bats usually have large ears.



An insectivorous bat with a captured moth (left). A bat box provided as a roosting site (right). Bat boxes should be placed within easy reach of an open water surface. Bats emerging at dusk look for water first.

For further information: Contact: Dr Corrie Schoeman http://lifesciences.ukzn.ac.za/Staff/Biodiversity/biodiv\_evo\_staff/Durban/schoemanc.aspx also see: http://www.ecosolutions.co.za/about-bats/pest-control http://www.batgoods.com/item/The-Bat-House-Builder-Handbook-155



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# Soil management practices

In an earlier chapter, the factors contributing towards increased risk of eldana damage were explored. In this chapter, and the chapters that follow, management practices that alleviate these risks are described.

### **Preparing for planting**

reparation for planting, and planting itself, combine to be the most costly operation on a cane farm. However, the re-plant represents a major opportunity for investment in the future, and for the correction of the ills accumulated during the previous cropping cycle (creeping grass encroachment and spread, compaction, soil acidity, stool damage, RSD, mosaic, etc).

Best management practices (BMPs) for re-planting are also best management practices for eldana control when they alleviate eldana risk factors (by reducing soil bulk density and acidity; by increasing soil organic matter content and silicon availability). When optimally integrated, these practices can greatly reduce annualised re-plant costs by allowing an increase in age at harvest (where appropriate), and by increasing the number of high yielding ratoons.

Research has shown that the cumulative yields of all ratoons are correlated to the yield achieved in the plant crop. For maximum profitability, it is most important to ensure that all best management practices are applied to the plant crop. The best opportunity to control creeping grasses is in fallow fields or when old sugarcane stools are to be eradicated prior to re-planting. Some glyphosate products and Arsenal GEN 2<sup>®</sup> are registered to kill cane and at the same time will control the grasses. It is best to apply herbicide when the cane is knee-height, fully emerged and actively growing, but not too tall to give protection to the grasses beneath it.

### Glyphosate

The use of a surfactant with glyphosate will help the herbicide action if stipulated on the herbicide label. Planting should be delayed to allow for repeat spotsprays to any surviving cane or grass as it emerges. This reduces the amount of live runners becoming buried during ridging and other mechanical planting operations. It is important not to plough out fields heavily infested with *Cynodon dactylon* as this buries some runners too deeply. Delayed emergence then allows escape from non-residual agrochemicals such as glyphosate.

### **Control of creeping grasses**

A less than optimal crop age at harvest (to minimise eldana damage) has been linked with an increased incidence of creeping grass infestations. This is due to a reduced period of ground shading by a full sugarcane leaf canopy. In particular, creeping grasses have become a problem on sandier and acid soils (Cynodon is especially tolerant of soil acid saturation). As cane can be slow to canopy due to factors such as water stress, nematodes, thrips, yellow sugarcane aphid, rusts and soil acidity, creeping grasses can actively compete for water and nutrients.



A severe infestation of the creeping grass *Cynodon dactylon*.

### Arsenal GEN 2®

A superior level of control can be attained with Arsenal GEN 2<sup>®</sup>. However, good agricultural practices are essential for applying this product as it is residual and can kill germinating plant cane. A fallow period of at least 4 months AND 600 mm rain is necessary before planting a green manure or the new sugarcane crop. During this time the herbicide is broken down by microbial activity. Arsenal GEN 2<sup>®</sup> should only be applied once, and subsequent spot spraying should be with glyphosate only.



A severe infestation of the creeping grass *Cynodon dactylon*, 12 weeks after spraying with 5.2 L/ha Arsenal GEN 2<sup>®</sup>.

# Combatting herbicide residue build-up

Because of the possibility of accumulative residual herbicide effects on yield with advancing ratoon age, it may be beneficial to growers to alternate products of different modes of action after a few seasons.

The highest risk is associated with commonly used hexazinone + diuron and metribuzin + diuron tank mixes, which are both C1 + C2 mixtures (see SASRI Herbicide Guide). Repeated use of these tank mixtures for many years may increase the chances of residual herbicide damage to sugarcane and the possibility of weeds becoming resistant. Diuron residues have been shown to damage roots and to increase the severity of root rots in other plants, and so could increase the risk of eldana damage if sugarcane root growth is impaired.

It is advisable to rotate herbicides or use tank mixtures which contain products that have different modes of action according to weed spectrum and spraying conditions, e.g.

- s-metolachlor + ametryn + MCPA (K3 + C1 + 0) or
- acetochlor + ametryn + paraquat (K3 + C1 + D) or
- terbuthylazine + mesotrione + s-metolachlor + paraquat (C1 + F2 + K3 + D).

Also, inputs of labile organic matter at planting can accelerate herbicide residue degradation due to increased microbial activity.

Consult the SASRI Herbicide Guide for updated weed control recommendations.

### Compaction

Compaction is a long-standing problem in the South African sugar industry. It restricts water intake, water holding capacity and rooting depth, thereby increasing the risk of eldana damage. The tendency to become compacted is greatest when soil water content is near field capacity.

### **Detecting compaction**

The presence of a compacted layer may be revealed by:

- ponding on a soil with fine, sandy texture
- pushing a thin rod (5 mm diameter) with a sharp point vertically into the soil, when a layer with high penetration resistance will be encountered
- digging a pit and examining root behaviour. Compaction will deform the roots, and cause them to swell and bend as they enter the 'hardpan'.

### **Preventing compaction**

The following are practices that can be employed to prevent the occurrence of compaction and stool damage:

• Make use of a controlled traffic system to prevent wheels from driving over cane stools. Potentially, the row spacing on each farm could be different, but most could make use of an inter-row spacing of 1.2 m followed by a 1.2 m production bed carrying two cane rows spaced 0.6 m apart. In a manually harvested system, the 'tramlines' need only be in every six or seventh row depending on the specific loader operation. By limiting traffic to defined lanes, overall compaction is minimised.

- Restrict large haulage trucks to loading zones.
- Avoid using infield transport when soils are wet. In addition, ensure that high flotation tyres are fitted.
- When loading mechanically, place as many rows as possible into one windrow to reduce the amount of traffic per unit area.
- Use a slewing loader to minimise stool damage.
- Use soil form information to plan a harvesting schedule. Harvest fields most prone to compaction during the dry season, using the soil information given in the table below.

# Restoring compacted soils

Most trial results have shown no immediate significant yield benefits from alleviating compaction in ratoons. This is because the root-tosoil interface is disturbed and takes time to recover. Ripping of ratoon fields should therefore be restricted to within two weeks of harvest.



The 1.2 m inter-row spacing combined with a 0.6 m row spacing arrangement that should be suitable for most farms is also referred to as the 1.8 m tramline system.



A slewing loader operating in a controlled traffic system results in reduced soil compaction and stool damage.

Soil description	Soil form	Suggested harvest season
Valley bottom soils	Valley bottom soils Estcourt, Katspruit, Bonheim, Rensburg	
Grey sandy loams	Longlands, Kroonstad, Westleigh, Glenrosa	Winter / Spring
Clay and clay loams	Arcadia, Tambankulu, Milkwood, Swartland, Shortlands, Hutton (Makatini)	Spring / Summer
Brown humics Inanda, Kranskop, Nomanci, Magwa		Summer
Recent sands and alluvial soils	Fernwood, Dundee, Hutton (Clansthal)	Summer

Suggested harvest programme for reducing the risk of compaction based on soil groups.

Consult SASRI's Controlled Traffic booklet and the following SASRI Information Sheets:

4.3 Subsoiling in ratoons

6.2 Compaction

14.4 Infield traffic management.

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- Rip compacted soils before planting. The shattering action of the subsoiler will be more effective in dry soils.
- To decrease natural re-compaction, filtercake or bagasse can be incorporated to a depth of 400 mm.
- Green manuring (e.g. with oats or Sunn hemp) will rejuvenate compacted soils and increase the plant crop yield.

### **Correcting subsoil acidity**

Correcting sub soil acidity alleviates stress by allowing deep rooting access to water reserves. Most green manuring plant species are more susceptible to acid soil conditions than sugarcane. Even though sugarcane is acid tolerant, particularly the variety N12, acid soils are still yield limiting. Lime is the ideal product for correcting topsoil acidity, since it supplies Ca (calcitic lime) or Ca and Mg (dolomitic lime), and also increases soil pH. With increasing pH, aluminium toxicity in the topsoil is eliminated. Lime should be broadcast evenly several weeks before planting a green manure crop and thoroughly incorporated with at least two passes of a disc harrow, before ploughing to a depth of about 250 mm, to give it time to react with the soil.

To limit water stress in the cane crop, it is important to address subsoil acidity so that the cane roots can penetrate the subsoil and access deep water in times of drought. Lime is generally not very effective for the correction of subsoil acidity, since in soils with more than about 15% clay, lime incorporated into the topsoil is not very mobile in the short-term.

Gypsum, on the other hand, is more mobile in the soil than lime, and, with time and rainfall, it moves into subsoils where it reduces the toxic effects of aluminium and supplies much needed calcium for healthy root growth. Gypsum is also a valuable sulphur fertiliser; the crop requires about as much sulphur as phosphorus.

Gypsum will cause the displacement of Mg from the topsoil, particularly in sandy soils. Gypsum applications should be accompanied by applications of dolomitic lime in order to ensure adequate supplies of magnesium for crop growth.

Several suggestions have been made to explain how gypsum ameliorates Al toxicity:

- by decreasing the ratio of Al to Ca
- through the formation of non-toxic ionic pairs
- by self-liming, i.e. sulphate displacing hydroxide off soil surfaces into the soil solution
- by precipitation of basic aluminium hydroxy-sulphate minerals out of the soil solution by promoting increased root uptake of nitrate at depth, resulting in raised pH in the root zone.



Effect of acid saturation on cane yield. The Aluminium component of excessive acid saturation impairs root development, reduces yield and increases the likelihood of water stress and eldana damage. (N12 is particularly tolerant of acid conditions; other varieties – Nx – are less tolerant).

### When to soil sample

Since the incorporation of lime and gypsum is possible only prior to planting, soil samples should be taken well before the planting operation. This will allow sufficient time for the samples to be processed in the laboratory, and for amendments to be ordered. A useful strategy adopted by an increasing number of growers is to take soil samples after the penultimate harvest (i.e. at the commencement of growth of the last ratoon before the planned replanting).

### **Ion Pairing**

 $Al^{3+} + CaSO_4 \rightarrow AlSO_4^+ + Ca^{2+}$ toxic non-toxic – can be more easily leached

### **Self-liming Effect**

1) 60H-[Fe,Al]-OH + 6CaSO<sub>4</sub>  $\rightarrow$  3(HO-[Fe,Al]-SO<sub>4</sub>)<sub>2</sub>Ca<sup>2+</sup> + 3Ca(OH)<sub>2</sub>

2)  $2Al^{3+} + 3Ca(OH)_2 \rightarrow 2Al(OH)_3 + 3Ca^{2+}$ insoluble

### Formation of Basic Aluminium Hydroxy-Sulphates

 $3Al^{3+} + K^+ + CaSO_4 + 3H_2O \rightarrow KAl_3(OH)_6(SO_4)_2 + 3H^+ + Ca^{2+}$ insoluble in

pH range 4-5



When a nitrate ion is taken up a bicarbonate ion is exchanged in order to maintain charge balance

# Lime and gypsum on slopes

In order to optimise incorporation into the soil on steep slopes, lime and gypsum should be broadcast over the whole area immediately after the drawing of furrows (lime and gypsum applications must not be only in the furrow).

Furthermore, in minimum-till operations, it is advisable to prevent acidity problems from arising by top-dressing with low rates of lime during ratoons when soil tests indicate that acidity is on the increase. The top-dressed lime will, with water movement and the assistance of earthworms, gradually be moved into the soil.

### **Re-acidification**

Re-acidification with each ratoon is one of the causes of ratoon yield decline (along with compaction and stool damage caused by infield traffic, disease build-up, etc).

Current liming recommendations aim to reduce acid saturation to 20%. Further liming to less than 20% has a minimal effect on the yield of the plant crop, and on certain highly buffered clay soils it would be prohibitively expensive. However, it may be more viable on low clay eldana prone soils.

## Example: Calculation of 'per ratoon' liming requirement for limiting re-acidification:

ammonium sulphate requires 5 kg lime/kg N to neutralise acidity;

diammonium phosphate (DAP) requires 3.5 kg lime/kg N;

urea requires 2 kg lime/kg N; and

LAN requires 1.3 kg lime/kg N.

For a crop on a sandy soil yielding 80 tc/ha with an input of 160 kg N/ha as LAN, an approximate annual lime requirement is calculated as follows:

1.3 kg of lime x 160 kg N = 210 kg of lime (counters acidification caused by  $NH_4^+$  nitrification),

Plus removal of Ca and Mg in 80 tc/ha to the mill, equivalent to 330 kg of dolomitic lime based on average stalk Ca and Mg contents.

= 540 kg/ha/ratoon total lime

LAN: Dolomitic lime is added to the ammonium nitrate to stabilise it. At approximately 0.7 kg lime per kg N this reduces the acidifying effect on the soil and also adds small quantities of calcium and magnesium.



Re-acidification begins immediately in the plant crop and reduced yields can be expected in later ratoons. By liming to an acid saturation level below 20%, an increased number of high yielding ratoons could be attained.

### **Maintaining Si availability**

With soil re-acidification, acid saturation will increasingly limit the availability of silicon to later ratoons (see page 21 for the effect of acid saturation on extractable Si). Growers should consider maintenance liming by top-dressing with low rates of lime or silicate during ratoons, to restrict re-acidification and maintain silicon availability.

### Soil biological activity

Increasing soil biological activity promotes natural eldana control. Acid soil conditions impact negatively on soil biological activity. Evidence of this is retardation in the breakdown of surface applied organic matter (e.g. crop residues) on acid soils. In this context, it is noteworthy that most beneficial earthworm species appear to be sensitive to soil acidity, and liming frequently results in a rapid increase in earthworm populations. The best ways of improving soil biological activity are to make sure that your soils are treated for excessive acidity, that they are not compacted, and that they have enough organic matter. The addition of organic matter alleviates several eldana risk factors. It reduces soil bulk density by acting as a glue that helps provide structure to all the smaller particles; it helps prevent compaction; it increases water infiltration and retention, and it can lead to increased root growth. Organic matter increases soil biological activity and maintains the soil food web which includes predators of eldana.

### **Earthworms**

Earthworms can be regarded as a grower's best friend. Their presence is indicative of a healthy soil containing all the other components of the soil food web, including predators of eldana.

The burrowing of earthworms improves the physical properties of the soil, moving surface organic matter and allowing the movement of lime deeper into the soil, creating channels through which plant roots may more easily penetrate and creating habitats for other smaller organisms, including predators of eldana.

In addition to increasing soil porosity and aeration, their activity also improves soil drainage and water



A diverse range of life forms exist in a healthy soil. Soil organic matter is the storehouse for the energy and nutrients used to fuel the soil food web. Bacteria, fungi, and other soil dwellers transform and release nutrients from organic matter. Predaceous arthropods and nematodes are supported by the web and these prey on pests reducing their impact. (Adapted and re-drawn from http://www.nrcs.usda.gov/wps/ portal/nrcs/detailfull/soils/health/biology.) penetration while eliminating hardpan conditions. Secretions in earthworm intestines glue soil particles together into larger aggregates which aid in erosion control.

Most earthworm species are highly sensitive to soil acidity, and tend to thrive in a calcium rich environment created by liming. Keeping the soil surface covered with residues is also crucial for the proliferation of earthworms. Thus cool burns to ensure large amounts of remaining tops, or better still, green cane harvesting, are desired practices.

### **Organic matter inputs**

### **Green manuring**

Green manuring can contribute during a re-plant as an organic matter input that limits soil re-compaction, improves water infiltration and retention and supports the soil food-web. It also provides an important break in the pest and disease spectrum which builds up over the course of a sugarcane cycle.

Green manures contribute towards the establishment of a healthy plant crop, setting up a field for a healthy and vigorous ratoon life. The various green manure species differ widely in their tolerance to soil acidity, some being highly sensitive to acid soil conditions, while others such as cowpeas are more tolerant. Nevertheless, soil acidity has been shown to limit the growth of all species, including sugarcane. It is recommended that soil acidity be corrected in advance of green manuring, in order to obtain as high a biomass as possible from a green manure, and to prepare for the following cane crop.

Recent research has shown that for most commonly used green manure crop species and fallow durations, including a long (10 month) fallow, green manures economically outperform a weed fallow or plough-out/re-plant without any fallow. When viewed over



A large number of earthworms is a good indicator of a healthy soil.







A lush crop of black oats grown during winter 2011 at THS estates on the North Coast. Black oats are good at catching and holding nutrients to be released at a later stage for sugarcane. They also reduce numbers of harmful nematodes, and release chemicals which help to suppress creeping grasses. These chemicals are specific as to which other plants they affect, and do not affect cane germination negatively. the entire lifespan of a crop, it is more profitable to grow a green manure than to have a weed fallow, or to have no fallow at all. At worst, green manures do not lose growers money, even with a long fallow. It is therefore possible to get all the agronomic benefits of green manuring at minimal cost.

Refer to SASRI's Booklet: Green Manuring.



Bulk density of a Fernwood and a Shortlands soil with and without organic amendments (FYM = farmyard manure; Control = no organic amendments).

### **Composted material**

The input of composts, farmyard manures and filtercake or crop residues following ripping operations also limits re-compaction and supports the soil food-web.

In an experiment conducted on two different soils, the application of 40 t/ha filtercake and 40 ton/ha farmyard manure decreased the bulk density of a Fernwood soil by 8% and 17% respectively and by 5% and 7% respectively for a Shortlands soil. These data highlight the potential benefits of organic matter additions to reduce the eldana risk associated with certain soils. A reduction in bulk density indicates a less compacted soil, allowing more pore space for air and water and the movement of life in the soil, such as roots, earthworms and predators of eldana.

Management practices which promote the conservation and accumulation of organic matter:

- Conservation tillage practices (reduced tillage).
- Use of green manure crops in crop rotations (e.g. sunn hemp, black oats).
- Application of farmyard manures, chicken litter, pig slurry and/or composts.
- Application of mill wastes (e.g. CMS, filtercake, fly ash).
- Optimal mineral fertilisation (in particular lime and nitrogen).
- Preserving crop residues (e.g. green cane harvesting instead of burning) and keeping the soil covered.



### Vertical mulching

Vertical mulching is the incorporation of an ameliorant through a vertical slot in the soil. It is an alternative technique of adding organic matter to the soil. Soils that will particularly benefit from this practice are from the grey group and duplex soils derived from Dwyka tillite, Natal Group Sandstone (Ordinary) and Beaufort and Middle Ecca (Vryheid) sediments (Sterkspruit, Wasbank, Mispah, Westleigh, Kroonstad, Katspruit, Glenrosa, Estcourt, Milkwood, Longlands, Valsrivier, Swartland and Cartref). The majority of these soil forms are associated with increased eldana risk.



Factors which limit rainfall efficiency in many of these soils include the following: low water intake rates, low total available water capacity, surface crusting and high erodibility, low organic matter content, slow internal drainage and poor aeration at depth, a strong tendency to compact and a potential for saline and sodic conditions to develop when irrigation is practised. About 60% of the soils under sugarcane fall within this classification.

Composted filtercake is a very effective conditioner for hardsetting duplex and shallow grey soils. Trials have shown that vertical mulching with filtercake to a depth of about 450 mm in the planting row, results in significantly higher yields and an increased number of higher yielding ratoon crops.

In a trial on a Longlands form soil where filtercake at 100 t/ha was applied once only, before planting and never again thereafter, yield responses to vertical mulching were still being obtained nine years later. The cumulative response after a plant and eight ratoon crops amounted to 98 tc/ ha. Other improvements included increased water infiltration rate, lower bulk density, improved water holding capacity, increased rooting depth and improved N and P use. The effects of buried filtercake last considerably longer than filtercake incorporated into the soil surface.

It is difficult to give guidelines on the economics of vertical mulching, as many factors affect the cost. These include the type of ameliorant to be used, the availability of the ameliorant, the amount to be applied, transportation and the equipment to be used. Estimates of the costs and benefits of vertical mulching with 100 t/ha of filtercake on a farm 20 km from the mill.

Transportation at R1.50 /t/km	R 3 000/ha
Tractor and implement	R 1 500/ha
	R 4 500/ha
Expected additional response after nine crops	11.8 tRV/ha
Gross income at R3300 /tRV	R 38 940/ha
Net income	R 34 440/ha
Net income per annum	R 3827/ha
Break-even period	about two years.



This type of implement used for vertical mulching has a ripper tine with vertical 'wings' attached. The implement shown is fitted with crumble busters which may help to breakdown larger soil clods and/or assist with surface residue management. The implement is pulled through the soil to a depth nearing the top part of the wings (about 400 mm) to allow the organic ameliorant to fall into the slot kept open by the wings. The ameliorant, from the hopper, is dispensed through a guide pipe of about 200 mm diameter directly into the open slot behind the tine.

For further information see SASRI Information Sheet 4.9 Vertical Mulching.

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### **Improving silicon nutrition**

Silicon is a major component of sand, silt and clay minerals. Because of this abundance, it typically has not been considered as a limiting factor in soil fertility. However, much of this Si is not readily available to the plant. Silica plays multiple roles in grass species, alleviating both abiotic and biotic stresses, such as water deficit, extreme high and low temperatures, heavy metal toxicity, salinity, plant disease and insect pest attack. In particular Si has been shown to increase yield and to decrease rust severity and eldana damage in sugarcane. It has also been found to be associated with aphid resistance.

With the exception of K, sugarcane is known to take up more Si than any other mineral nutrient. Much of the Si ends up at the mill and is not recycled back to the field. For this reason, soils can become depleted of Si.

Silicon is transported from the roots to the shoots in the xylem along with the transpiration stream. Silicon is deposited in the leaf epidermal cells, xylem vessels, cell walls, and cuticle following evaporation of transpiration water. Silicon is deposited as a 2.5 mm layer in the space immediately beneath the thin (0.1 mm) cuticle layer, forming a cuticle–Si double layer in leaf blades.

The accumulation of silicon in the epidermal cells and cell walls of sugarcane leaves results in the development of more erect leaf blades whilst the thicker, stronger cuticle layer limits non-stomatal water loss. Reduced transpiration and water loss through the cuticle layer minimises water usage, especially during hot, dry conditions.

Trial results show that, where silicon has been applied to ameliorate deficient conditions, damage caused by eldana can be greatly reduced. This is due to increased drought resistance and a stalk rind that is more difficult for larvae to penetrate. A toughened rind delays larval penetration which renders larvae more susceptible to desiccation, insecticide application and/or predation.





Eldana has been shown to be negatively affected by plant silica. These effects include abrasion of mouth parts (top – unabraded larval mandibles; bottom – mandibles of a larva fed on high Si plant material).

### Extractable soil silicon status and suggested rates of application.

Si mg/L in soil	< 5	5 - 10	10 - 15	> 15
Si status	Very deficient	Deficient	Marginal	Satisfactory
Si required per crop (kg/ha)	150	100	50	nil

Note. CalmaSil is approximately 10% Si. Multiply kg/ha x 10 for calmasil requirement (for further information see http://www.pbd-lime. co.za/calmasil.htm).

### **Silicon application**

Apply Si to soil that has already been corrected for acid saturation. Applying a silicon carrier to a soil where low pH allows a lot of aluminium to be present in solution, will result in the loss of plant available silicon from the carrier. The formation of hydroxy-aluminosilicates, which are non-toxic to plants, is thought to be at least partly responsible for the amelioration of Al toxicity by Si. However, much of the applied Si becomes unavailable for plant uptake as follows:

$$4\text{CaSiO}_{3} + 4\text{Al}^{3+} + 6\text{H}_{2}\text{O} \rightarrow$$
  
$$2\text{Al}_{2}\text{Si}_{2}\text{O}_{5}(\text{OH})_{4} + 4\text{Ca}^{2+} + 4\text{H}^{+}$$
  
unavailable silicon

To avoid this, topsoil acid saturation should be corrected (see effect of acid saturation on extractable Si - page 21) by conventional liming prior to green manuring. A soil analysis following green manuring, when the soil has had enough time to react and stabilise, can be used to determine whether extractable Si in the corrected soil has become satisfactory or not. If silicon remains marginal or deficient, then the use of an amendment is recommended. For example, if soil extractable Si is found to be marginal then 50 kg/ha Si (500 kg/ha calmasil) would be required per crop.

Ideally silicon deficiency is best corrected at crop establishment by incorporating the silicate source several weeks before planting. The silicate source should be spread evenly and mixed in well with at least two passes of a disc harrow before ploughing to a depth of about 250 mm.

For full value, in a ratoon or minimum tillage situation, the silicate carrier should be applied as a top-dressing to facilitate maintenance of soil pH, Si availability, Ca and Mg. It should be incorporated carefully in between rows using a shallow ripping operation or by hand hoeing. When applied in larger quantities without incorporation, it can form a hard crust.



# Varietal resistance

Each variety has a different susceptibility rating to eldana. Plant stress such as nematode infestation also plays a vital role in the resistance exhibited by the cane. In this chapter, varietal resistance, the use of quality seedcane and new varietal developments are discussed. rowing resistant varieties is the most cost effective component of IPM systems for managing pests and diseases. SASRI plant breeders take into consideration several pests and pathogens when making the crosses and selections that lead to the release of superior varieties.

An eldana resistant variety defends itself using multiple mechanisms. Some resistance mechanisms are constitutively expressed (pre-formed), as either physical or chemical barriers, while other resistance mechanisms may only be induced after attack through a network of signal transductions and rapid activation of gene expression.

Furthermore, defence can be categorised as carbon or nitrogen-based. For example, constitutive resistance to eldana is known to be in part due to lignin, tannin and fibre contents (carbon-based) which contribute towards rind hardness and indigestibility. Additionally, as part of a resistant physiological reaction, the contents of these can increase around borings in response to eldana feeding.

Nitrogen-based defence employs various resistance proteins and nitrogen containing secondary metabolites. It occurs primarily, but not exclusively, in immature stalks and tops which contain more nitrogen than mature stalk parts. Because the upper parts of the cane plant are less mature than lower parts, the physiological response to damage involving both carbon and nitrogen based defence appears more potent in the upper parts, at least in resistant varieties. Eldana is found less frequently in the upper stalk parts despite lower fibre and silicon contents, and a softer rind.

A susceptible variety fails to defend itself either in the lower or upper plant parts. In this case plant nitrogen is freely used as a dietary resource by eldana. Carbon



A simplified view of the major pathways leading to plant defence. (Adapted from "Secondary metabolites and plant defense," in Plant Physiology 5th edition, L Taiz & E Zeiger [2010] Sinauer Associates).

present as sugars is far in excess of nitrogen, present as protein and free amino acids, in terms of the dietary requirements of eldana. Thus eldana survival and growth is limited by stalk nitrogen content.

Since the young immature stalk of a susceptible variety is poorly defended, eldana can infest at an earlier age, as soon as a dead leaf for egg-laying appears. This is hastened by drought stress which can also cause the accumulation of excess free amino acids in the stalk. Devastating infestations in susceptible varieties under drought conditions manifest themselves through earlier infestation, shorter generation times and increased larval survival rates.

### **Indirect defence**

Plants can use natural enemies of insect herbivores as bodyguards. Less than 25 years ago, a new type of defence mechanism termed indirect defence was first described in maize. Indirect defence has since been reported in many different plant species that release complex bouquets of volatiles, known as herbivore induced plant volatiles or SOS volatiles, into the air from their green vegetative tissues following attack by insect herbivores. Predators and parasitoids of insect herbivores respond to SOS volatile releases which act as long range attractants.

In sugarcane, damage to green tissues caused by topborers (e.g. *Sesamia calamistis* and *Chilo sacchariphagus*) elicits the long range attraction of natural enemies (provided that natural enemies are present in the habitat – see section on Habitat Management). Once in the vicinity of borers, parasitoids orientate themselves by detecting short range volatile attractants emanating from frass. Eldana damages the green tissues of its wild hosts (e.g. the umbels of papyrus), therefore parasitoids are successfully able to locate larvae. However, in sugarcane, eldana damage is primarily in the lower stalk with damage to green tissues being relatively rare.

By boring the lower stalk it is possible that eldana avoids eliciting the emission of long-range attractive SOS volatiles and so escapes its natural enemies. However, parasitoids have been shown to still be able to find eldana larvae when placed in close proximity, probably using only short-range cues emanating from frass.

Indirect defence against eldana in sugarcane may be compromised due to a number of reasons:

- no induction of long range attractant SOS volatiles (except when young cane or tops are damaged) to,
- negative effects of 12 month clear cutting (which would remove parasitoids and hosts alike, over large areas),
- negative effects of burning on predators and parasitoids, and
- the absence of a reservoir of parasitoids (when natural hosts of eldana are not present in wetlands and watercourses).

Another possibility is that by boring the lower stalk eldana avoids more effective defence mechanisms in immature stalk, to which it is not (yet) adapted. Habitat management seeks to reduce adaptation to sugarcane defences by providing natural hosts which are defended differently.

The regional research stations used in SASRI's plant breeding programme. Of particular interest, in terms of breeding for eldana resistance, is the the coastal long cycle (3a) programme which has been running on the Gingindlovu research station since 1998.

	Research station	Environmental conditions represented	Representative soil forms
1	Pongola	Northern irrigated areas	Hutton High base status
2	Empangeni	Coastal high potential	Hutton, Shortlands Low base status
3a	Gingindlovu (Long cycle)	Coastal average potential (18 months)	Westleigh
3b	Gingindlovu (Short cycle)	Coastal average potential (12-15 months)	Glenrosa
4	Kearsney	Coastal hinterland	Cartref
5	Bruyns Hill	Midlands (Humic soils)	Inanda
6	Glenside	Midlands (Sandy soils)	Cartref

### New variety development

The successful production of sugarcane in South Africa is attributed to the continuous supply of locally developed, high yielding sugarcane cultivars by SASRI. Modern sugarcane cultivars are complex hybrids of *Saccharum officinarum*, *S. barberi*, *S. sinense* and *S. spontaneum*. Such hybrids are produced in South Africa through the artificial stimulation of flowering in a controlled environment.

Parent genotypes for each region of the industry are chosen using a number of criteria such as high sucrose yield, and desirable agronomic traits; good ratooning, disease resistance and resistance to eldana.

The selection programme starts with seedlings raised in the glasshouse at Mount Edgecombe. About 250 000 seedlings are raised from true seed each year, 50 000 for each region. Each regional research station represents the general conditions of that region and is characterised by a unique selection programme lasting between 12 and 15 years from seedlings to release. The selection stages comprise evaluations at the single plant level, through to fully replicated cultivar trials in later stages, when sufficient clonally propagated material has accumulated.

The research stations most suitable for targeting eldana resistance (Gingindlovu and Kearsney) have been in operation since 1998. Two genotypes (01G1662 and 02K0663) gazetted for release in 2014/15 were at the single line stage in 2001 and 2002 at the Gingindlovu and Kearsney research stations respectively. These new varieties (N58 and N59) have improved resistance to eldana.

### Variety selection tool

SASRI has developed V-Choice, a web-based variety selection tool to assist growers with variety choice for their specific growing conditions. The system assists with variety selection by creating a shortlist of appropriate varieties for specific conditions, and eliminates the need to sift through each and every SASRI Variety Information Sheet in order to choose correctly.

### Low eldana risk is correlated with a degree of resistance to nematodes.

	Rainfed	Irrigated	Nematodes
	N17	N17	susceptible
	N21		very susceptible
		N25	intermediate
Low risk of economically	N33		intermediate
damaging infestations,	N39		intermediate
provided cane is not	N41	N41	intermediate
stressed.	N42		intermediate
	N47		
May be aged or carried over	N51		susceptible
if appropriate.	N52		
		N53	
	N55		
	N56		
		N57	
	N58		
	N59		
	N12		intermediate
		CP66-1043	
Moderate risk of	N19	N19	verv susceptible
economically		N22	
damaging infestations,		N23	intermediate
provided cane is		N24	very susceptible
not stressed.	N31		intermediate
	N37		susceptible
	N40	N40	susceptible
Carry-over in coastal region		N43	susceptible
with caution.	N45		
	N48		
		N49	intermediate
	N50		
	N54		
	NCo376		susceptible
High risk of economically		N14	resistant
damaging infestations.	N16		susceptible
		N26	very susceptible
Do not age or carry over.	N27		very susceptible
		N30	very susceptible
	N35		susceptible
	N36	N36	susceptible
		N46	susceptible

Note: Varieties in each eldana risk category are listed in order of year of release.

The system is made up of a six-step process whereby users choose different options from drop-down boxes at each step. Users are asked to specify:

- their production region (mill supply area),
- irrigation regime (dryland/supplemental/full irrigation),
- planned age of harvesting (10-15, 15-18, 18+ months),
- planned time of harvesting (early, mid, late season),
- general yield potential conditions of the field (low, moderate, high), and
- perceived eldana threat: Make a situation/field specific assessment as to threat level (no threat, moderate threat, high threat) taking the following into consideration:-

- 1) historical regional and on-farm data
- 2) soil clay content
- soil total available water (as influenced by subsoil acidity etc)
- 4) nematode community pathogenicity
- 5) soil bulk density
- 6) organic matter content
- 7) extractable soil silicon content.

Perceived eldana threat could be adjusted lower if any or all of risk factors 3 – 7 are alleviated. This would serve to increase variety diversity on the farm by increasing the number of varieties selected.

As each choice is made, the system eliminates varieties from the list and only carries forward varieties that conform to the selections. The variety list carried forward at each stage becomes smaller and smaller until a final variety shortlist is left at the end. The grower can then click on any of the varieties in the shortlist to see the detailed SASRI Information Sheet.

It is important to understand that the system makes a 'rigid' objective judgment based purely on available data. Before making any final choices, growers are encouraged to consult their Extension Specialist, who will use their experience and knowledge to verify the final selections.



Available on the SASRI website: www.sugar.org.za/sasri.

### Benefits of a diverse variety disposition

The area planted to a single variety in individual mill areas has been known to exceed 70% (and even higher on an individual farm basis). For example, the dominance of N12 was linked to this variety's perceived resistance to drought stress and damage caused by eldana, and changing to a wider spread of niche-specific varieties was considered risky.

It has been demonstrated that diverse variety dispositions can produce higher economic returns compared to dispositions dominated by single varieties. This phenomenon is due to the greater exploitation of growing conditions by niche varieties, as opposed to the generally stable performance of a less productive variety over a wide range of conditions. Niche varieties are adapted to specific soil types and harvest ages. Results from trials have demonstrated that such varieties produced higher RV yields than N12 when specific regional conditions, harvest age and soil conditions are taken into consideration.

Dominance by a single variety poses a huge risk to production in the event of that variety succumbing to any new pest or disease. In recent years the industry has been challenged by maize streak virus (MSV), thrips, tawny rust and the yellow sugarcane aphid. Different varieties show varying levels of susceptibility to these pests and diseases, highlighting the need to increase variety diversification.



### Seedcane

The benefit of good quality seedcane produced in a well-managed nursery is varietal purity and reduced transmission of pests and diseases. Seedcane taken from commercial fields is often contaminated with offtype varieties, including unwanted varieties infected with disease. The production of seedcane under nursery conditions allows for regular inspections and effective eradication (roguing) of unwanted stools. Good management of this nursery consequently provides a controlled environment for rapid bulking.

Unfortunately due to the eldana epiphytotic there are instances where seedcane can become infested with eldana. Ideally, sugarcane should not be used for seed if eldana is present. If the use of damaged seedcane is unavoidable, follow the procedure below:

- Strip the dead leaf material off the stalks. Attempt to select stalks that show no sign of borer attack (par-ticularly if a hot water tank is not available).
- Treat the seedcane in a hot water tank at 50°C for 30 minutes. This will kill any larvae, eggs or pupae present.
- Since the seedcane is to some extent damaged, with fungal colonisation of borings by *Fusarium* species beneficial to eldana, treatment with a fungicide becomes essential. Any *Fusarium* present can colonise the new plants as an endophyte, increasing susceptibility to eldana. The following available fungicides are registered for 5 minute cold soaks after hot water treatment: Benlate (7.5 g per 10 L water) and Panoctine 40% solution (20 ml in 10 L water).

### In the pipeline

In a recent trial the lowest level of eldana damage was recorded in a hot-water plus fungicide treatment (azoxystrobin + fludioxonil + mefenoxam) which is currently being developed as a seedcane treatment. This result is supported by observations made several years ago where the fungicide Eria® (difenoconazole + carbendazim) reduced eldana numbers by up to 50% when used as a seedcane treatment. Possible mechanisms underlying this effect include the exclusion of the *Fusari-um* fungus which is beneficial to eldana from colonising the plant, and the alleviation of plant stress through beneficial plant physiological effects of some fungicide active ingredients.



### Nematode control

Controlling nematodes decreases susceptibility to water stress and increases yield.

Damage to the shoot-roots of sugarcane by ectoparasitic nematodes affects the uptake of water thus increasing the likelihood of water stress which increases the eldana risk. It is therefore not surprising that there is a correlation between resistance to nematodes and resistance to eldana.

### Soil sampling for nematodes

Soil sampling is essential to ascertain whether or not a pathogenic nematode community is present.

The following fields should be sampled for nematodes:

- Fields with previous history of nematode damage.
- Sandy soils (<20% clay).
- Where a continued or dramatic yield decrease has been noticed.
- Fields to be replanted following a green manure.

If a nematode problem is present in the field it should also be addressed within an IPM system. A suitable green manure can drastically reduce the population of potentially damaging plant parasitic nematodes before planting (e.g. oats decreases numbers of *Meloidogyne*; see the SASRI Green Manuring booklet for other crops that can be used).

The application of organic amendments at planting (e.g. filtercake and farm manures) can also reduce nematode numbers if they encase the sett forming a physical barrier against the nematodes (see diagram above).

### **Economic benefit**

Despite the problems associated with using nematicides, they represent an important tactic in both nematode and eldana IPM systems. By applying a nematicide at planting and to each of the following ratoon crops, growers can considerably increase cane yield.

Over and above the direct economic benefits from using nematicides, other additional (often unseen) benefits include:

- quicker cane canopy leading to less weed control (reduced costs),
- more high-yielding ratoons (reduced annualised re-plant costs),
- reduced eldana damage, and
- some nematicides (e.g. Vydate) have been shown to reduce thrips and aphid infestations.



Use of an organic matter barrier (filtercake ~ 100t/ha) to protect early root development. (In trials this practice resulted in up to 23 tc/ha increase in the plant crop and 16 tc/ha increase in 1R).

It pays to control nematodes: Increased profitability through the use of a nematicide on a sandy soil (10% clay).

Cost of nematicide and application /ha *	R 2 700
RV price (per ton)	R 3 300
Yield response example (20% ~ from 66t/ha to 79t/ha) tc/ha increase	13
Typical RV%	12%
RV increase (tons/ha)	1.56
Gross return (Rand/ha)	R 5 148
Less the cost of nematicide treatment	-R 2 700
Nett return (Rand/ha) **	R 2 448

\*Using a wheelbarrow applicator, assuming that a labourer can treat one hectare per day at a rate of 30 kg/ha with Vydate.

\*\*Nett returns will be higher in lower clay content soils and decline close to zero at 20% clay due to reduced yield response to nematicide with increasing clay content (see graph below).



### % Soil clay content

Percentage yield response to nematicide in soils of different clay contents. For soils approaching 20% clay it is advisable to have the nematode community pathogenicity assessed, or to perform on-farm observation trials in order to compare nematicide treatment with no treatment.



Successive ratoon crops

An increased number of higher yielding ratoons can be obtained through the use of a nematicide on nematode infested sandy soils.



Five month old plant cane grown on a sandy soil untreated (left) and treated (right) with a new generation nematicide undergoing registration trials.



# Crop protection and nutrition

Plants with an optimal nutritional status have the highest resistance (tolerance) to pests and diseases. Susceptibility increases as nutrient concentrations deviate from the optimal.

# Crop protection and nutrition

# Control of pests and diseases in young cane

ollowing a green manure and the use of eldana-free seedcane, a new eldana infestation in plant cane can only come from outside of the field in the form of migrating moths. These have been shown to cause infestations distributed more or less evenly across a plant cane field. More in keeping with the mating biology of eldana, the infestation settles down into a spatially stable patchwork of clumps in ratoons.

The evenness of the plant cane infestation is thought to be due to the effect of tillage. This disrupts localised colonies of predaceous insects (e.g. ants) and increases nitrogen supply due to increased N-mineralisation. The latter makes the fine control of N supply most difficult in the plant crop, particularly in high organic matter soils. Severe eldana infestations have been linked with excessive nitrogen supply, especially when drought stress occurs.

It is well known that damage due to thrips and rust is more pronounced in plant cane than in ratoons, and this has been linked to higher leaf N content often found in plant cane. Both thrips and rust delay canopy closure which leads to increased weed competition, and the evaporation of water from the soil due to surface heating; increasing eldana risk.

It is therefore important that thrips and rust are controlled and that plant stress and excessive N-fertilisation are avoided in the plant crop.

### **Thrips control**

For the control of thrips, the insecticide Bandit<sup>®</sup> (imidacloprid, a neonicotinoid) is most effective when applied in the furrow at planting at a rate of 2 L/ha. Bandit<sup>®</sup> is registered for ground application in the furrow only.

Independent of insecticidal function, this class of insecticide has beneficial plant physiological effects. Neonicotinoids are known to enhance plant vigour and stress tolerance. They do this by stimulating a plant hormone known for its role in plant defence against pathogens such as rusts, and which can also improve crop stress responses especially to heat, which commonly accompanies drought.



Thrips damage to young sugarcane leaves.

### Yellow Sugarcane Aphid (YSA)

During 2013 a new insect pest was discovered attacking sugarcane in South Africa. The yellow sugarcane aphid (*Sipha flava*) originates in North and Central America and is a relative newcomer to Africa, first being recorded in Morocco in 2006.

YSA has a wide host range among the grasses including Panicum, Cynodon, Paspalum, Pennisetum, wheat, maize and oats. Melinis grass is not attacked.

Reports from North American literature indicate that if two leaves are damaged when the sugarcane crop is three months old then there may be around 5% lower final yield. However, damage to more leaves than that may result in as much as 20% yield loss. Insecticides are likely to provide effective YSA control should natural enemies or weather fail to keep populations in check. Bandit<sup>®</sup> and Allice<sup>®</sup> applied for thrips control have been shown to control YSA to some extent in plant and ratoon crops respectively.

A new class of insecticide is being tested which has a different mode of action from Bandit<sup>®</sup> and Allice<sup>®</sup>. It inhibits the feeding of aphids which then starve. This IPM friendly insecticide does not affect natural enemies which continue to prey upon treated aphids, so building up their own numbers.

Yield increases in plant cane after the application of Bandit<sup>®</sup> often approach 30% and growers are encouraged to take advantage of this chemistry for growth enhancement, stress resistance and thrips control in plant cane. The advantage is cumulative since higher yields in ratoons are correlated with healthy high yielding plant cane crops. Allice<sup>®</sup> is registered for application to the canopy in ratoon crops for thrips control.

### **Rust control**

For the control of rusts the fungicides Abacus<sup>®</sup> and Amistar<sup>®</sup>Xtra (both containing members of the strobilurin and triazole fungicide classes) are recommended. Two applications give the best results. The first application is applied at the 6 leaf stage, preventively, or at the first sign of rust infection. The second application is made one month after the first application.

In common with neonicotinoid insecticides, strobilurin fungicides have beneficial plant physiological effects. Crops treated with strobilurins can yield more than untreated ones, especially when there is a shortage



YSA prefers to feed on the lower leaf surface and along the mid-vein. With feeding, the lowest two or more leaves turn yellow then red/purple. This appears superficially like drought stress or herbicide damage. Extensive damage may kill young plants and both young and older cane is attacked. Aphid numbers quickly build to numbers too large to count for sampling purposes.



Orange rust is currently spreading in Africa. Note: tawny rust has recently emerged in South Africa. Please look out for unusual symptoms.

of water. Treated crops have been shown to be able to utilise nitrogen especially well, partly as a result of improved root growth. The increased nitrogen assimilation leads to an inhibition of ethylene production under transient stressful conditions. Consequently fewer leaves are unnecessarily sacrificed, allowing the plant to accelerate recovery growth when the transient stress level is reduced.

A series of trials were carried out on a farm using neonicotinoid and strobilurin/triazole chemistries to control thrips and rust respectively. The results are tabulated below. Trial 1 was conducted during the severe drought of 2010. Treatment with fungicide resulted in a 94% increase in yield, more than covering the cost incurred. It can be seen that with increasing untreated yields (trials 1 through 5), percentage yield increases due to treatment become smaller but remain profitable. In trial 5, despite very little rust being evident, a 9% yield increase was still achieved. Yield increases are due to combined beneficial plant physiological effects with pest and disease control.

It is not yet known whether varietal differences in physiological response to these chemistries occur in sugarcane. Nevertheless, varieties that may particularly benefit from combined neonicotinoid strobilurin/triazole treatments include N27, N31 and N41, since these are of intermediate resistance to brown rust and have been noted to harbour higher than average thrips numbers during summer. Other rust intermediate varieties could also benefit (N16, N35, N37, N39, N42, N50 and N51 for brown rust; N12, N16, N25, N41, N46, N49 and N57 for tawny rust).

### **Observation Trials**

On-farm observation trials can demonstrate the profitability of any new practice under local conditions.

Whilst there is no substitute for the scientifically rigorous trials that SASRI conducts in investigating variety and treatment combinations across stress environments, the potential for increasing profits through the use of these registered chemistries already exists. An Extension Specialist can provide the proper guidelines for easy-to-implement on-farm observation trials.

Some basic guidelines are:

- 1. Choose a place in a field where the soil and cane growth is known to be uniform.
- Keep it simple; compare a maximum of three treatments i.e. your standard treatment plus two variations (a control, or standard treatment, is vital in order to measure any improvements over standard practice).
- 4. Repeat treatments at least three times.
- 5. Start the trial at least 5 m inside the field to overcome any end effects on the cane growth.
- 6. Each 'plot' should be at least five rows wide and a minimum of 10 m long.
- 7. Distinguish your treated and untreated rows with some visible marking e.g. wooden pegs. A rough sketch of the map of the trial will also help.
- 8. Apply all the treatments on the same day.
- 9. Explain to your staff where the field is and what special precautions to take, if any.
- 10.Monitor the trial for visible differences in crop vigour, colour, and stalk height and numbers.

Trial	Chemistry	Untreated yield tc/ha	Treated yield tc/ha	% Yield increase	Value of tc/ ha increase R/haª	Cost of application R/ha	Additional profit R/ha
1	<sup>b</sup> Strobilurin/triazole	11	21	94	3960	1500	2460
2	Strobilurin/triazole	21	34	62	5148	1500	3648
3	°Neonicotinoid	27	35	30	3168	450	2718
4	Neonicotinoid	39	43	11	1584	450	1134
5	Strobilurin/triazole	95	103	9	3168	1500	1668

## Results from trials (1 to 5) where neonicotinoid and strobilurin/triazole chemistries were used to control thrips and rust respectively.

a) Based on the 2014 RV price of R3300 per ton and assuming 12%RV. b) Fungicide 1.6L/ha, two aerial applications to canopy, 28 days apart, total cost = R1500/ha. c) Insecticide, one knapsack application to furrow; 1 man-day/ha @ R150/day plus cost of product = R450/ha.

### Nitrogen management

Nitrogen (N) management of plant cane is critically important. Prior to 2011, FAS nitrogen recommendations were based on soil nitrogen mineralisation potential as provided in a soil test (N mineralisation Categories I to 4). In many instances, N application rates would be in excess of optimal rates because yield potential was not taken into consideration. For example, a blanket recommendation of 160 kg N/ha for category I soils would be excessive if the soil was shallow and yields in the region of only 50 t/ha were the norm. In a deeper category I soil, 160 kg N/ha would be more likely to be optimal, given normal rainfall.

To counteract over-application it was previously recommended that the FAS nitrogen rates be reduced by 20 to 30 kg N/ha where eldana was a concern, e.g. on shallow soils or where rainfall was comparatively low.

Since 2011, FAS has been recommending N based on mineralisation category combined with expected yield (for a particular field, the yield estimate is supplied by the grower) and expected residual N from green manures. The FAS recommended rate is optimal given the yield target for a particular field.

Since the estimate of expected yield should already take eldana risk into account, there is no longer a need to reduce applied N from the recommended level. Recent research has shown that to do so has an insignificant effect on eldana damage, and in fact could lead to yield reduction by up to 15 tc/ha.

### Green manures and nitrogen

Soaring fertiliser prices are prompting growers to look more carefully at their nutrient sources. Legume green manures 'fix' nitrogen directly from the atmosphere. When these plants decompose, much of this N becomes available to the subsequent cane crop. Nitrogen fertiliser can thus be reduced when this biological N is taken into account.

The amount of N available from a legume depends on the species grown, the biomass produced and the percentage of N found in the plant tissues. Not all the N fixed by legumes becomes available to the first cane crop; on average, around 40 - 60% of the total legume N is available.

Where green manure type and yield data were not supplied to FAS with your soil sample, use the table on page 62 as a guide to the amount of N that can be saved



It is not necessary to reduce N application rates below those recommended by FAS. Since 2011, recommendations have taken into account fieldspecific expected yield which should already reflect eldana risk factors (TAW, etc). Remember that for every 2 kg N/ha reduction below the recommendation, upwards of 1 tc/ha can be lost.

after growing these commonly-used green manure crops. Cut down by up to the amount assumed available in the first season (column 4).

Since release of the N from green manures is not immediate, some fertiliser N (typically 20 - 50 kg/ha N) should be applied soon after planting the cane to ensure continuous N supply. Plant N supply should thereafter be monitored by leaf sampling.

### Lime and calmasil applications

Eldana prone sandy soils have low buffering capacity making them vulnerable to relatively large initial pH increases after liming. This in turn can dramatically reduce the efficiency of surface-applied urea through ammonia volatilisation, especially in single applications, banded on the row. Losses of urea-N on such soils can exceed 50%. Average nitrogen availability of various green manure crops.

Сгор	Dry matter yield tons/ha	% N	N availability kg/ha
Sunn Hemp	2 m tall ~ 9 t/ha	2.5	Total N = 225 kg/ha; assume 110 kg/ha avail- able in the first season.
	1½ m tall ~ 4 - 6 t/ha	2.5	Total N = 100-150 kg/ha; assume 50-75 kg/ ha available in the first season.
Cow Peas	60 cm high ~ 1-3 t/ha	2.2	Total N = 22-66 kg/ha; assume 10-30kg/ha avail- able in the first season.
CoulDooro	Dryland 3-4 t/ha	2-2.5	Total N = 60-100 kg/ha; assume 30-50 kg/ha available in the first season.
Soy Beans	Irrigated max. 10 t/ha	2-3	Total N = 200-300 kg/ha; assume 100-150 kg/ha available in the first season.
Velvet Beans	~ 7-10 t/ha	2.3	Total N = 161-230 kg/ha; assume 80-115 kg/ ha available in the first season.
Oats (non-legume)	~ 1-5 t/ha (35 cm high ~ 1½ t/ha) (good N catch crop -forages N at depth)	1.6	Total N = 16-80 kg/ha; assume 5-25 kg/ha available in the first season. Being a non- legume the C:N ratio is higher and N may be more slowly available.

These same soils are also prone to other important N fertiliser loss mechanisms such as leaching and denitrification. This implies that overall N fertiliser use efficiency is low on such soils, but that urea will be worst affected because it alone undergoes significant volatilisation losses on acid soils, even prior to liming.

Liming induced mineralisation of N from organic matter may only be of a temporary nature, but it is a significant factor contributing to luxury uptake of N by plant cane grown on, for example, humic soils in the Midlands. Although many of these soils have several properties which suggest a low eldana risk (high clay content, high organic matter content and high TAW), high levels of N mineralisation following liming poses a risk.

# Nitrogen management following a drought

Where yields have been seriously affected by drought there may be a significant amount of residual nitrogen in the soil from the previous years' application. Because it is difficult to determine exactly how much is present, the best approach is to split the next crops' N requirement, initially applying 50%. This can be followed by leaf analysis in order to determine the amount required, if any, for the second

#### FAS thresholds for the soil N volatilisation index.

N volatilisation loss rating	Guidelines for fertiliser use
< 5% Soil pH < 7	Urea may be applied without constraints (follow best management practice).
< 5% Soil pH ≥7	Alternative N sources should be consid- ered due to high pH.
5 - 10%	An alternative N source to urea is pre- ferred.
> 10%	Urea should not be used. Alternative N sources should be considered due to high volatilisation potential.

Note: Urea should not be used when green cane harvesting is practised. Up to 30% of the applied N may be lost through volatilisation due to the presence of the urease enzyme in the crop residue. Losses from LAN are minimal (<1%). For 2) and 3) above, although an alternative to urea should be considered, it is possible to improve urea-N efficiency by: burying the urea to a depth of about 75 mm, or broadcasting rather than banding on the soil surface, or by splitting the N application.

application. Avoiding over-application of N, particularly following a drought (and in plant cane), is essential if eldana numbers are to be rapidly reduced from the high levels experienced during drought.

### Split applications of N

Thrips and rust are associated with high leaf N contents particularly in plant cane. By splitting N application 50% before, and 50% after the thrips peak, spring/early summer rust damage and summer thrips damage will be reduced. A similar effect can also be expected for damage caused by the yellow sugarcane aphid.

N applications should also be split when N losses are likely, particularly on eldana prone sandy soils or soils prone to waterlogging. For example, heavy spring/early summer rains leach nitrogen beyond the root zone leading to accelerated soil re-acidification and a need to reapply N. Split N reduces the resultant acidification and the amount of N that would need to be reapplied.

Splitting N application also affords the grower an opportunity to reassess the yield target of a field based on short- to medium-term rainfall forecasts. In the case of the second half of summer being predicted to be drier than expected, less N could be added in the second application in line with a decreased yield target. This would reduce eldana risk.

Similarly, if drought is predicted, split N can accommodate the possibility that the drought does not in fact materialise. An increased amount can be added in the second application. Again, eldana risk is reduced.

### **Phosphorus (P)**

Phosphorus (P) is critically important for root growth and hence reduced water stress during crop establishment. For this reason, plant crops are far more responsive to P than ratoons.

Availability of phosphorus is primarily dependent upon the pH of the soil. However, soil pH doesn't affect phosphorus availability directly. Instead, soil pH levels indicate how certain minerals (iron, aluminium and calcium) interact with phosphorus in the soil, and it is this interaction that affects phosphorus availability.

When the soil pH (water) is less than 5.5, iron and aluminium concentrations are very high and react very quickly with phosphorus, creating iron or aluminium phosphate minerals. The best way to correct this problem is to correct the pH with lime. Lime neutralises the soil acidity and decreases the concentration of iron and aluminium in the soil solution. In short, lime reduces phosphorus fixation due to soluble iron and aluminium.



Thrips (*Fulmekiola serrata*) numbers peak in summer and decline as older plants become more resistant.

Fertiliser expenditure for ratoons should focus on N and K nutrition. Soil testing after each ratoon will indicate P levels; if adequate, there is usually no need for maintenance P dressings.

### Phosphate fixing soils and silicon availability

The strong tendency of phosphate to bond with certain clays reduces the plant-availability of phosphorus supplied in fertilisers. Phosphorus fixation is of considerable economic significance in crop production. High phosphorus-fixing soils require the application of phosphorus at rates well in excess of crop requirements to nullify fixation effects and ensure that sufficient phosphorus remains available for plant uptake.

Phosphorus fixation increases with increasing clay content of soils, and is particularly marked in naturally acidic high clay oxisols found in the Midlands (Inanda, Kranskop, Magwa, Clovelly, Griffin, Hutton, Lusiki and Sweetwater). As well as fixation due to soluble iron and aluminium, P is also fixed to aluminium and iron sesquioxides. Silicon can adsorb to these same sesquioxides, but less strongly than phosphorus. Research done in rice has shown that Si adsorption is decreased (and plant availability of Si is increased) when sufficient P is applied to block adsorption sites, before the application of silicate.

Phosphorus is relatively immobile in the soil. It is common practice to apply P in the furrow at planting so that it is immediately available to the newly developing roots. Concentrated furrow application reduces the effect of P fixation in this zone.

However, during drought, the plant obtains its water from deeper layers of the soil where P has not been applied, and where silicon is likely to be deficient due to fixation. As a consequence, the shortened internodes formed during drought are silicon deficient and poorly defended against eldana. It can be appreciated that, to ensure rooting is not restricted, and that silicon availability is maintained, P deficiencies need to be corrected following the correction of acid saturation. Current research aims to determine the effect of P on Si availability when P is applied before, at the same time, or after silicate. The likely beneficial effect of incorporated broadcast P on silicon availability in the bulk soil is also being investigated.

### Potassium (K)

Provided whole-cycle P and lime requirements were satisfied at planting, ratoon yields are determined largely by N, K and water supplies. Importantly, N and K both need to be supplied optimally in order to maximise returns.

Research findings show that applying only N fertiliser to a crop poorly supplied with K results in drastic decreases in sucrose concentrations. K removals in the harvest are frequently underestimated, with the result that soil K levels (and inevitably yields) decline sharply with ratooning.

Increasing K applications to a sandy K-deficient soil has recently been shown to suppress eldana damage. Likely mechanisms include increased stalk strength. K is known to increase stalk strength in maize and other crops. Another explanation is the role of K in mitigating drought stress. Efficient stomatal functioning is highly dependent on adequate K concentrations in the guard cells. Leaf turgor also largely depends on K concentration, with excessive water loss occurring where K is deficient. K-fed plants maintain higher leaf water potential, turgor potential and relative water content as compared to K-deficient plants, thus allowing the crop to withstand periods of drought stress more successfully.

In a trial on the Oribi flats, which was on a sandy soil with particularly low water retention, plants in low K treatments were visibly more stressed than those in high K treatments during dry periods. Eldana is known to favour plants that are under any form of stress.

Where soil K levels are marginal or limiting, an increase in N supply typically results in decreases in K concentrations in the plant due



Effects of applied K on percentage internodes bored by eldana in the trial on the Oribi Flats.

to dilution effects. When water shortage is encountered, the plant will be more easily stressed leading to increased eldana risk.

Under conditions of adequate K supply, however, increasing N supply increases K uptake. Increasing concentrations of K with increasing supply of N is largely due to increased uptake of cations arising from the need for cation-anion balance accompanying nitrate uptake.

In acid soils, N is mostly in the ammonium form due to the negative effects of low pH, low Ca levels and low organic matter contents on the bacteria responsible for the conversion of ammonium to nitrate. In acid soils there may be inhibition of K uptake due to competition between ammonium and K for absorption.

Since the rate of conversion of ammonium to nitrate increases with increasing soil temperature and pH, ammonium inhibition of K uptake could be implicated in lower uptake of K in acid soils during late winter and early summer when soil temperatures are relatively low. Correcting soil acidity and inputs of organic matter will improve K nutrition (and also that of Si and P) resulting in reduced eldana risk.

### **Optimising nutrient supply**

An optimised nutrient supply, illustrated in the form of a "nutrient pyramid", ensures healthy plant growth and is usually considered optimal for pest and disease resistance as well. As a rule, plants with an optimal nutritional status have the highest resistance (tolerance) to pests and diseases. Susceptibility increases as nutrient concentrations deviate from this optimum. The interaction between plants and disease organisms and pests is complex. However, the roles of many mineral nutrients are well established in some areas of host-pest/disease interaction. Micronutrients are required in minute concentrations in the crop relative to macronutrients such as nitrogen and potassium. For example, a high-yielding crop may remove about 200 kg/ha of potassium, yet only 0.3 to 0.4 kg/ha of zinc and 0.09 kg/ ha of copper. Nevertheless, micronutrients are of no less importance than the macros; plants cannot grow in their absence, and crops grown in micronutrient-deficient soils may exhibit similar losses in productivity to those grown in macro-nutrient deficient soils.

Lime applications in excess of crop requirements, such as those typically emanating from 'Albrecht' based recommendations, frequently induce deficiencies of the metal micronutrients. Furthermore, uneven spreading of lime may result in localised areas with elevated pH, and thereby micronutrient problems. Highly visible evidence of this is the widespread and patchy "ratoon chlorosis" on the KZN north coast, reflecting the iron deficiency resulting from the uneven application of large quantities of high-pH filtercake over the years.

As noted earlier, crop requirements for micronutrients are orders of magnitude lower than for macronutrients. The range between sufficiency and toxicity for several of the micronutrients, in particular boron and copper, is extremely narrow. Therefore, caution is required in their use.

# 'Stalk strength' and eldana resistance

Thinner, weaker cell walls leak nutrients from within the cell to the apoplast (the space between plant cells). This can create a fertile environment that stimulates the germination of fungal spores. Mineral nutrient levels directly influence the amount of leakage as well as the composition of what is leaked.

Susceptibility to eldana has been linked to the presence of *Fusarium* stalk rot fungi that are beneficial to the insect. *Fusarium* invades the stalk surrounding borings by releasing enzymes, which dissolve the



The relative proportions of macronutrients (N, P, K), secondary nutrients (calcium, magnesium and sulphur), and micronutrients for sugarcane (numbers under particular nutrients represent typical removals to the mill in kg/ha for an 80 tc/ ha crop). The specifics will vary according to variety, soil and environmental conditions. Note: Silicon (not shown) removal can approach that of K.



### Impact of soil pH on nutrient availability for crop uptake.

middle lamella (the "glue" that bonds adjacent cells). The activity of these enzymes is strongly inhibited by calcium, which explains a close correlation between the calcium content of plant tissues and their resistance to fungal rotting diseases.

Potassium is essential for the synthesis of cellulose in plants which is a primary component of cell walls. Additionally K-deficiency causes cells to become leaky, resulting in high amino acid concentrations in the apoplast. Calcium and boron deficiencies also cause a build-up of Suggested micronutrient application rates. With the exception of iron, the indicated rates apply to soil incorporation at planting which should be sufficient to second ratoon harvest. On soils with less than 15% clay, as well as in the case of ratoon fertilisation, rates should be reduced by 25 to 50% to avoid toxicity problems.

Micronutrient	Elemental Rate kg/ha	Source*	Source rate kg/ha
Zn	10	Zinc sulphate (heptahydrate: 22% Zn)	45
Cu	5	Copper sulphate (pentahydrate: 25% Cu)	20
Mn	20	Manganese sulphate (27% Mn)	74
В	0.5	Solubor (20% B)	2.5
Мо	0.2	Na-molybdate (39% Mo)	0.51
Fe (foliar)	-	Ferrous sulphate	1 to 2% solution (in 300 - 400 L water/ha) at 5 to 6 leaf stage (may need to be repeated)

\* Note that this is not a comprehensive list of all the products available on the market.

amino acids. Nitrogen is a key component of amino acids; therefore, an excessive supply of N, combined with an under-supply of K and Ca, can bring about higher amounts of amino acids in plant tissues. These mineral imbalances lower resistance to *Fusarium* by creating a more favourable environment for the fungus, which in turn creates a more favourable environment for eldana.

As discussed earlier, plant tissues contain and produce a variety of defence compounds, which hinder insect and fungal attacks. Boron plays a key role in the synthesis of these compounds. Borate-complexing compounds trigger the enhanced formation of a number of plant defence chemicals at the site of invasion. The level of these substances and their anti-fungal and anti-insect effects decrease when the N supply is too high. Boron deficiencies are most likely on sandy soils, where this nutrient may be lost by leaching. This suggests that greater attention needs to be given to boron nutrition, particularly in eldana prone sandy soils.

However, of all of the micronutrients boron poses the greatest danger when applied to the crop due to extreme toxicity when over-applied; for this reason various borates have been used as herbicides. Growers should seek advice when applying any micronutrient since the window of optimal supply is narrow, and it is all too easy to apply an excess resulting in toxicity.

Typical rates for soil applications of micronutrients are listed above. With the exception of iron, single applications at the rates indicated in the table are usually sufficient for three or more years. In the case of iron, soil applications of iron sulphate are largely ineffective, and foliar fertilisation with this product is therefore preferable.

### **Eldana under irrigated conditions**

Whilst eldana levels are on average lower under irrigation as compared to rainfed cane, high levels of infestation can be experienced where irrigation scheduling is sub-optimal, or when soils become saline/sodic.

A lack of irrigation scheduling most often leads to over-irrigation. Over-irrigation results in high electricity and water costs, leaching of expensive nutrients, soil loss through erosion and yield loss due to anaerobic soil conditions. The plant stress imposed by waterlogged soils has been linked to an increased eldana risk.

Accurate irrigation scheduling is not widely practised in the sugar industry despite the many scheduling tools available to sugarcane growers. This leads to very low water use efficiencies of approximately 50% of what could be achieved theoretically. Every effort should therefore be made to avoid over-irrigation through the use of one of the many scheduling tools available from SASRI.

On the other hand, with increasing competition for limited water resources, periods when water is not available to meet full crop water requirements are becoming more frequent. Making more effective use of water is, therefore, vital to sustain production and to minimise eldana risk.



Critical stages of crop water requirements.

Rather than reducing total irrigated area by abandoning fields, there is good evidence that spreading limited water over a relatively larger area results in optimal overall returns due to gains in irrigation and rainfall use efficiency. In fact, during periods of water restrictions, it has been observed that overall yield can often increase rather than decrease. This is due to widespread over-irrigation when water is plentiful.

When prioritising irrigation water applications during restrictions, consider the most sensitive growth phase to water stress. This is the rapid growth phase beginning just prior to the establishment of a full crop canopy and ending just before the drying-off phase. Therefore, try to ensure that there is adequate irrigation during this period.

As the cane matures, subsequent to this 'rapid stalk elongation period', water can be saved by reducing the amount of irrigation applied and extending the interval between irrigation applications (drying-off), without severe impacts on sucrose yields. During this period, eldana populations have insufficient time to increase significantly.

Available water should rather be used for refilling the soil profile on recently harvested fields than for irrigating old and maturing crops. If necessary, give preference to fields that have had only a few ratoons, rather than fields which have had many ratoons and are due to be replanted soon.

Better whole-farm water use efficiency can also be obtained by reducing irrigation on drought tolerant eldana resistant varieties without causing severe yield losses. These are N25 and N41 for early season harvest, and N25, N53 and N57 for late season harvest. Further, water saving can be achieved by switching to a dual row tramline system. In a drip irrigated trial, the water use efficiency and yield of N25 was higher in dual rows spaced 1.8 m apart than in single rows spaced 1.5 m apart.

### Salinity and sodicity

Preventing or correcting salinity and sodicity reduces the risk of eldana damage.

Sugarcane is regarded as a relatively salt sensitive plant. Salinity induces water stress which is evident in cane by premature wilting, scorching of the leaves, restricted growth and increased eldana risk.

Trials have shown that saline/sodic soils can be successfully reclaimed. However, this is usually an extremely expensive and difficult operation. For this reason, a policy of 'prevention is better than cure' should be adopted from the outset. Adequate surface and subsurface drainage is essential to permit effective leaching of accumulated salts from the soil.

Where saline/sodic conditions are suspected, representative soil profile samples must be taken from the area concerned at depths of 0-300, 300-600 and 600-900 mm. Samples should be submitted to the Fertiliser Advisory Service (FAS) at Mount Edgecombe for salinity/sodicity assessment.

To reclaim a saline soil (high calcium and magnesium salts, low proportion of sodium salts) leaching out using heavy applications of water of acceptable quality will suffice. Adding calcium in the form of gypsum to saline (not sodic) soils only increases the salt content further and aggravates the salinity problem.

Crop Protection and Nutrition
When reclaiming sodic and saline/sodic soils, the goal is to replace the sodium with calcium and then leach the sodium out. There are two possible approaches for doing this:

- 1. Dissolve any limestone (calcium carbonate) already present in the soil, or
- 2. Add calcium to the soil.

If free lime is present in the soil, it can be dissolved by applying sulphur (6 tons/ha). Sulphur is oxidised in the soil to form sulphuric acid which reduces the pH and dissolves the lime. The resultant dissolved calcium replaces sodium on the clay particles thus improving soil structure. Adding sulphur only makes sense when a soil is sodic and has free lime present.

If free lime is not present in adequate amounts as determined by a soil test, then add calcium. The most common form of calcium used for this purpose is gypsum (5-10 tons/ha). Since sodic and saline/sodic soils are only slowly permeable, the ameliorants should be incorporated as deeply as possible (300 mm) to facilitate the supply of calcium ions to replace sodium. Following the application of the ameliorant the soil must be leached with heavy applications of good quality water.

Restoration of sodic soils is slow because soil structure, once destroyed, is slow to improve. Growing a salttolerant crop in the early stages of reclamation and incorporating organic matter (composts, green manures, etc.) will increase water infiltration and permeability speeding up the reclamation process.


## Surveys and insecticides

A comprehensive plan to combat the outbreak of eldana must include frequent surveys. Growers are encouraged to conduct their own field surveys. These can be carried out in a manner similar to those of local P&D teams.

## Surveys and insecticides

Conducting regular surveys in the field ensures the following:

- Increased awareness of pest activity, including changes in pest populations.
- Provision of up-to-date information on damage levels.
- Provision of data that can be used to compare damage and eldana numbers from season to season.
- Allows for the early detection of problems, resulting in the availability of more management options.

From these surveys, a pattern of eldana distribution and intensity will be established. Such information can be used as an aid for decisions on harvesting priorities, plough-out and replant variety selection.

## Understanding and conducting eldana surveys

- Eldana/100 stalks (E/100) indicates the number of eldana (including pupae) in 100 stalks, and is a measure of the eldana population in the field at the time of the survey. E/100 is used by LPD&VC Committees to assess the eldana hazard in a region. It is also used to set maximum permissible eldana levels in fields to be harvested as well as fields to be carried over. While a value of approximately 5E/100 seems low, this represents a larval population of around 6000/ha.
- % Internodes bored (%IB) is a more useful measurement than % stalks bored. This measures the intensity of an infestation and is directly related to crop loss. Losses exceed 1% of RV per 1%IB and can be as high as 4% of RV per 1%IB. For loss calculations shown in this manual, a value of 1.5% of RV per 1%IB has been used.
- % Stalk length red (%SLR) is an easier survey measure than %IB. It refers to the measured length of damaged tissue that has turned red as a percentage of the entire length of the stalk. It also tells us the % length of the stalks that has no sugar in it, i.e. 5% SLR means that 5% of the length of all the stalks in the field has no sugar.



#### **Conducting a survey**

- 1. Examine the size and shape of the field. On a diagram, divide the field into a number of sections each of roughly one hectare.
- Sample twenty stalks in each section according to a set pattern e.g. walking four rows and sampling five stalks at intervals along each row. Aim to sample stalks so that the whole section is represented in the sample (see diagram). There must be no bias in selecting stalks for sampling.



Sampling for eldana (20 stalks per one hectare section).

- 3. Count the number of internodes, and then split each stalk along its length.
- 4. For each stalk sampled, count the number of internodes that have been bored and count the number of eldana larvae found (if any).
- 5. From the results, work out the following:
- %SLR:

The length of discolouration in a stalkx 100The total length of that stalk

• %IB:

The number of damaged internodes in a stalkx 100The total number of internodes in that stalk

The above calculations give values for one stalk. Take an average for all the stalks by adding all the individual values and dividing the resulting number by the number of stalks sampled.

For example, if you have 20 individual values of: 0% 10% 20% 15% 0% 0% 10% 20% 15% 0% 0% 10% 20% 15% 0% 0% 10% 20% 15% 0%then the average percentage is: 0+10+20+15+0+0+10+20+15+0+0+10+20+15+0 = 9%20

#### • E/100 stalks:

Divide the total number of larvae recovered by the number of stalks in the sample. This gives the average number of larvae per stalk. Multiply this by 100 to calculate the number of eldana larvae per 100 stalks.

#### Identifying the causes of stalk damage

#### Eldana

Eldana saccharina (Lepidoptera: Pyralidae)

**Identification:** Active, brown, leathery larva, moves backwards and forwards

**Symptoms:** Insect frass (faeces) indicates present in stalk, usually in lower third. Borings observed when stalks split open. Tissue around borings usually red.

**Comments:** Major pest causing economic loss over a large area. If detected, action required. Enters stalk through soft bud scales.

#### Sesamia

Sesamia calamistis (Lepidoptera: Noctuidae)

**Identification:** Pink larva, less active than eldana. Does not move backwards.

**Symptoms:** Causes 'dead-hearts' in young cane. Spindle pulls out easily, may have foul odour. Exit holes observed near top of tiller.

**Comments:** Minor pest controlled by natural enemies. May be confused with white coloured busseola.



#### Chilo

Chilo sacchariphagus (Lepidoptera: Crambidae)

Identification: Striped larva

**Symptoms:** Shot-holes through the leaves. Side-shooting on stalk. Red borings, usually towards top of stalk.

**Comments:** Major sugarcane pest in Mozambique. Poses a major biosecurity risk to RSA sugar industry. Looks the same as maize borer (*C. partellus*), distinguished using DNA analysis.

#### Red rot

Causal organism

Fungus: Glomerella tucumanensis

**Symptoms:** Elongated red lesions on the leaf midrib. Internal reddening of the stalk tissue. White patches may be observed within reddened tissue

**Notes on the disease:** Usually associated with borer damage and cracks. More common in the Midlands.

#### Sour rot

Causal organism

Fungus: Phaeocytostroma sacchari

**Symptoms:** Orange-red rotting of internal stalk tissue. Orange to black discolouration of the rind. Rind may have rough appearance due to black fruiting structures/pustules. Distinct sour odour.

**Notes on the disease:** Common in mature, droughtstressed cane in the Midlands. May result in substantial sucrose losses.

#### Insecticides

IPM is not merely a biological or "organic" pest control programme; it does not preclude the use of pesticides. IPM is a decision-making process that considers and utilises all available pest management options to suppress potential pest outbreaks below an acceptable, pre-determined injury level or action threshold, while reducing risks to human health and the environment. So, before using any pesticide, be sure that it is necessary.

All of the other components of IPM are designed to suppress the pest population below an action threshold. A decision to use an insecticide is based on the presence of the pest at levels above the action threshold, if no other intervention is possible.

#### Economics of ageing of cane

The following scenarios are based on actual field data:

In scenario 1 it can be seen that the level of control afforded by the application of insecticide approximately paid for the cost of application (hence an ET of 3%IB). However it is worth noting that because the eldana population is reduced with insecticide application, additional benefit will accrue from reduced moth infestation of the ratoon and neighbouring fields.









Scenario 1: Carry-over during a summer of normal rainfall where damage of 3%IB, equal to the ET, was detected in the previous August. Damage increased by three times to 9%IB at harvest in the absence of insecticide application. Under normal rainfall, damage at harvest was reduced by one third (from 3 to 2%IB) when insecticide was applied. (Gain (loss) is relative to a 12 month harvest).

Age of crop (months)	Normal rainfall		
	tRV/ha		
	Without insecticide	With insecticide	
12	5.5	5.5	
18	10.8	10.8	
Final %IB at 18 month harvest	9	2	
Loss calculation	0.015 x 9 x 10.8 = 1.46 tRV/ha	0.015 x 2 x 10.8 = 0.32 tRV/ha	
Actual Yield 18 months	9.34 tRV/ha	10.48 tRV/ha	
Annualised yield	6.23 tRV/ha/annum	6.99 tRV/ha/annum	
tRV gain /annum	0.73	1.49	
Value of RV gain	R 2409/ha/annum	R 4917/ha/annum	
Value of reduced inputs to 18 month cycle	R 3200/ha/annum	R 3200/ha/annum	
Gain	R 5609/ha/annum	R 8117/ha/annum	
Cost of insecticide treatment*	R 0/ha/annum	(R 2400/ha/annum)	
Nett gain	R 5609/ha/annum	R 5717/ha/annum	

\*eight aerial applications x (R150 for chemical plus R300 for microlite) = R3600/ha = R2400/ha/annum.

In scenario 2, where the risk of eldana damage is increased due to low rainfall, the contrast in profitability between using and not using an insecticide during crop aging can be appreciated.

Scenario 2: Carry-over during a summer of low rainfall where damage of 3%IB, equal to the ET, was detected in the previous August. Damage increased by nine times to 27%IB at harvest in the absence of insecticide application. Under low rainfall, damage at harvest increased by one third (from 3 to 4%IB) when insecticide was applied. (Gain (loss) is relative to a 12 month harvest).

Age of crop (months)	Low rainfall		
	tRV/ha		
	Without insecticide	With insecticide	
12	5.5	5.5	
18	9.29	9.29	
Final %IB at 18 month harvest	27	4	
Loss calculation	0.015 x 27 x 9.29 = 3.76 tRV/ha	0.015 x 4 x 9.29 = 0.56 tRV/ha	
Actual Yield 18 months	5.53 tRV/ha	8.73 tRV/ha	
Annualised yield	3.69 tRV/ha/annum	5.82 tRV/ha/annum	
tRV gain (loss) /annum	(1.81)	0.32	
Value of RV gain (loss)	(R 5973/ha/annum)	R 1056/ha/annum	
Value of reduced inputs to 18 month cycle	R 3200/ha/annum	R 3200/ha/annum	
Gain (loss)	(R 2773/ha/annum)	R 4256/ha/annum	
Cost of insecticide treatment	R 0/ha/annum	(R 2400/ha/annum)	
Nett gain (loss)	(R 2773/ha/annum)	R 1856/ha/annum	

It can be seen that under the low rainfall condition, ageing of cane was not economically viable without insecticide application. In this example, an annualised loss of R2773/ha was incurred compared to harvesting at 12 months. The use of insecticide increased annualised revenue by R1856/ha over that obtained from a 12 month harvest.

Not every carry-over field will need to be treated. For example, no benefit will be derived from treating a resistant variety growing on 'good' soil where stress is unlikely. It is in situations where there is a strong likelihood of severe eldana infestations that this treatment will be beneficial.

A severe eldana impact on young cane is typically due to high numbers in the previous crop with below ground infestation of stools. This was common following the 2010 drought. Treating the crop at the time of the April-May moth peak or the August-November moth peak in affected young cane may well reduce subsequent eldana infestation levels.

#### Using Fastac®

Since a survey of eldana damage in August is a reasonable predictor of damage in the following April, it is possible to calculate the action or economic threshold (ET) for insecticide application.

The ET for the use of Fastac<sup>®</sup> is estimated to be 3%IB. When the threshold is exceeded in August, spraying results in a reduction in final damage that at least pays for the cost of treatment. When used optimally it has been found that the %IB level of damage present at harvest can be reduced by about one third, partly due to the accumulation of additional undamaged internodes.

Fastac<sup>®</sup> contains the active ingredient alpha-cypermethrin, an organic compound similar to the natural pyrethrins produced by the flowers of certain Chrysanthemum species. As well as direct insecticidal ef-

fects, pyrethroids also have insect repellent properties. Consequently Fastac<sup>®</sup> may have multiple effects; the killing of newly hatched dispersing larvae and repellence of moths away from the sprayed area.

In the case of repelled moths, it is important that natural host plants can be found nearby so that the moths do not solely infest unsprayed sugarcane in neighbouring fields. Repelled moths would be more likely to mate with moths from the unsprayed sedges, thus reducing the risk of eldana developing resistance to alpha-cypermethrin. Repellence can be augmented if Melinis is placed in cane breaks, further reducing damage to sugarcane.

#### **Correct application**

Insecticides are designed to be toxic to the pests they target. When used properly, they can protect your crop from damage. However, when the label instructions are not followed correctly, pests may not be controlled, human health may be impaired, and insecticides may contribute to soil, air, or water pollution.

#### **Ground application**

- Apply Fastac<sup>®</sup> at a rate of 200 ml formulation in 350 litres water/ha.
- Apply once every two weeks for 16 weeks (eight applications).
- First application should be in August, and the last in November, to selected carry-over fields.

#### **Aerial application**

Aerial application of Fastac<sup>®</sup> may only be done by a registered aerial application operator using a correctly calibrated, registered aircraft according to the instructions of SANS Code 10118 (Aerial Application of Agricultural Pesticides).

A spray mixture containing 200 ml  $Fastac^{\tiny(\!R\!)}$  in a final volume of 30 litres per hectare is recommended.

As this product has not been evaluated at a reduced volume rate, the registration holder cannot guarantee efficacy, or be held responsible for any adverse effects



Targeting the spring moth peak with an insecticidal programme prevents the build-up of damage during the summer and limits the size of the subsequent autumn moth peak. To minimise the impact on natural enemies of eldana (beneficial insects) spraying should be limited to the August – November period. if this product is applied aerially at a lower volume rate than recommended.

#### Some important considerations for aerial spraying:

- The difference in temperature between the wet and dry bulb thermometers, of a whirling hygrometer, should not exceed 8°C.
- Stop spraying if the wind speed exceeds 15 km/h.
- Stop spraying under turbulent, unstable and dry conditions during the heat of the day.
- Spraying under temperature inversion conditions (spraying in or above the inversion layer) and/or high humidity conditions (relative humidity 80% and above) may lead to the following:
  - Reduced efficacy due to suspension and evaporation of small droplets in the air (inadequate coverage).
  - > Damage to non-target areas through drifting of the suspended spray cloud away from the target field.

#### **New insecticides**

SASRI is continuing research into improving and refining recommendations for using insecticide for eldana control. New insecticides, with different modes of action, are also being investigated. In due course, several insecticide options for eldana control will become available.

For example, an insecticide that inhibits the production of chitin, a major component of insect exoskeletons and egg casings, is different in mode of action from the pyrethroids. Larval contact results in inability to produce a new exoskeleton and to moult successfully to the next growth stage, thus causing death. Sub-lethal effects include increased susceptibility to entomopathogenic fungi which produce the enzyme chitinase as a means of breaching larval exoskeleton defence. Female adult contact results in reduced egg viability due to interference with chitin production during egg maturation. This mode of action is considered 'IPM friendly' in that it has no effect on adult insect predators of eldana, such as foraging ants.

Another insecticide belonging to the anthranilic diamide class is also being tested against eldana. This class is based on natural ryanodine from the plant *Ryania speciosa* which was used as a botanical insecticide in the 1940s. Modern synthetic variants act by keeping insect muscle cell Ca<sup>2+</sup> channels open and depleting Ca<sup>2+</sup> stores, leading to gradual muscle contraction, paralysis and death. Anthranilic diamides are particularly effective against lepidopteran larvae and, in contrast with the pyrethroids, have little impact on beneficial insects. Trials have shown that a reduced application frequency still gives superior control than that of the standard Fastac<sup>®</sup> programme.

Adult lepidoptera are less susceptible to anthranilic diamides than larvae. However, sub-lethal effects due to partial muscle paralysis result in adult mating disruption. In eldana it is likely that lek formation and movement of females towards leks is inhibited. An added advantage over the pyrethroids may be that moths are not able to leave the sprayed field (are not repelled) such that the eldana problem is not simply exported to neighbouring fields.

#### **Risk to beneficials**

Like most commercial crops, sugarcane is a monoculture. Such habitats tend to be easily exploitable by what we call pest species (eldana, thrips, aphids, etc). While many natural enemies (beneficials) act to reduce pest populations, this is not always rapid enough or at a sufficient level to allow commercial crop production, thus IPM measures are practised, one of these being the use of insecticides.

Insecticides are designed to kill insects; however by practices such as adjusting the timing of spraying or formulations used, the impact on beneficial insects can be reduced, but not eliminated.

Past studies have shown that ant numbers (key predators of eldana) are reduced during the time of spraying the synthetic pyrethroid alpha-cypermethrin, but returned to the levels shown in control plots after spraying ended. At the same time eldana levels and damage were significantly lower in sprayed plots.

Insecticides do reduce the populations of beneficials, but only temporarily. Just how robust insect populations are in sugarcane, is shown at harvest when the entire habitat is destroyed (even more-so when burnt) and populations devastated. However beneficial insect numbers soon re-establish in the new crop especially in fields adjacent to undisturbed conserved areas.

It is therefore very important that damage to nontarget areas through insecticide drift is avoided. New chemistries, currently undergoing the registration process, will also contribute towards the conservation of beneficials because of improved pest specificity.

#### **Remote sensing**

Due to the very unusual and complex nature of the mating biology of eldana it has not been possible to develop a pheromone trap for monitoring. Monitoring therefore relies on stalk sampling as described earlier. This can be a hit-and-miss exercise due to the spatial clumping that low level eldana populations exhibit.

Remote sensing of stressed areas between and within fields could become a valuable technique for directing surveys. It could also be used to map areas most likely to benefit from IPM interventions including insecticide treatment. In the absence of the ability to correct the causative stress factor, targeted insecticide application would reduce costs as well as environmental damage.

#### **NDVI explained**

The NDVI (normalised difference vegetation index) is calculated from reflectance (R) measurements in the visible red and near infrared (NIR) portions of the spectrum:

$$NDVI = \frac{R_{NIR} - R_{Red}}{R_{NIR} + R_{Red}}$$

where  $R_{_{NIR}}$  is the reflectance of NIR radiation and  $R_{_{Red}}$  is the reflectance of visible red radiation.

The NDVI has been correlated to many variables such as crop nutrient deficiencies and long-term water stress. However, rather than exclusively reflecting the effect of one parameter, NDVI has to be considered as a measurement of amalgamated plant vigour that reflects various plant growth factors. Therefore, the underlying factor for variability in a typical vegetation index cannot be blindly linked to a management input or environmental stress without some knowledge of the primary factor that limits growth. For example, in a field where N is the limiting factor to growth, the NDVI may show a strong correlation with the N availability in the soil; however, in another field, where water is the limiting factor, the NDVI may be just as strongly correlated with TAW.



A NDVI image taken from an unmanned aerial vehicle showing bare ground (red), dead leaf (also red), water-stressed (orange) and mildly stressed to unstressed (green to blue) canopy within and between fields (photo credit - Iain Thompson @ 3Dmapping Africa).



Typical reflectance spectrum of a healthy and a stressed plant.



# Harvesting and crop residue management

The application of crop residues to a field has shown numerous benefits to the sugarcane plant. This chapter discusses the benefits of using crop residues correctly, as well as additional factors in eldana management. y forming a mulch layer, crop residues prevent the soil from drying out. A crop residue blanket can conserve up to 100 mm of soil water per year, considerably reducing eldana risk in drier years. Crop residue conservation reduces soil and water losses from cane fields, particularly on steep slopes. Crusting, poor water infiltration, erosion and loss of soil organic matter are all reduced. Quantifying these effects is difficult, but in a trial on a Longlands (Waldene) soil (11% slope), crop residue reduced rainfall loss by 90% and soil loss by 60% compared to a bare soil over a six month period. Soils associated with an eldana risk (sandy and/or shallow soils) are particularly likely to benefit from the conservation of crop residues.

Residue blankets contain considerable quantities of dry matter and nutrients, particularly nitrogen (dead leaves 0.4% and green leaves 2% of dry matter) and potassium (dead leaves 0.2% and green leaves 1.2% of dry matter). When a field is burnt pre- and/or post-harvest, 70–95% of the dry matter, N and S are lost from the system, with lower losses of other nutrients. Harvesting cane green and retaining the crop residue has considerable positive effects on organic matter conservation, soil biological activity, nutrient cycling and N fertility of the soil.

In general about 40 to 60% of N from the crop residue is available to the crop in the first year. In the second year 40 to 60% of the remaining N becomes available and similar percentages in the third and following years. When management of a field is changed, it will take the field about 5 years to come into equilibrium with the new practice. This means that after equilibrium has been reached, plant nutrient contributions from crop residue will be at a peak. In the case of K, reserves of this nutrient in the crop residue are readily extracted through leaching by rain water and nearly all is available to the crop in the first year. The P turnover is also relatively quick.

To account for the nutritional value of crop residue, and to avoid over-application of N, it is best to have soil and leaf samples analysed regularly. The more favourable nutrient supplies resulting from crop residue conservation will be reflected in the analyses, thereby enabling reductions in fertiliser requirements to be realised.



A blanket of sugarcane tops and dry leaves preserves soil water, prevents erosion and feeds the soil food-web, thereby increasing control of eldana by arthropod predators. Leaves and green sugarcane tops also release nutrients to the new crop.

#### Advantages of green cane harvesting

Green cane harvesting has also been shown to positively affect sugarcane production in terms of the following:

- **Reduced herbicide usage.** A good crop residue blanket can suppress weed growth almost completely although more commonly, some weeds escape and need to be treated with herbicide. Costs may vary from 0 to 100% of those of burnt fields, but is usually about half of the costs of weed control under burnt conditions.
- Increased yield during dry years. The average yield response to green cane harvesting in a long-term trial over 60 years of cropping was 9 tc/ha/annum compared with burnt cane and subsequent burning of tops, and 2 tc/ha/annum when tops were scattered and not burnt. These figures are commonly used in the South African sugar industry to represent the response that can be expected from a crop residue conservation system. Average responses to green cane harvesting versus burning (with tops scattered) for

all spring and summer harvested crops (starting in September) were 6%, 5% and -1% in dry, average and wet seasons respectively. For crops harvested in winter the responses were -1% and -13% for average and wet years, respectively. Green cane harvesting in spring and early summer (September through December) is therefore most likely to result in consistent yield increases. However, areas where losses are likely to be incurred through green cane harvesting are wet valley bottoms, on soils with a high water table and in Midlands areas where low soil temperatures can be a problem.

- Decreased deterioration (loss of pol %). Green cane harvesting eliminates the deterioration that occurs between burning and harvesting. Only freshly cut cane is removed from the field. This is particularly advantageous during spring and early summer since increasing temperatures and rainfall increase the rate of deterioration in burnt cane. The rate of pol loss in early summer for burnt cane (approximately 2.3%/day) can be about 40% higher than for cane cut green. In addition, wet conditions following a burn makes extraction of cane from the field problematic, further increasing burn to crush delays.
- Improved soil health. Crop residues create a stable environment in which the soil food web can thrive and predation of eldana larvae and adults is increased. If practised during spring and early summer, conserved predators are able to impact upon the spring moth peak and upon any larvae present in the stubble. There is also evidence that a residue blanket increases the uptake of silicon by the cane plant. Higher stalk silicon content delays eldana larval penetration, thereby increasing exposure to predation.

Considering the yield increase experienced through green cane harvesting, and combining this with better cane quality and the conservation of eldana predators, it makes sense to green cane harvest in spring and early summer. Priority rating for crop residue retention according to soil group.

Soil group	Soil form	Erosion hazard	Priority
Grey sandy loams	Longlands	High	High
Red to dark loams	Shortlands	Low	Moderate
Black clays	Milkwood Arcadia	Low	Moderate
Brown humic	Inanda Hutton	Low	Low
Valley bottom	Katspruit Rensburg	Low	Very low

#### **Economic calculations**

**EconoCane** is a spreadsheet based calculator developed by SASRI which compares the economics of harvesting burnt and green sugarcane and finds the most cost efficient sugarcane harvesting practice. The output is the final cost per ton for planting to harvesting burnt or green sugarcane with various loading and transport options of the harvested cane, delivery to the mill and delivery of residue to an energy centre for co-generation (which might also be the mill).

Activities accounted for are planting, fertilising, herbicide use, irrigation, harvesting (manual vs mechanical and burnt vs green cane harvesting), loading (range of loading and loader options), baling, transport (various options) and losses due to delays. Maintenance of mechanical equipment is also included. It has many costing outputs including the breakeven price to deliver residue for co-generation.

Due to its complexity a specialist at SASRI will run the spreadsheet calculator after receiving an Extension Request for Advice (ERA) from an Extension Specialist.

#### Additional factors in managing eldana

#### Detaching dry leaf material from the stalk

This practice reduces the dry leaf area in contact with stalks. Larvae hatching from eggs laid on detached dry leaf material are more likely to be predated. In addition, exposure of the stalk leads to an increase in toughness of the cuticle just below the wax layer, making it harder for young larvae to penetrate.

The optimum timing for this operation is before or at the spring moth peak, during the period August to October. A team of about 25 labourers per hectare is sufficient. It is not necessary to do a thorough cleaning of the stalk, a light cleaning will suffice. The dry leaves should be moved away from the base of the stool.



Hand tools for removal of dead leaves from the stalk.

Harvesting and Crop Residue Management

#### Burning

Burning is recommended where heavy eldana infestations occur in severely droughted cane. The reasons for this are:

- to ensure good field hygiene by not leaving infested stalks concealed under crop residues,
- to enable cutting at the soil surface, so removing larvae that would have been left in a stubble, and
- to destroy the reservoir of eggs, pupae and adult moths associated with dry leaf material.

Tops should never be burnt and should always be scattered. Eldana does not lay eggs on green leaf material and larvae only very rarely bore the tops. Research trials have shown that a good cover of cane tops can have as much as 70% of the beneficial effects of a full residue blanket.

Droughts are a regular occurrence in the South African sugar industry. It is best to be prepared by paying attention to all aspects of soil and water conservation and basic crop husbandry. When drought strikes, the decision tree shown below can help growers in managing stressed cane. of millable stalks have been found to be left in the field (e.g. 80 tc/ha with 3.2 tc left in the field represents a revenue loss of more than R 1250 per hectare).

Loading zones should also be cleared of all stalks and pieces left behind, even if they are not fit to be sent to the mill. Leaving eldana-infested stalks in the field or at the zone provides a residual eldana population that will infest ratooning cane and will result in increased eldana levels in young cane.

#### Ripening

Chemical ripeners slow down sugarcane growth, increase cane quality and cause the emission of natural plant stress signals (e.g. the plant hormone ethylene), all factors known to attract eldana. An application of Ethephon<sup>®</sup>, which is metabolised to ethylene in the plant, is usually made 12 weeks prior to target harvest date. Eldana damage can increase significantly during this period. If eldana pressure is such that it will impact on RV yields, it is advisable not to apply ripeners.

It is also important to note that, following late season ripening, eldana numbers can be drastically increased if ripened fields are carried over due to unforeseen circumstances.

#### **Field hygiene**

It is important to remove all whole stalks and pieces of stalk from the field. In many instances as much as 4%



Decision tree for handling drought-affected cane.



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