REFEREED PAPER

CROP NUTRITION AND SOIL TEXTURAL EFFECTS ON ELDANA DAMAGE IN SUGARCANE

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Abstract

The stalk borer *Eldana saccharina* Walker (Lepidoptera: Pyralidae) (eldana) causes substantial economic losses in the South African sugar industry. Reliable information is required regarding possible roles of crop nutrition and soil properties on eldana damage levels. The objective of this study was to make use of field trial data to elucidate the effects of macronutrients and soil properties on eldana damage. Data from 16 harvested crops in ten N response trials – with N rates varying from zero to well in excess of crop requirements for optimum growth – revealed only three instances where eldana damage increased with increasing N application rate. In field trials (two sites) where Si was included as a treatment, eldana damage decreased with Si application in one out of the four crops. A survey carried out in the North Coast and Midlands South regions, with soils varying extensively in clay and organic matter contents, revealed that eldana damage increased markedly with decreasing clay and organic matter levels, as reflected by volume weight measurements (R^2=0.76, n=23). This relationship has not previously been reported. These findings indicate that: (1) crops growing on sandy, lower organic matter soils are more likely to suffer high levels of eldana damage than those with a lower volume weight; (2) the current practice of curtailing N application rates in an effort to reduce eldana damage inevitably results in yield reductions and appears unwarranted on soils with low (<1.25 mg/L) volume weights; and (3) Si and K application (on deficient soils) was highlighted as a means of limiting eldana damage, and research on these and other nutrients' effects on eldana should continue to receive priority.

Keywords: Eldana saccharina, nitrogen, potassium, silicon, soil texture, volume weight

Introduction

The stalk borer *Eldana saccharina* Walker (Lepidoptera: Pyralidae) (eldana) causes substantial economic losses in the South African sugar industry. Numerous research efforts have highlighted the importance of crop nutrition on the levels of damage inflicted by this pest, mostly in relation to nitrogen (N) in both sugarcane (Carnegie, 1981; Atkinson and Nuss, 1989; Coulibaly, 1990) and maize (Sétamou *et al*., 1995). Increased N rates, particularly during periods of crop stress, have led to significant increases in eldana numbers in sugarcane (Carnegie, 1981; Atkinson and Nuss, 1989; Meyer and Keeping, 2005; Keeping *et al*., 2012). It is postulated that eldana first invaded sugarcane only when populations of its higher-N natural host plants, the Cyperaceae, were removed in the process of wetland cultivation; prior to this, sugarcane was less attractive due to its lower N content (Atkinson, 1979).

Insect responses to host plant stress vary, depending on the type of stress (e.g. moisture, light, CO_2 and increased soil N) and on the feeding guild of an insect (e.g. sap-feeders, leaf-feeders, stem borers and gall formers). For the majority of stem borers, increased plant moisture stress leads to increased insect growth and survival (Galway *et al*., 2002; Huberty and Denno, 2004). In many plants, including sugarcane, moisture stress also leads to the mobilisation and increased availability of N to herbivores feeding on stressed plants (White, 1984; Atkinson and Nuss, 1989).

In contrast to N, silicon (Si) provision (in soils with low available Si levels) can ameliorate several abiotic stresses, including moisture stress (Ma, 2004; Liang *et al*., 2007), and can reduce eldana damage by 70% in sugarcane (Keeping and Meyer, 2006; Kvedaras and Keeping, 2007; Keeping *et al*., 2013). As a consequence of research into the effects of nutrition on eldana damage levels, growers in eldana-prone areas are often encouraged to apply Si to their fields, and to reduce N application rates by 10-30 kg/ha (SASRI, 2005).

Optimal N application rates play an important role in attaining commercially viable sugarcane yields, and reduction of N may result in serious yield losses (Stranack and Miles, 2011). Is it warranted, under all conditions, to reduce N application rates in an effort to reduce eldana damage? The answer may lie in an examination of the prevailing soil properties. Soil type plays a crucial role in the extent of a crop's stress level, and surveys have shown that there is a marked and consistent relationship between soil parent material and the incidence of eldana (Paxton, 1982; Nuss *et al*., 1986). Furthermore, extensive surveys conducted in commercial cane found that eldana populations did not respond positively to N fertiliser applications (Carnegie, 1981). Hence, it is postulated that soil properties might have a substantial effect on the potential for eldana damage in various fields. This might in turn affect the extent to which a reduction in N application rates is warranted.

The objective of this study was thus to make use of field trial and survey data to elucidate the effects of macronutrients and selected soil properties on eldana damage, and to revisit the justification for reducing N rates to limit this damage.

Materials and Methods

Nutrient trials

Nitrogen trials: trial details

Ten rainfed N response field trials, established during the period 2009-2012, were included in this study. Details of each trial are presented in Table 1. At each trial site, N rates varied from 0 kg N/ha to well in excess of the rate recommended by the Fertiliser Advisory Service (FAS) at the South African Sugarcane Research Institute at Mount Edgecombe. Soil varied in texture from 8 to 41% clay, and organic matter from 1.44 to 6.64%. Sixteen crops were harvested in total from the ten trials. An eldana survey was conducted during the harvest of each crop, when ten stalks were removed at random from the net rows within each plot, split lengthways, and the total number of internodes and internodes bored by eldana, plus the total number of larvae and pupae per stalk were counted. These data were used to calculate per cent internodes bored [(number of internodes bored) / (total number of internodes) x 100] as well as the numbers of eldana larvae and pupae per 100 stalks (e/100). Per cent internodes bored is reported here, as it is a permanent, cumulative record of eldana infestation, and a measure of eldana damage most relevant to growers. The e/100 results are not reported, as these values are prone to fluctuation during the season.

Silicon trials: trial details

Two of the N response trials listed in Table 1 (Inanda and Doringkop) also included two rates of Si (zero and 300 kg/ha Si as Calmasil®). Silicon treatments were included in the eldana surveys.

Potassium trials: trial details

One of the N response trials listed in Table 1 (Oribi) also included three rates of potassium (K) (zero, 120 and 240 kg/ha K as KCl). Potassium treatments were included in the eldana surveys.

Nitrogen, silicon and potassium trials: data analysis

For each harvested crop, data reflecting the per cent internodes bored were analysed using analysis of variance (ANOVA). Differences between individual treatments were determined by means of least significant difference (LSD) tests. In instances where the data were not normally distributed, they were transformed using a square root or $\log_{10}$ transformation. In cases where normality could not be achieved despite transformation, the data were analysed using the non-parametric Kruskal-Wallis one-way ANOVA. Differences between individual treatments were determined using the two-sample non-parametric Mann-Whitney U test. All statistical analyses were conducted using Genstat (14th Edition).

Table 1. Details of nitrogen response trials reported in the study.

Project code	Trial site	Established	Topsoil clay (%)	Topsoil organic matter (%)	N rates (kg/ha N)	[Ŧ]Recommended FAS N rate (kg/ha N)	Number of replications	Variety	Number of crops harvested	Harvest age (months)
09CM01	Tugela	Apr 2008	25	2.36	0; 70; 140; 210	180	3	N39	2 (R)	14
09CM01	Eston	Oct 2009	8	2.03	0; 120; 240	110	3	N12	1 (R)	20
09CM01	Eshowe (1)	Nov 2009	20	3.20	0; 80; 120; 160; 200	130	3	N39	2 (R)	17
09CM01	Eshowe (2)	Nov 2009	24	6.64	0; 80; 120; 160; 200	110	3	N39	2 (R)	17
08RE05	*Inanda	Nov 2009	41	6.10	0; 80; 160	80	4	N37	2 (PC, R)	PC: 12 R1: 18
08RE05	*Doringkop	Dec 2009	24	2.31	0; 105; 210	130	4	N39	2 (PC, R)	PC: 20 R1: 14
09CM01	Empangeni	May 2010	21	1.89	0; 100; 180	175	3	N36	2 (R)	13
09CM01	[Ø]Oribi Flats	Nov 2010	9	1.44	0; 90; 180	115	3	N39	1 (PC)	21
09CM01	Stanger	Oct 2011	14	1.96	0; 50; 100; 150; 200	110	4	N39	1 (R)	12
09CM01	Mount Edgecombe	Oct 2011	17	2.41	0; 75; 150; 250	160	4	N49	1 (R)	12

*trial also included Si rates. [Ø]trial also included K rates. [Ŧ]FAS N rate recommended at the trial site. PC = plant crop; R = ratoon crop(s)

Eldana and soil properties

Survey details
Three rainfed areas, with high eldana incidence, were sampled for soil characteristics and eldana numbers and damage.

In the Midlands South area, six fields were sampled on six different farms near Eston in June 2011. In each field, topsoil (0-20 cm) samples were collected using a Beater auger. Twenty to thirty subsample cores were collected in a zigzag pattern across each field, thoroughly mixed and sent to FAS for routine analysis, as well as particle size distribution (hydrometer method, Day, 1965) and organic carbon (Modified Walkley-Black, Walkley, 1935) determinations. Organic carbon values were converted to organic matter per cent using a conversion factor of 1.724 (Nelson and Sommers, 1996). Density of milled (<1 mm) soil samples, also referred to as volume weight (g/mL soil), was determined.

For each field, the most recent Pest and Disease (P&D) team survey results were collated. Depending on the farm, P&D surveys were conducted in January, May and October 2011. Twenty random stalks were collected in each field and split in half lengthways. Per cent internodes bored and e/100 values were calculated as above; only per cent internodes bored data are reported here.

The same sampling and analysis routine was followed in eight fields on three different farms in the Midlands North area in September 2011, near Table Mountain. Again, recent P&D team survey data for each field were used, while soil samples were collected, as above.

Information from the fields of a rainfed farm on the north coast (Verulam area) was also included in the survey. Nine fields, with widely varying soil texture, were selected. From each field, topsoil (0-20 cm) samples were collected using the method described above, and sent to FAS for analyses. Pest and Disease eldana survey results from September 2012 were obtained for these fields. During the P&D survey, 12 randomly selected stalks were processed, as above, for eldana numbers and damage.

Details of the 23 fields surveyed are displayed in Table 2.

Eldana and soil properties: data analysis
Eldana damage ratings (% internodes bored) for the above samples were plotted against soil organic matter per cent, clay per cent and soil silicon (mg/L). In analysing the data, use was made of the Cate-Nelson procedure (Cate and Nelson, 1971). This method separates the data into two groups in a stepwise fashion, utilising pooled sums of squares to determine the separation point at which the predictive ability (R^2) within the two groups is maximised. This procedure allowed the data to be divided statistically into two groups, separated by a ‘critical’ threshold. Per cent internodes bored data were also plotted against volume weight, and an exponential regression curve fitted to the data (Genstat, 14th Edition).

Table 2: Details of farms and fields surveyed for *Eldana saccharina* (eldana) and soil characteristics.

Area	Farm name	Field number	Variety	Crop age at eldana survey (months)	Clay (%)	Soil organic matter (%)
Midlands South	Eston House	36	N31	22	53	5.64
	Coppins	2 i	N31	20	47	5.09
	Broadacres	516	N12	18	10	1.48
	The Recess	68	N12	17.5	12	1.48
	Ikwesi	13	N31	23	6	1.34
	Solitude	178	N31	12	6	1.07
Midlands North	Xiba	9.1	N12	20	31	3.96
	Xiba	9.10	N37	18	35	4.56
	Xiba	10.1	N37	20	30	3.61
	Bonnieblink	3.1	N12	22	24	2.70
	Bonnieblink	16.2	N31	24	15	2.13
	Bonnieblink	15.3	N12	24	16	2.56
	Wanderers Rest	5	N12	20	48	4.76
	Wanderers Rest	12	N12	20	43	4.70
North Coast	Inanda	44	N42	10	30	5.33
	Inanda	47	N37	11	28	5.04
	Inanda	49	N37	20	14	2.22
	Inanda	56	N39	10	12	1.91
	Inanda	62	N39	10	22	4.56
	Inanda	80	N37	16	10	1.24
	Inanda	81	N37	16	10	1.00
	Inanda	86	N31	8	10	0.83
	Inanda	118	N39	9	20	1.96

Results and Discussion

Nutrient trials

Nitrogen trials

Of the 16 sugarcane crops harvested in the ten N trials, only four showed significant differences in eldana damage levels as a result of N application rates. The results from these crops are depicted in Figure 1. In the remaining 12 crops, no effect of applied N on eldana was apparent (data not shown).

Of the four responsive crops shown in Figure 1, three (ratoon crops from Empangeni, Doringkop and Eshowe 1) showed increased eldana damage with increasing N rates. The other trial (Mount Edgecombe) showed a decrease in eldana damage with increasing N.

In two cases (Empangeni and Doringkop – Figure 1), there was a significant increase in eldana damage from zero N to the first N increment. However, it would be only of academic interest to discuss this increase, as it would not be commercially feasible to grow sugarcane without any N at all for more than a season or two. Dropping N rates to zero might reduce eldana damage, but would frequently reduce yields to below the threshold of economic viability. Consideration of eldana damage levels at zero N is therefore likely to be irrelevant to most commercial growers.

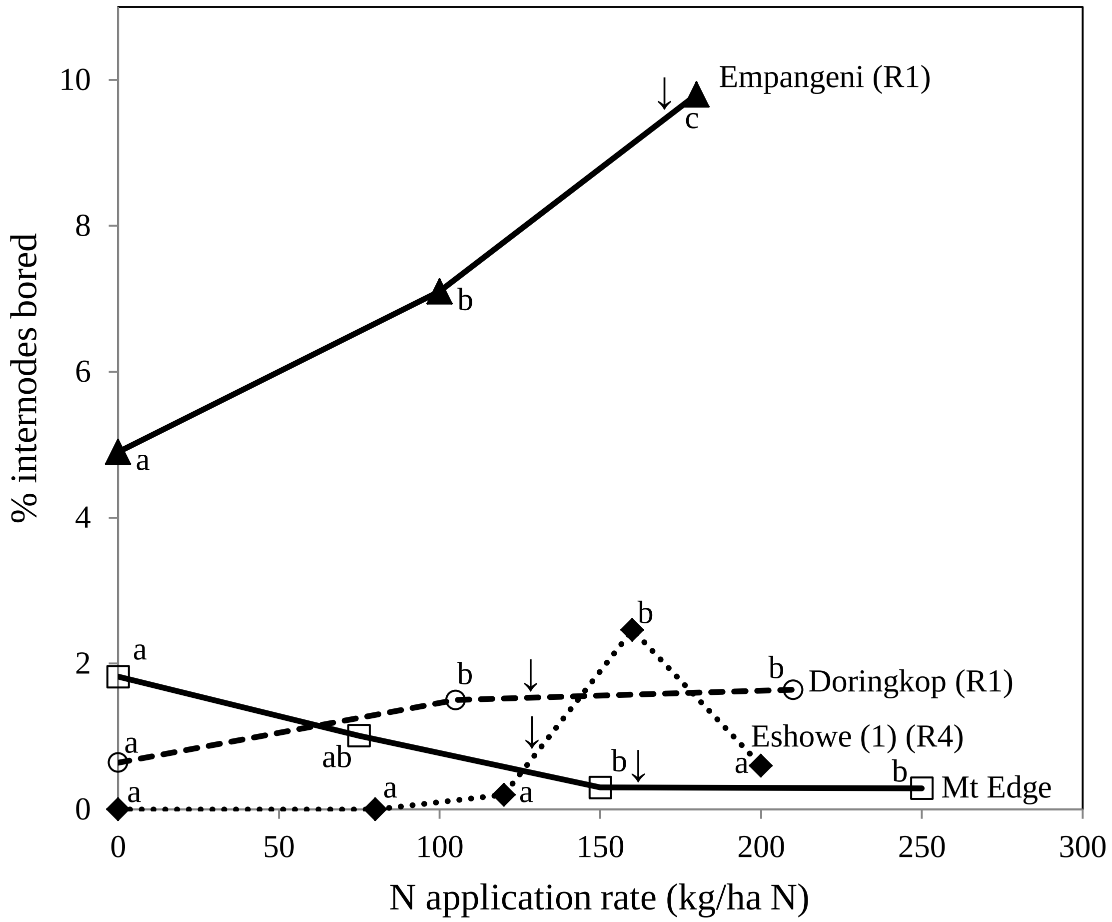


Figure 1. Effects of nitrogen (N) application rate on *Eldana saccharina* (eldana) damage (per cent internodes bored) in sugarcane grown at selected trial sites listed in Table 1. Only the trial harvests showing significant differences are presented. Within each trial site, data points with different letters indicate significantly different ($P<0.05$) levels of eldana damage (eldana damage levels are not comparable across different trial sites). ↓ marks the N rates recommended for each trial site by the Fertiliser Advisory Service at the South African Sugarcane Research Institute.

Consideration of a slight reduction in the N rate recommended by FAS is of more practical relevance. The arrows in Figure 1 show the N rate recommended by FAS (before reduction for eldana-prone fields). Currently, reduction of N by 20 kg/ha is recommended in eldana-prone areas (SASRI, 2005). At all four trial sites, reducing N by a further 20 kg/ha would not have caused significant reductions in eldana damage levels (LSD values not shown), assuming a linear extrapolation between the tested N rates. Hence, none of the 16 trial harvests is likely to have benefitted from N rates 20 kg/ha lower than the recommended FAS rate, in terms of reduced eldana damage. This makes it debatable whether reducing N application rates by approximately 20 kg/ha below the recommended FAS rate is justified in terms of reduced eldana damage.

A further pertinent observation is that seven of the 16 trial crops grew during all or part of the 2010 drought. Rainfall from January to September 2010 was the lowest ever recorded in some coastal mill supply areas, and rainfall was well below the long term mean for all mill supply areas except those in Mpumalanga (Singels *et al*., 2011). Interestingly, despite having grown during this severely water stressed period, only one (Eshowe 1, fourth ratoon) of the seven crops showed a significant increase in eldana damage with increasing N; and this increase was not consistent with increasing N, the highest N rate showing less eldana damage than the penultimate N rate (Figure 1). In pot trials, increasing N rate coupled with water stress has been shown to result in greater eldana damage than in unstressed pots (Atkinson and Nuss, 1989). Consequently, under drought conditions, field plots with higher N should experience greater eldana damage; this was not usually the case in the field trials under study.

Reports on the effects of N on eldana are therefore conflicting. In pot trials, where eldana larvae are inoculated equally onto all treatments and where water stress can be controlled, increased N application rates – especially in the presence of water stress – can lead to greater eldana damage (Atkinson and Nuss, 1989; Meyer and Keeping, 2005; Keeping *et al*., 2012; see also Sithole *et al*., 2011). In rainfed field trials where stress levels, though present, are uncontrolled, and where the crop is not artificially infested, some researchers (present study; Atkinson and Nuss, 1989; Stranack and Miles, 2011) have found little or no evidence that increased N rates caused increased eldana damage, while others showed a positive association between eldana numbers or damage and increasing N fertiliser rate (Carnegie, 1981; van Antwerpen *et al*., 2011). In the same study, Carnegie (1981) also reports that extensive field surveys in commercial cane did not confirm these results.

Such results make it difficult to reach a straight-forward conclusion or recommendation regarding the effects of N on eldana under commercial field conditions. Unlike in pot trials, growers' fields are not artificially infested with eldana. Furthermore, unlike a field N response trial scenario, growers' fields are not a patchwork of different N application rates, representing a maze of different diet qualities for the eldana moths to choose from. The answer to this question may be that, like many biological questions, it is 'a little of both'. Natural infestation of growers' fields may be more or less random at first – as in a field trial – but upon a chance landing in a more stressed, high-N field of cane, survival success, as in a pot trial, will be greater than it might have been in a low-N field. It is thus a moot point as to whether N application rates should be reduced in eldana-prone areas: the majority of field trials and commercial surveys suggest that this is not warranted, while pot trials suggest the opposite. The survey data in the second part of this paper shed more light on the matter.

Silicon trials

As reported above, the Doringkop and Inanda trials included two Si treatments each (0 and 300 kg/ha Si). Two harvests were conducted at each trial site. In one out of these four harvests, an application of Calmasil® caused a significant (P=0.04) decrease in eldana damage, from 1.70±1.83% (with zero Si) to 0.82±0.92% internodes bored where Calmasil® was applied. This occurred in the first ratoon crop at Doringkop. The zero Si plot soil test average at Doringkop at that time was 13.4±0.3 mg/L Si, while the 300 kg/ha Si plots had 17.3±0.7 mg/L Si. Interestingly, these two readings straddle the FAS threshold of 15 mg/L.

It is noteworthy that in these trials Si treatments effected only very modest increases in leaf Si levels. During the growth of the first ratoon crop at Doringkop, at four months of age, Calmasil® application increased leaf Si from 0.62±0.01% Si to 0.68±0.01% Si (P<0.001), while at six months, the difference was less marked (though still significant): 0.78±0.01% Si (without Calmasil®) and 0.82±0.01% Si (with Calmasil®) (P=0.002). Similar small increases in leaf Si in response to Calmasil® treatments of 4 and 8 t/ha were observed in a field trial at Eshowe (Keeping *et al.*, 2013). The satisfactory range used by FAS for leaf Si is 0.75-2.00%

(Miles and Rhodes, 2008). Calmasil® contains appreciable levels of Ca, and researchers often query whether any effects of this product may be attributed to Ca, rather than Si. Application of Calmasil® did not, however, significantly increase leaf Ca at either four or six months in the first ratoon crop at Doringkop; leaf Ca levels (~0.31%) fell within the 'satisfactory' range of 0.15-0.39% (Miles and Rhodes, 2008).

Eldana damage levels at harvest of the three other crops in these trials did not show significant differences between treatments.

These results support, to some extent, the literature illustrating the protective effect of Si in sugarcane against eldana damage under both pot and field trial conditions (Keeping and Meyer, 2006; Kvedaras and Keeping, 2007; Keeping *et al*., 2013).

Potassium trials

Increasing potassium (K) rates at the Oribi trial significantly decreased eldana damage, with 3.62, 2.00 and 1.73% stalks bored at zero, 120 and 240 kg/ha K, respectively (LSD=1.35, P=0.05). Plants deficient in K are reported to show reduced resistance to pests and diseases (Kingston, 2000; Marschner, 1995; Amtmann *et al*., 2008), and anecdotal evidence suggests that K may have a similar effect on eldana. Potassium plays a critical role in stomatal opening and closure (Marschner, 1995), with K-deficient plants proving less able to withstand the effects of dry conditions than their K-replete counterparts (Wood and Schroeder, 2004). A role for K in reducing water stress, and hence eldana damage, is thus likely.

Potassium's protective role against diseases is generally linked to K deficiency; little evidence exists to show that increased levels of K above the crop's critical threshold level will continue to increase the plant's resistance to disease (Marschner, 1995; Amtmann *et al*., 2008). The data from Oribi show that plants in the zero K plots showed significantly more eldana damage than those in the 120 kg/ha K plots; the decrease in damage from 120 to 240 kg/ha K was not significant. Although all plots showed leaf K levels greater than the 1.05% threshold recommended by SASRI (Miles and Rhodes, 2008), yield response to K was significant (data not shown), indicating that, in the absence of applied K, the sugarcane was K deficient. No effect of K on eldana development and survival was found in a laboratory study by Denké *et al*. (2000); the present results therefore make the relationship between K and eldana worthy of further research.

Eldana and soil properties

Results from the eldana and soil surveys, conducted across a variety of soil types, indicate a number of interesting and previously unreported relationships between eldana damage and soil factors.

The trend for decreased eldana damage with increasing Si was illustrated above, where, in one case, Calmasil® application significantly decreased per cent internodes bored. Results from the eldana and soil survey were consistent with this finding. Figure 2 illustrates the association between increasing soil Si and lower eldana damage.

In Figure 2, the Cate-Nelson separation splits the data into two distinct groups. At 'higher' levels of available soil Si (>10 mg/L Si), eldana damage was low. Below 10 mg/L Si, however, the potential for eldana damage increases dramatically, with up to 78% internodes bored occurring in some cases. Clearly, therefore, where conditions are favourable for eldana, low-Si fields show significant potential for severe infestations and damage, while high-Si fields appear far more resilient.

It is noteworthy that this separation occurs at a value (10 mg/L Si) that is not far removed from the currently used FAS threshold of 15 mg/L for available Si.

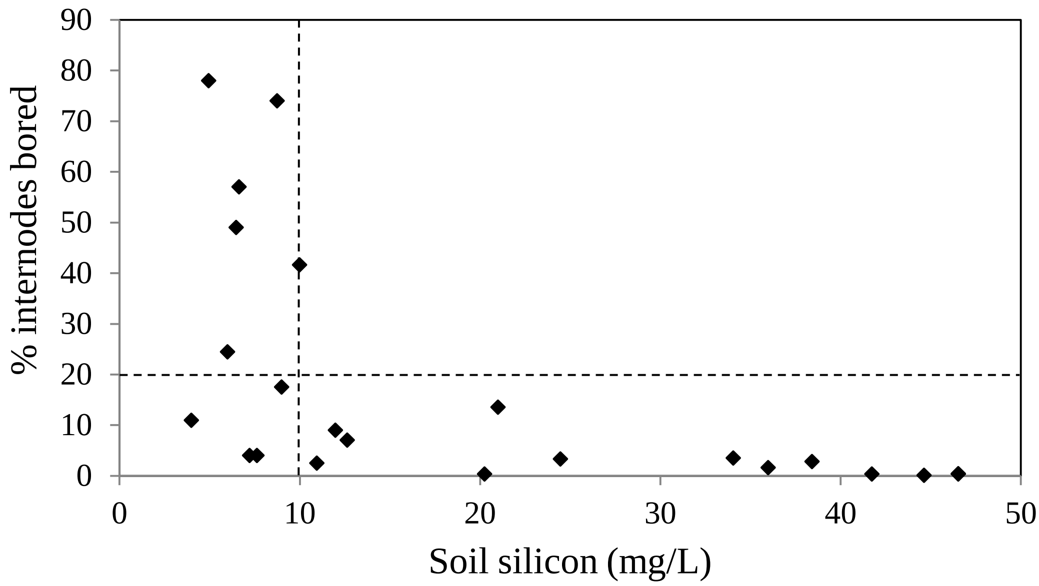
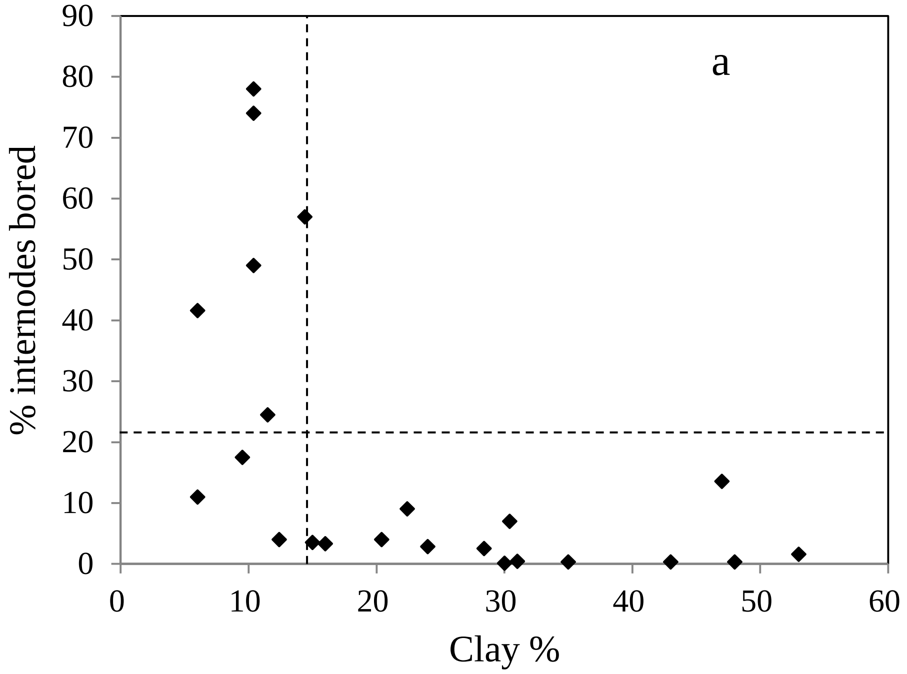


Figure 2. Per cent internodes bored by *Eldana saccharina* (eldana) larvae versus soil silicon level (mg/L) in 23 fields in the Midlands North, Midlands South and North Coast areas. Diamonds represent data points, while the dashed lines illustrate a Cate-Nelson separation.

Figure 3 depicts the relationship between eldana damage and clay and organic matter per cent.

The Cate-Nelson separation in Figure 3a again illustrates a division that can be made according to soil properties, in this case clay %. Above ~15% clay, internodes bored did not reach levels greater than 13.5% and seldom above 10%. Below 15% clay, however, eldana damage ranged as high as 80% internodes bored (Figure 3a).

The mechanism underlying this relationship is probably partly related to crop stress. As plants become stressed by weather or other environmental factors, increased amounts of nitrogen become available in the plant's tissues, improving the food source for young insects (White, 1984). There is a strong positive relationship between water stress and eldana damage and numbers (Atkinson and Nuss, 1989; Sithole *et al*., 2011). As the sugarcane plant becomes more stressed, so stalk N levels increase (Atkinson and Nuss, 1989). Although eldana moths do not appear to actively select more stressed sugarcane plants (Atkinson and Nuss, 1989) and larvae are limited in their motility and ability to choose their direction of movement (Leslie, 1993), ingestion of a higher-protein diet in stressed plants increases larval survival and biomass, while reducing life-cycle time (Atkinson and Nuss, 1989). 'Chance' arrival of eldana larvae on a stressed plant can thus lead to higher eldana populations (and therefore sugarcane damage) due to lower larval mortality and faster generation times. Increased clay content in soils leads to improved plant-available soil water (Or and Wraith, 2000); consequently, the higher a soil's clay content, the less often a crop growing on that soil is likely to experience water stress. Lower clay content soils are thus more likely to produce stressed crops, leading to greater eldana survival and damage to the crop.



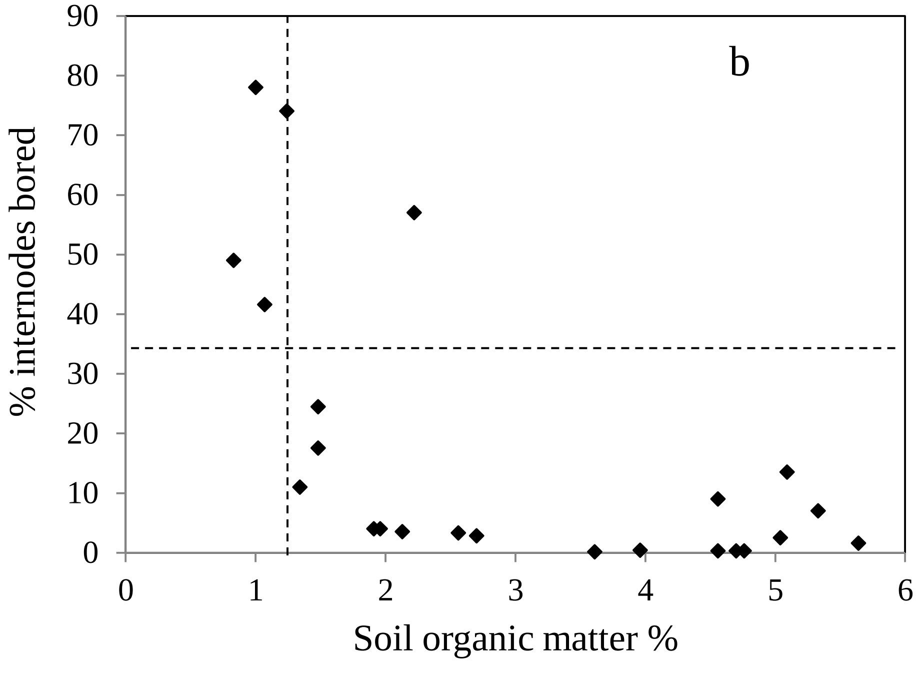


Figure 3. Per cent internodes bored by *Eldana saccharina* (eldana) larvae versus (a) clay % and (b) soil organic matter % in 23 fields in the Midlands North, Midlands South and North Coast areas. Diamonds represent data points, while the dashed lines illustrate a Cate-Nelson separation.

A similar trend is seen in Figure 3b, where eldana damage is plotted against soil organic matter. The Cate-Nelson separation here splits organic matter levels at ~1.2%, above which, with the exception of one data point, eldana damage levels are generally low. Below 1.2% organic matter, eldana damage levels are potentially high, presumably when environmental conditions are conducive (moisture stress). Organic matter plays a similar role to clay in terms of water-holding capacity (Baldock and Nelson, 2000) and its effects on crop stress, and so the relationship in Figure 3b is hardly surprising. In addition, clay protects and stabilises organic matter in the soil (Baldock and Nelson, 2000), with the result that clay % and organic matter % values are correlated in many soils; hence the similarity between Figures 3a and 3b.

Clay and organic matter levels in soil are, to some extent, conveniently reflected by the single measurement of volume weight (also called sample density). Increased organic matter leads to a lower volume weight, as does increasing clay content. Humic soils, therefore, with high clay and organic matter, typically have volume weights of 0.8-0.95 g/mL, while the densities of sandy soils are in the range 1.4-1.5 g/mL. Per cent internodes bored were plotted against the volume weight in each surveyed field. The results are presented in Figure 4.

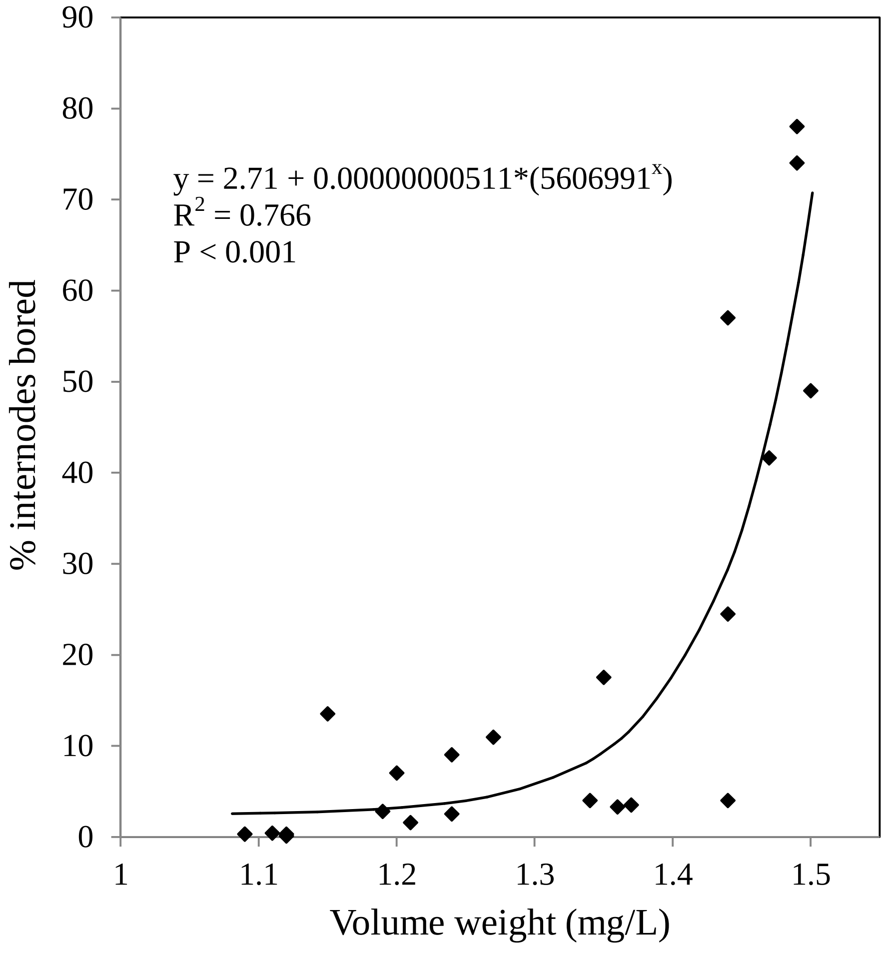


Figure 4. Per cent internodes bored by *Eldana saccharina* (eldana) larvae versus volume weight (mg/L) in 23 fields in the Midlands North, Midlands South and North Coast areas.

The exponential curve plotted in Figure 4 accounts for 76.6% of the variance in eldana damage, when plotted against volume weight. This relationship clearly indicates that as volume weight increases (decreasing clay and organic matter levels) so does the likelihood of eldana damage; sugarcane crops grown on soils with volume weights above approximately 1.25-1.30 mg/L showed a high susceptibility to eldana damage. Those grown on soils below this level (i.e. with higher clay and organic matter content) showed substantially lower overall levels of damage. This relationship, presumably arising largely from the increased potential for crop stress on sandy, low organic matter soils, has not previously been reported for eldana. It thus establishes and formalises an important link between soil characteristics and eldana damage potential.

Should N application rates be reduced to combat eldana damage?

This question was raised earlier in the paper. Evidence from pot trials (Atkinson and Nuss, 1989; Meyer and Keeping, 2005; Keeping *et al*., 2012) indicates that increasing N rates coupled with water stress were associated with significantly higher eldana damage than lower N rates. There is similar evidence from field trials (Carnegie, 1981; van Antwerpen *et al*. 2011); however, moisture stress was not considered. Present data, however, along with other field trial reports and commercial field surveys (Carnegie 1981; Atkinson and Nuss, 1989; Stranack and Miles, 2011), do not support these results, and consequently bring into question the practice of reducing field applied N in order to minimise eldana damage. This raises an economically challenging conundrum for growers and their advisers. The literature abounds with evidence of the positive effect of nitrogen on sugarcane yields (e.g. du Toit, 1958; Meyer *et al*., 1986; Keating *et al*., 1997; Stranack and Miles, 2011). At a rate of approximately 1.45 kg N/t cane (Meyer *et al*., 2007), R16 worth of N (at R11/kg N) would, under conducive growing conditions, produce roughly R300 in cane yield. Reducing N application rates by 20 kg/ha might, for argument's sake, reduce cane yields by 13 t cane/ha, impacting growers' economic returns. Would this be sufficiently offset by a concomitant reduction in eldana damage?

The soil and eldana surveys reported here shed some light on the situation. Fields with sufficient (>10 mg/L Si) soil silicon and low (<1.25 g/mL) volume weight, and under a wide range of environmental conditions, showed little propensity for high levels of eldana damage, regardless of N rate. It would appear, therefore, that N reductions to combat eldana damage on these soils are not warranted.

Conclusions

This paper considers the effects of certain soil characteristics and nutritional factors on the level of damage inflicted by *Eldana saccharina* in sugarcane

A noteworthy finding of this study was the high correlation of eldana damage with clay and organic matter levels in soil.

- Field surveys revealed that above ~15% clay, and/or ~1.2% soil organic matter, the potential for high levels of eldana damage was significantly reduced.
- According to the field surveys, eldana damage levels were far less likely to reach high levels in crops grown on soils with volume weights lower than approximately 1.25 to 1.30 mg/L.

Of 16 crops harvested in ten field N response trials, only three showed a significant increase in eldana damage with increasing N application rates, while in one trial damage decreased with increasing N. It is noteworthy that literature reports of N-induced eldana damage largely emanate from studies in pots, rather than the field. The findings in this paper thus bring into question the economic benefits of the widely accepted practice of reducing N application rates in order to minimise eldana damage.

It is the contention of the authors that reducing N application rates on soils with high clay and organic matter contents, while invariably leading to restricted sugarcane yields, are unlikely to cause significant reductions in eldana damage levels, and therefore appear unwarranted.

The field trial results provided limited experimental evidence for Si application as a means of protection against eldana damage. However, higher (>10 mg/L) levels of available soil Si were clearly associated with lower eldana damage; below this figure, high levels of damage could occur where conditions were conducive.

One set of field trial results indicated a significant reduction in eldana damage with increasing levels of K application. The role of K and other nutrients (e.g. calcium and phosphorus) in reducing eldana damage warrants further study.

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