THE IMPACT OF TRASH AND TILLAGE MANAGEMENT OPTIONS AND NEMATICIDE APPLICATION ON CROP PERFORMANCE AND PLANT-PARASITIC NEMATODE POPULATIONS IN A SUGARCANE/PEANUT FARMING SYSTEM

By

NV HALPIN[1], GR STIRLING[2], WE REHBEIN[1],
B QUINN[3], A JAKINS[3], SP GINNS[1]

[1]*Queensland Department of Agriculture, Fisheries and Forestry, Bundaberg,*
[2]*Biological Crop Protection, Moggill,*[3]*Isis Productivity Limited, Childers*

Neil.Halpin@daff.qld.gov.au

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Abstract

PLANT-PARASITIC NEMATODES (PPN) are a significant productivity constraint in the sugarcane farming systems of the Bundaberg/Childers region. This experiment was established to examine the impact of strategies like trash retention and reduced tillage on nematode populations and crop performance. A sugarcane field that was due for plough-out had two trash managements, green cane trash blanket (GCTB) retained or residues removed by burning (Burnt), split for two tillage treatments, conventional tillage (Conv.) and direct drill (DD). The site was sown to peanuts in August 2010. Following the peanut crop, the tillage treatments were re-instituted and sown to sugarcane (KQ228⁽ᴾ⁾) in September 2011 using a double-disc opener planter. When the established cane crop was at the four leaf stage all plots were split for +/– nematicide. Nematicide was applied to see if this option would retard the reinfestation of PPN during the plant cane phase. Treatments were split again for +/– nematicide in the ratoon phase. Trash management had no impact on peanut productivity whereas tillage did. The Conv. treatment produced 39% greater peanut yield than the DD treatment. Early plant cane development was retarded in the DD plots, a trend that continued through to the harvest of the plant cane crop where the Conv. treatment improved productivity by 36% compared to DD plots. However, there was no tillage effect on cane productivity in the R1 crop. While nematicide application in the plant cane crop significantly reduced total PPN numbers, there was no impact on yield. Application of nematicide to the ratoon crop significantly reduced sugar yield. This study confirmed other work demonstrating implementation of strategies like reduced tillage reduced populations of total plant-parasitic nematodes (TPPN) in the ratoon phase; suggesting that the soil was more suppressive to PPN in those treatments. Further work is required to over-come the lack of crop performance when the DD treatment is implemented for the peanut break crop and in the plant cane phase.

Introduction

Plant-parasitic nematodes (PPN) are a significant constraint to the productive capacity of sugarcane soils and cost the Australian industry 3.29M tonnes of cane annually (Blair and Stirling. 2007). Historically, nematodes were only thought to be an issue on sandy soils of Bundaberg (Bull 1981), but nematode survey work identified PPN in all soils growing sugarcane in the southern region (Blair *et al.*, 1999). Lesion nematode (*Pratylenchus zeae*) and root-knot nematodes (*Meloidogyne spp*) were considered the most important pest species based on abundance and density in the field (Blair *et al.*, 1999).

Root knot nematodes (RKN) are confined to sandy soils (<20% clay) and well-structured clay loams; whereas lesion nematodes were found in 100% of cane paddocks sampled (Blair *et al.*, 1999). *Meloidogyne javanica* accounted for 76% of the *Meloidogyne spp* isolated from southern sugarcane soils. PPN have been implicated as part of the biotic constraint of yield decline (Chandler, 1984; Pankhurst *et al.*, 2001). Yield decline is defined as the loss of the productive capacity of soils under long-term sugarcane production (Garside *et al.*, 1997).

The traditional method of controlling nematodes in sugarcane farming systems has been through the application of nematicide. Bull (1981) demonstrated productivity responses of 20%–60% when nematicides were applied in the Bundaberg district. However responses were variable, as nematicide application only controlled nematodes for a short time (49–77 days).

Breaking the sugarcane monoculture with legumes significantly reduces PPN populations and, at the same time, increases the population of beneficial free living nematodes (FLN) (Stirling *et al.*, 2002). In a monoculture, the FLN/PPN ratio is about 2:1 whereas following a legume break the ratio is 20:1.

This ratio can be used as a measure of soil health. However this change in PPN populations is short lived and there is no residual effect of cropping history by the ratoon phase (Blair and Stirling, 2007; Stirling *et al.*, 2002).

Stirling *et al.*, (2003) suggested that cultural and biological control should form the basis of nematode management strategies. They were able to demonstrate that soil suppression to PPN could be established through additions of organic matter and that this control lasted for seven months. Omnivore predators and fungi were positively correlated with suppression when organic materials with a high carbon to nitrogen (C/N) ratio (e.g. sugarcane trash) were used as a soil amendment.

The soil was most conducive to PPN populations when bacteria dominated the soil biology; similar to when legume residue was incorporated. They further suggested that manipulating the timing and method of incorporating cane and legume residue might alter the soil biology to one that is more suppressive to PPN (Stirling *et al.*, 2003).

Implementation of direct drill (no-till) planting techniques significantly reduced PPN populations in the first year after planting and also increased numbers of omnivorous and predatory nematodes in comparison to the conventional till treatment (Stirling *et al.*, 2010).

The latter observation indicated that direct drill treatments had a higher Structural Index, a measure of the stability of the soil food web.

This experiment was implemented to determine the practicality of trash management and tillage options as methods of improving soil health and suppression in a field situation. Treatment effects on peanut and sugarcane productivity as well as PPN populations were monitored.

To further assess treatment impact on PPN populations, treatments were split for +/–nematicide application in the plant cane crop and these plots were split again in (+/– nematicide) in the R1 crop.

Materials and methods

A paddock that had a history of PPN was selected for the trial. It was co-located with a trial that was reported in 2013 (Halpin *et al.*, 2013). The site was located at Toft's Rd Farnsfield on 'Quart' or Yellow Kandosol soil type. (Wilson 1997) describe this as a grey sandy loam surface soil over an acid mottled yellow sandy clay loam.

The field was sampled in July 2010 in a standing crop of Q190⁽ᴰ⁾ third ratoon sugarcane. Paddock average PPN populations are presented in Table 1.

Table 1—Numbers of plant parasitic nematodes (PPN) / 200 mL soil in July 2010.

RKN	Lesion	Spiral	Stubby	Dagger	Total PPN
173	113	66	160	12	524

The sugarcane crop was harvested as a green cane trash blanket (GCTB) in August 2010 and two trash management practices, burnt (Burnt) and GCTB, were instituted. These trash management practices were split +/– tillage. The tillage treatments were conventional (Conv.) and direct drill (DD). This provided four treatments GCTB DD, GCTB Conv., Burnt DD, Burnt Conv. in plots that were five cane rows wide (1.8 m) and 40 m in length.

The Conv. treatment consisted of two passes of a rotary hoe, followed by a deep ripping, then a final rotary hoe operation to provide adequate tilth. The cane stool was sprayed out in the DD plots through the application of Roundup Power Max @ 6 L/ha.

After burning the trash, and prior to imposing tillage, fine agricultural lime was applied at 3 t/ha to raise soil pH and ensure adequate calcium status for the following peanut crop. The potassium requirement of the peanut crop was supplied by the application of muriate of potash at 200 kg/ha, pre-plant. Lime and muriate of potash was broadcast on the soil surface to all treatments and then tillage treatments were applied.

The peanut crop was planted on 27 October using a modified double disc opener planter (Halpin *et al.*, 2010), with inoculant (Group P) supplied via water injection technique.

The peanut crop was grown using standard culture with weeds controlled via applications of herbicides and foliar diseases managed via fungicide applications on a 10–14 day basis. The peanut crop was harvested 156 days after planting.

After peanut harvest, the conventionally tilled plots had peanut residues incorporated and weeds controlled by one pass of a rotary hoe on two separate occasions. Weeds and volunteer peanuts were controlled via herbicide mixes of Glyphosate, 2,4-D and Fluroxypyr in the DD plots.

Sugarcane (KQ228) was planted on 7 September 2011 using a whole-stick planter modified with a double disc opener, to minimise soil disturbance. Shirtan® 250 mL/200 L water and Lorsban ® 1.5 L/ha was applied to the setts to prevent pineapple disease and wire worm attack respectively. Fertiliser, GF 506 at 176 kg/ha supplied 40 kgN, 3.5 kgP, 30 kgK and 8 kgS/ha, was supplied in a separate operation using a 'Flexicoil Barton Disc' opener 10 cm either side of the sett post planting. Pre-emergent herbicides Dual Gold® and Gramoxone® were applied at spiking stage.

All plots were randomly split for +/– nematicide (Nemacur 400®) that was applied at 10 L/ha (400 g/L Fenamiphos) when the plant cane crop was at the 4–5 leaf stage (4 November). The applicator was set up to apply the liquid chemical in a band approximately 20 cm either side of the plant line (40 cm treated band on the bed). The applicator was equipped with finger rakes to incorporate the chemical and it was irrigated in that evening.

The crop was side-dressed with another 70 kgK and 70 kgN/ha on 2 December when a slight profile was formed using discs. This action created some soil disturbance. Early sugarcane crop development was documented by means of shoot count.

A mid-season biomass assessment was conducted in the plant cane crop only. Both plant and ratoon crop yields were determined by hand harvesting (Liu and Kingston, 1993). CCS was determined from a six-stalk sub-sample.

The ratoon crop (R1) was grown as a GCTB over the entire trial and was fertilised to supply 140 kgN and 120 kgK/ha. All plots were randomly split for a further nematicide application of Rugby® 100G (100 g/kg Cadusafos) at 40 kg/ha on 1 November 2012. The granular nematicide was applied via a 'stool splitter' and irrigation was supplied that evening to activate the product. All crops were irrigated via a high pressure travelling irrigator.

Approximately 20 × 12 mm diameter cores to a soil depth of 10 cm were collected from each plot for nematode assessment. Nematodes were extracted from the soil by placing soil on a Baermann tray for 96 h (Whitehead and Hemming 1965). Nematodes were recovered by sieving twice over a 38 µm sieve.

Data were analysed using Genstat (release 16.1, VSN International) as a split plot design in the peanut phase with trash management being the main plots and tillage the sub-plots. The plant cane phase data was analysed as a split-split plot with nematicide application being the sub-sub-plot. The ratoon phase was analysed as a split-split design with whole plots being the original four treatments, nematicide application in the plant cane crop as the sub-plot and the ratoon nematicide application as the sub-sub-plot. Pair-wise test of means were conducted at P = 0.05 using Fischer's Protected LSD.

Results and discussion

Crop performance

Peanut

Tillage significantly affected productivity with the Conv. plots yielding 39% better nut-in-shell yield than the DD treatment (Table 2). (Halpin *et al.*, 2010; Halpin *et al.*, 2013) reported similar yield reductions in peanuts grown in sugarcane soils in the absence of tillage. Volunteer sugarcane and billy-goat weed (*Ageratum houstonianum*) were problematic in the DD plots, particularly in the GCTB DD treatment. It is likely that this competition would have negatively impacted on peanut performance.

Table 2—Trash and tillage management effects on nut-in-shell and kernel yield of peanuts. Treatment means followed by the same letter are not statistically different (P<0.05).

Treatment	Nut-in-shell yield (t/ha)	Kernel yield (t/ha)
Trash		
GCTB	3.61	2.55
Burnt	3.33	2.37
P value	0.244	0.336
Tillage		
DD	2.90[b]	2.06[b]
Conv.	4.04[a]	2.86[a]
P value	<0.001	0.002

There was a trend for trash management to interact with tillage treatment where maintaining trash in a tilled situation improved peanut productivity, yet reduced productivity in a direct drill situation (Figure 1). However this effect was not statistically significant (P = 0.099).

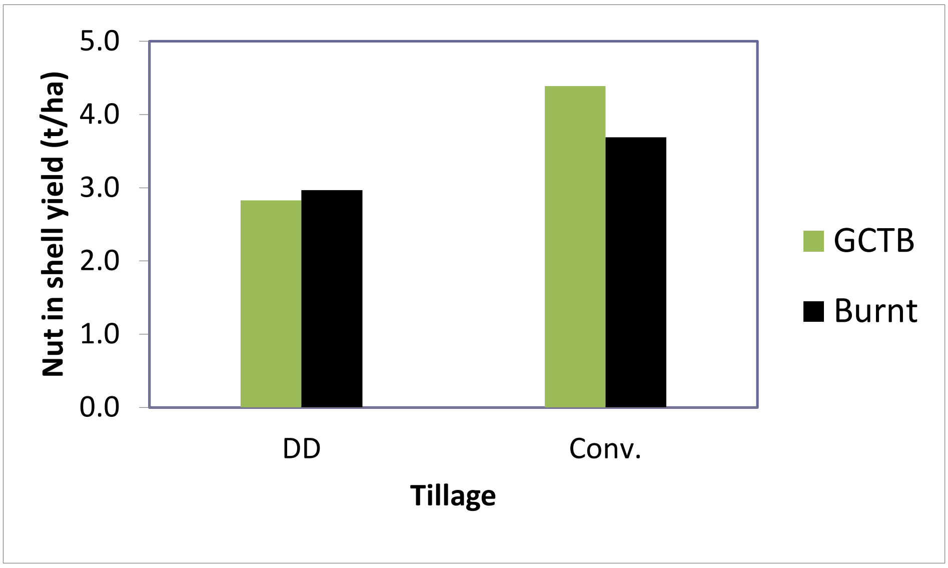

Fig. 1—Effect of trash management and tillage on peanut nut-in-shell yield (t/ha).

Sugarcane–plant crop

The DD treatment was slower to emerge than the Conv. treatments. This difference was maintained throughout the plant cane crop with the DD plots always having significantly fewer shoots than the Conv. plots (Figure 2). Trash management had no effect on shoot development. Similarly the nematicide application had no effect on shoot numbers with the exception of the number of shoots at harvest, where the untreated plots had 8% more shoots than the treated (Table 4). Weed management was more problematic in the DD treatment.

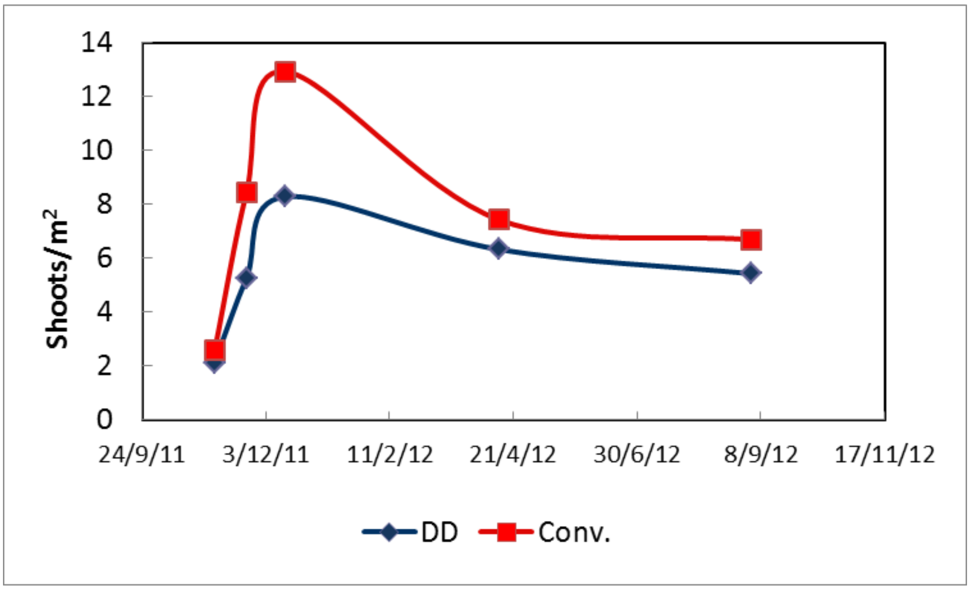

Fig. 2—Tillage effect on shoot development in the plant cane crop, shoots/m^2.

Nematicide application or previous cane crop trash management had no effect on productivity at the time of mid-season biomass sampling in April. However, the Conv. treatment had 29%, 26% and 17% more total biomass (fresh weight), total biomass (dry weight) and stalks than the DD treatment respectively (Table 3). There were no treatment interactions.

Table 3—The effect of trash management, tillage and nematicide application on sugarcane productivity and stalk numbers in April 2012. Treatment means followed by the same letter are not statistically different (P<0.05).

	Total biomass fresh weight (t/ha)	Total biomass dry weight (t/ha)	Stalks/m^2
Trash management			
GCTB	107.4	22.78	6.81
Burnt	108.3	23.74	6.93
P value	0.865	0.321	0.564
Tillage			
DD	94.1b	20.61b	6.32b
Conv.	121.6a	25.91a	7.42a
P value	0.013	0.020	0.021
Nematicide application			
No	107.3	23.17	6.86
Yes	108.4	23.34	6.88
P value	0.730	0.771	0.946

The tillage treatment effect on productivity measured in the mid-season assessment continued through to harvest. The Conv. plots yielded 36% more cane and sugar yield than the DD plots. This increased productivity was driven by 23% more stalks in the Conv. plots than in the DD treatment. There was a non-statistical trend for the Conv. plots to also have a higher individual stalk weight (Table 4).

The tillage response at this trial is surprising as a co-located tillage trial that was planted with a whole-stick planter with a conventional opener immediately after this trial produced no tillage response(Halpin *et al.*, 2013).

Potentially, the lack of soil disturbance, reduction in planting material (eyes/ha), greater weed pressure and lower soil temperature could explain these differences in performance between the two planters/trials. However, none of these variables were measured in enough detail to compare the two trials.

Neither nematicide application nor previous cane crop trash management impacted any of the measured crop performance indicators at harvest.

If anything, there was a trend for the application of nematicide to reduce crop performance. There were no statistically significant interactions (data not shown).

Table 4—Trash management, tillage and nematicide application impacts on total biomass, cane yield, CCS, sugar yield, stalks/m^2 and individual stalk weight of the plant cane crop. Treatment means followed by the same letter are not statistically different (P<0.05)

	Total biomass (t/ha)	Cane yield (t/ha)	CCS	Sugar yield (t/ha)	Stalks/m^2	Individual stalk weight (kg/stalk)
Trash management						
GTCB	122.1	91.2	15.47	14.07	5.97	1.53
Burnt	125.4	92.3	15.40	14.19	6.13	1.47
P value	0.769	0.910	0.651	0.936	0.728	0.259
Tillage						
DD	106.4^b	77.6^b	15.48	11.98^b	5.42^b	1.45
Conv.	141.1^a	105.9^a	15.39	16.29^a	6.68^a	1.56
P value	0.005	0.008	0.683	0.004	0.021	0.196
Nematicide application						
No	126.5	93.9	15.49	14.52	6.30^a	1.54
Yes	120.9	89.5	15.39	13.74	5.80^b	1.47
P value	0.120	0.175	0.449	0.132	0.015	0.210

Sugarcane–ratoon crop

The tillage treatment that dominated plant growth responses in the plant cane crop didn't carry through to the ratoon crop. There was no effect of nematicide application on the plant cane cycle on the ratoon crop's productivity.

Interestingly, the application of nematicide at the start of the ratoon phase significantly reduced total biomass, and cane yield. This response was driven by a significant reduction in the individual stalk weight. CCS was depressed by the R1 nematicide application, combined with reduced cane production resulted in a significant sugar yield penalty of 1.3 t/ha (Table 5).

The exact reason for the yield reduction where the nematicide was applied in R1 is unclear, possibly the action of the coulter stool splitting may have contributed to the response.

Table 5—Trash and tillage management and nematicide application in the plant and ratoon crop effect on total biomass, cane yield, CCS, sugar yield, number of stalks/m2 and individual stalk weight in the ratoon 1 crop. Treatment means followed by the same letter are not statistically different (P<0.05).

	Total biomass (t/ha)	Cane yield (t/ha)	CCS	Sugar yield (t/ha)	Stalks/m^2	Individual stalk weight (kg/stalk)
Trash and tillage management						
GTCB DD	129.5	96.3	13.78	13.28	7.88	1.220
GCTB Conv.	127.8	96.8	13.76	13.32	7.93	1.205
Burnt DD	133.9	99.9	13.69	13.70	8.09	1.220
Burnt Conv.	133.8	100.6	13.73	13.82	8.08	1.270
P value	0.744	0.690	0.918	0.791	0.762	0.530
Plant cane nematicide application						
No	130.2	97.5	13.79	13.46	7.99	1.21
Yes	132.3	99.3	13.69	13.60	8.00	1.24
P value	0.497	0.370	0.302	0.592	0.969	0.196
R1 nematicide application						
No	135.7[a]	102.0[a]	13.90[a]	14.18[a]	8.06	1.27[a]
Yes	126.8[b]	94.8[b]	13.58[b]	12.88[b]	7.94	1.18[b]
P value	0.011	0.016	<0.001	0.003	0.393	0.002

Nematode populations

The peanut rotation reduced the total number of PPN (Figure 3), only for the populations to re-establish in the plant cane phase. This has been well established (Stirling *et al.*, 2002).

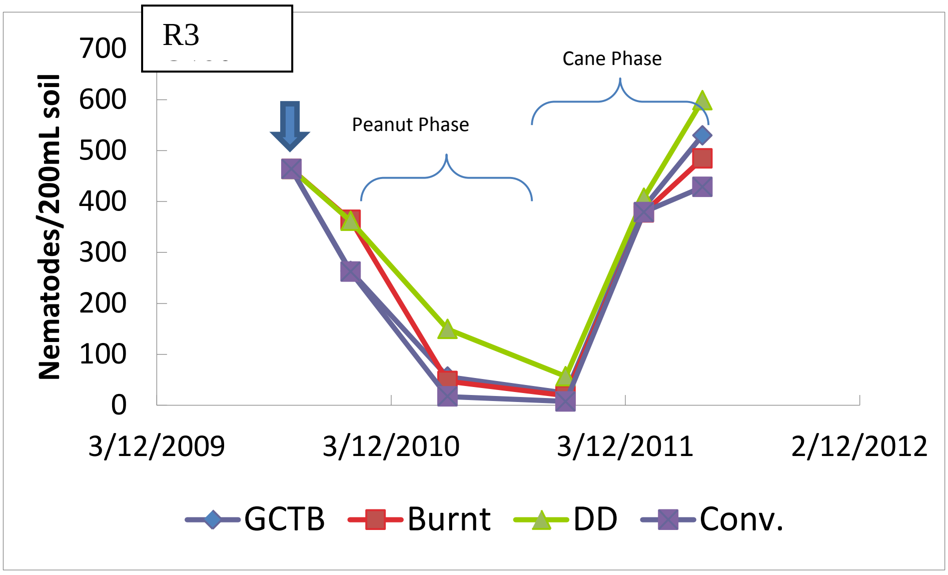

Fig. 3—Crop sequence effect on the total number of PPN. Values are back-transformed means (log x+1).

Trash management had no effect on the population of root knot (RKN), lesion or total plant parasitic nematode (TPPN) populations in the peanut or plant cane phase.

However, there were significantly more TPPN in the DD treatment than in the tilled plots during the peanut crop (Figure 4). This effect may have been driven by the poor control of weeds (*Ageratum houstonianum*) and volunteer sugarcane particularly in the GCTB DD treatment.

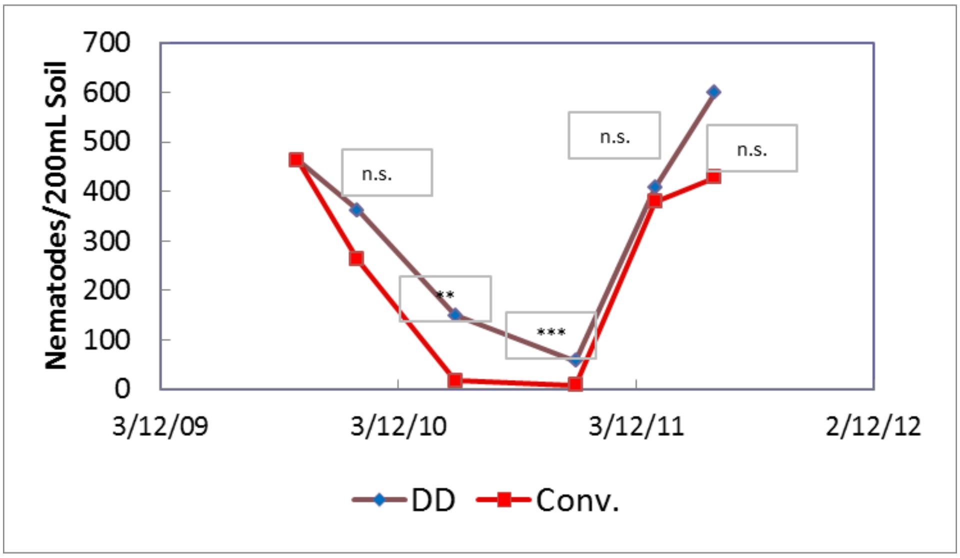

Fig. 4—Tillage effect on total plant parasitic nematode (TPPN) populations during peanut and plant cane phases. Values are back-transformed means. (n.s. = not significant; ** = P=0.001; *** = P=<0.001).

The poor correlation between numbers of TPPN in April 2012 and the sugarcane yield in the plant cane crop would suggest that the higher populations of TPPN in the DD treatment were not responsible for the low productivity of the DD treatment (Figure 5).

Similarly, there was no sugarcane yield response to nematicide application in the plant cane crop (Table 4), where if the numbers of TPPN were a yield constraint, productivity should have increased by the application of the control agent.

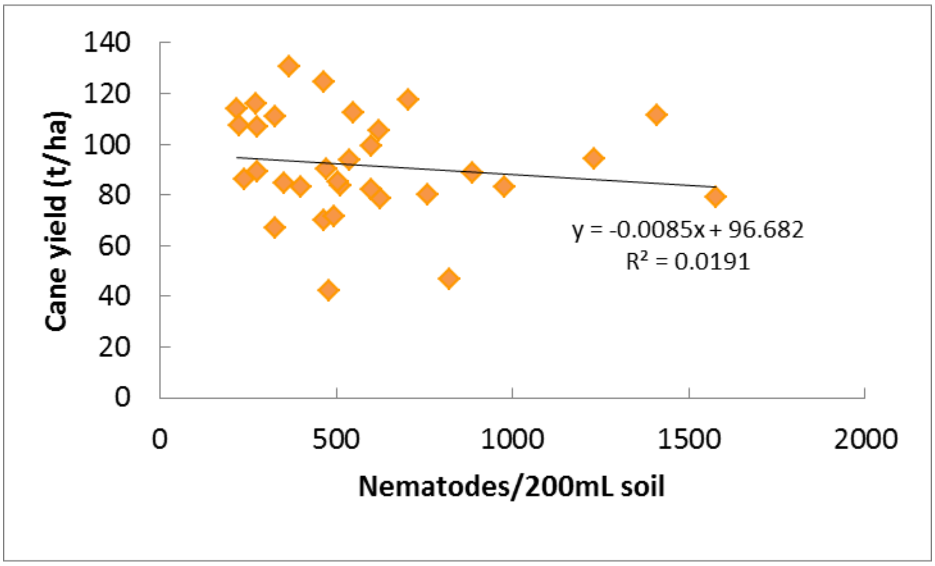

Fig. 5—Correlation between the number of TPPN in April 2012 and plant cane yield.

Nematicide applied to the plant cane crop (4 November 2011) significantly reduced the TPPN during the plant cane cycle by 40%. While there was still evidence of the plant cane nematicide still having an effect at the time of splitting plots for the R1 nematicide application, by the May 2012 sampling the nematicide effect was no longer apparent (Figure 6).

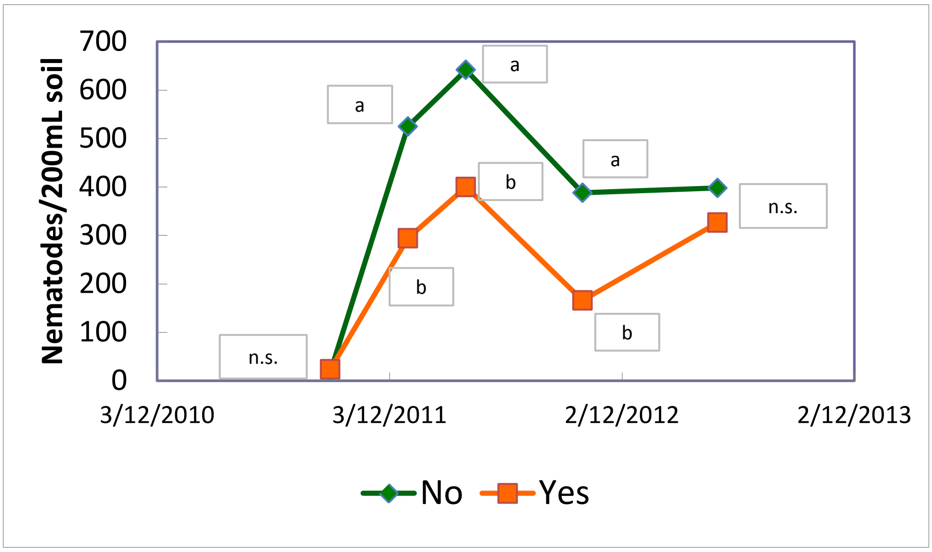

Fig. 6—Effect of nematicide application to the total number of PPN in the plant cane crop. Values are back-transformed means. Data points with different letters at a sampling date are significantly different (P=0.05).

The main reason we failed to obtain a growth or yield response to nematicides (Table 4) was that sugarcane was planted after peanut, which reduced nematode populations. For example, the highest populations of RKN for the April 2012 sampling were in the GCTB DD treatment, where there were 288 RKN/200 mL soil.

All other treatments had populations ranging from 112 to154 RKN/200 mL soil. At the same sampling time, the lesion nematode population was less than 150 nematodes/200 mL soil.

Nematicides were applied to determine if this would prevent the resurgence of nematode numbers in the plant cane crop, and perhaps see a response in the ratoon phase.

However, the poor efficacy of a single treatment meant that no response was obtained. Blair and Stirling (2007) used multiple applications of nematicide per season to reduce nematode populations and keep them low.

Nematode assessment prior to the harvest of the R1 crop revealed a trend for reduced lesion nematodes in the plots that received a nematicide application in the plant cane cycle. However this trend wasn’t statistically significant (P=0.053, Table 6).

Other than this result there was no effect of nematicide application on PPN. There was no effect on nematode populations from the R1 nematicide application.

The plots that were cultivated between crop cycles (from cane to peanuts and then from peanuts to cane) had the highest populations of TPPN prior to the harvest of the R1 crop (Table 6).

There was a trend for 57% more TPPN in the GTCB Conv. than in the GCTB DD treatment however this wasn’t statistically different.

There were significantly more TPPN in the Burnt Conv. plots than in the Burnt DD plots. Despite these differences in nematode populations there was no trash and tillage management effect on R1 crop productivity (Table 5).

Table 6—Root knot (RKN), lesion and total plant parasitic nematode (TPPN) numbers /200 mL soil in mid-May 2013 prior to the harvest of the first ratoon (R1) crop. Values are log (x+1) transformed (values in parenthesis are back-transformed means). Values followed by the same letter are not statistically different (P=0.05).

	RKN	Lesion	TPPN
Trash and tillage management			
GCTB DD	1.749 (55)	2.157 (143)	2.475[ab] (298)
GCTB Conv.	2.292 (195)	2.226 (167)	2.670[a] (467)
Burnt DD	1.652 (44)	2.127 (133)	2.426[b] (266)
Burnt Conv.	2.364 (230)	2.216 (163)	2.661[a] (457)
P value	0.072	0.567	0.042
Plant cane nematicide application			
No	2.017 (103)	2.254 (178)	2.601 (398)
Yes	2.012 (102)	2.108 (127)	2.515 (326)
P value	0.976	0.053	0.232
R1 nematicide application			
No	1.965 (91)	2.190 (154)	2.525 (334)
Yes	2.063 (115)	2.172 (148)	2.591 (389)
P value	0.378	0.763	0.193

Conclusion

This study has confirmed results from previous studies (Stirling *et al.*, 2010) that the implementation of reduced tillage techniques improves soil suppression, as demonstrated by the reduction in TPPN prior to the harvest of the R1 crop in the reduced tillage plots. However the difficulty of controlling volunteer cane and in-crop weeds in the peanut phase reduced the 'break effect' of the rotation crop in the direct drill treatment.

For this system to be transferable/adopted by industry, significant experimentation would be required to improve productivity of peanut crops that are sown directly into a GCTB situation. Similar work is required to improve the productivity of cane planted directly into a bed that has been undisturbed using a whole-stick planter with double disc openers.

This experiment highlighted a 1.14 t/ha nut-in-shell peanut and a 4.31 t/ha sugar yield reduction (in the plant cane crop only) through the implementation of direct drill relative to conventional tillage. That said, a co-located experiment highlighted no sugarcane yield reduction through the implementation of direct drill using a conventional opener.

This study has highlighted that growers shouldn't view nematicides as a 'cure all' for paddocks that have historically had high PPN numbers. Nematicides have high mammalian toxicity, have the potential to contaminate ground water (Kookana *et al.*, 1995) and are costly.

The cost of nematicide used in R1 was approx. $320–$350/ha, adding $3.50/t of cane in a 100 t/ha crop. Also, our study demonstrated that a single nematicide treatment at the application rate registered for sugarcane is not very effective in reducing populations of nematode pests.

Sugarcane is better managed in terms of water and nutrient inputs compared to the 1970s when Bull's experiments were conducted; therefore it is likely that crops now can better cope with nematodes.

The authors suggest the implementation of rotation crops like peanuts, adoption of precision controlled traffic farming to facilitate a reduction in tillage and maintenance of crop residues as primary tools to reduce the impact of nematodes.

Recent work has shown that soil immediately under the trash blanket is biologically suppressive to nematode pests (Stirling *et al.*, 2011a; Stirling *et al.*, 2011b) and so the challenge of the future is to improve farming systems so that suppressiveness is enhanced further down the profile.

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