Proceedings of the Australian Society of Sugar Cane Technologists, volume 41, 231-239, 2019

Peer-reviewed paper

Does rotating cultivars with intermediate resistance influence pachymetra root rot of sugarcane?

AS Jensen[1], BJ Croft[2], RC Parfitt[1] and PH Brown[3]

[1]*Sugar Research Australia Limited, Bundaberg, Qld 4670;* ajensen@sugarresearch.com.au
[2]*Sugar Research Australia Limited, Indooroopilly, Qld 4068*
[3]*CQUniversity, Bundaberg, Qld 4670*

Abstract Concerns have been raised by industry members over lower than expected cane yields associated with high oospore levels in sugarcane cultivars rated to have intermediate resistance to pachymetra root rot. This is a significant issue, as intermediate cultivars represent more than 70% of the sugarcane grown in Australia. It is possible that planting the same intermediate cultivar in successive crop cycles could lead to increased yield losses due to pachymetra root rot. This paper examines the residual soil-borne effect of the current major sugarcane cultivars on the following sugarcane crop in three field trials, located in the Herbert, Central and Southern growing regions. Levels of oospores of *Pachymetra chaunorhiza* and cane yields were assessed in ratoon crops of replicated cultivar-assessment trials and in subsequent crops of intermediate-resistant Q208$^{\phi}$ (planted on the sites of previous cultivar trials). The relationships between *Pachymetra* oospore levels and cane yield in Q208$^{\phi}$ crops and pre-plant oospore levels were examined. High oospore levels occurred in plots planted to some intermediate cultivars, as well as susceptible cultivars. In the following crop of Q208$^{\phi}$, which was planted into plots of the previous cultivar trial, *Pachymetra* oospore levels at harvest were related to oospore levels prior to re-planting at all trial sites. Cane yield (t/ha) of Q208$^{\phi}$ was significantly related to pre-plant oospore levels at a site near Bundaberg (P=0.0049). Yield losses of 21% were incurred at 120 oospores/g soil in Q208$^{\phi}$. Cultivation of Q208$^{\phi}$ following a crop of Q208$^{\phi}$ did not result in higher *Pachymetra* oospore populations or yield losses compared with planting Q208$^{\phi}$ after other cultivars of similar resistance rating. In the Herbert and Central field trials, *Pachymetra* oospore levels were lower and there were no significant relationships between oospore levels and yield in Q208$^{\phi}$ planted at these sites. We demonstrate that significant yield losses in Q208$^{\phi}$ are associated with high *Pachymetra* oospore levels that occur under intermediate and susceptible cultivars in the previous crop. There was no evidence to support the hypothesis that repeatedly planting the same intermediate cultivar could lead to host-cultivar-specific virulence in *P. chaunorhiza*. Greater emphasis should be placed on breeding and selecting highly resistant cultivars that are suited to soil types conducive to *Pachymetra*.

Key words *Pachymetra chaunorhiza*, cultivar resistance, yield loss, virulence

INTRODUCTION

Pachymetra root rot is an important disease of sugarcane and is endemic to Australia (Croft *et al.* 2000). The causal agent, *Pachymetra chaunorhiza*, is an oomycete of the family Verrucalvaceae (Dick *et al.* 1989). *Pachymetra* causes necrosis of the primary sugarcane roots, leading to stunted crop growth and dislodging of the root system during harvest (Magarey 1991b). The disease is spread through the soil by distinctly verrucous, thick-walled oospores, which can remain viable in the soil for more than 5 years. Pachymetra root rot is widely distributed and causes significant yield losses in the Northern, Herbert, Central (Mackay) and Southern (Bundaberg to Rocky Point) sugarcane-growing regions (Magarey 1995; Magarey *et al.* 2013; Holzberger *et al.* 2016). Cane yield loss in the intermediate cultivar Q124 was estimated to be 20% at 120 oospores/g soil (Magarey 1995). The relationships among cane yield loss, stool tipping and *Pachymetra* inoculum density is well established (Magarey 1994; Magarey and Bull 2008; Bhuiyan *et al.* 2016).

Resistant cultivars are the main management strategy for pachymetra root rot, as well as many other diseases of sugarcane. New cultivars are screened for *Pachymetra* resistance prior to release using a glasshouse pot technique (Croft 1989; Croft *et al.* 1998). *Pachymetra* resistance ratings of cultivars have been shown to be strongly related to soil oospore levels in plant and early ratoon crops of field trials (R^2>0.70 in most studies; Magarey 1991a; Magarey and Mewing 1994; Magarey *et al.* 2008; Magarey and Bull 2011). *Pachymetra* levels are monitored in commercial fields by counting the number of oospores present in soil samples (Magarey 1989a,b). Recommendations for cultivar selection and management of *Pachymetra* levels are made to growers based on the oospore thresholds measured prior to crop removal (in the previous crop) where possible, or else in the fallow period after cultivation (Plunkett and Magarey 2014).

Many of the *Pachymetra*-resistant cultivars are susceptible to sugarcane smut (caused by the fungus *Sporisorium scitamineum*) and have not been planted since the smut incursion in Queensland in 2006 (Bhuiyan *et al.* 2016). In 2017, more than 30% of sugarcane produced in Australia was attributed to Q208$^{\phi}$ (SRA 2018), a major commercial cultivar in all cane-growing regions – it is categorized as having intermediate resistance to pachymetra root rot. High oospore levels and higher than expected yield losses have been reported in some of the current commercial cultivars categorized as having intermediate resistance to *Pachymetra*, including Q208$^{\phi}$ and Q232$^{\phi}$ (Bhuiyan *et al.* 2016).

Here, we investigate the residual soilborne effect of different sugarcane cultivars on *Pachymetra* oospore populations and cane yield in a subsequent crop of the intermediate-resistant cultivar Q208$^{\phi}$.

MATERIALS AND METHODS

Trial design

Existing cultivar trials in the Herbert, Central and Southern regions were chosen as a basis for this study in order to provide a planting history of different cultivars at the same site in a replicated experimental design. Plots in each cultivar trial consisted of four rows of cane each 10 m long.

Experiment 1 – Southern region field trial

Experiment 1 was located on a sandy soil type at Yandaran (24°40'28.44"S, 152°6'58.38"E), north of Bundaberg. This field had high *Pachymetra* levels due to cultivation of the susceptible cultivar Q155 prior to 2011. A cultivar trial (Bhuiyan *et al.* 2016) was planted into this block in 2011 and harvested annually from 2012 to 2016. The trial consisted of five replicates of 16 cultivars, planted in a randomised complete-block design.

Experiment 2 – Herbert region field trial

A second-ratoon SRA plant-breeding program Final Assessment Trial (FAT) located near Abergowrie (18°29'24.02"S, 146°00'7.00"E) was used as a basis for Experiment 2. The soil type at this site was an Abergowrie red loam (Queensland Government 2018). This existing FAT consisted of 163 cultivars planted in a partially replicated design. Five commercial cultivars (with six replicates) and three experimental clones (Q253$^{\phi}$, QN05-1339 and QN05-178, each with two replicates) were selected for assessment (Table 1).

Experiment 3 – Central region field trial

A third-ratoon SRA plant-breeding program FAT located near Marian (21°6'52.97"S, 148°56'41.70"E), on a sandy clay loam soil type, was used as a basis for Experiment 3. This plant-breeding trial was planted in 2013 and harvested annually from 2014 through to 2017. The trial consisted of 72 cultivars, planted in a partially replicated design. Five commercial cultivars were selected for assessment, each having two replicates.

Planting and data collection

Replicated cultivar trials

Prior to harvesting the final ratoon crop of each cultivar trial, the positions of trial plots were marked using a 3M underground system. Marker balls were buried at a sub-cultivation depth of 60 cm.

Cultivar trials were harvested after approximately 12 months growth. Cane yield (t/ha) of the two centre rows in each four-row plot was measured using a commercial harvester and weighing truck.

Pachymetra oospore levels were measured in plots of the selected cultivars at harvest (or close to harvest) of the cultivar trial. Four soil cores were taken from each of the two middle rows using a 4 cm Dutch auger. Sampling was performed close to the stool on top of the row profile and to a depth of 25 cm. Soil samples were combined, thoroughly mixed by hand, and then a sub-sample of approximately 400 g was sent to the SRA assay laboratory at Tully for oospore quantification using standard methodology (Magarey 1989a,b).

Cultivar trials were ploughed-out and the dilution of oospore populations due to cultivation was estimated. Plots of the selected cultivars from two of the five replicates in Experiment 1, three of the six replicates in Experiment 2 and both replicates of Experiment 3 were sampled. The mean dilution of *Pachymetra* oospores at each site was calculated (dilution factor=average oospores/g soil post-cultivation/average oospores/g soil pre-cultivation). Pre-plant oospore levels in each plot were estimated by transforming oospore count data from the cultivar trial based on the overall dilution factor at each site (pre-plant oospores/g soil=oospores/g soil in cultivar trial x dilution factor).

Q208Φ planting

Q208Φ was planted across the plots of the previous cultivar trial, using a whole-stalk planter. GPS guidance was used at all three sites, so that cane billets were planted in the same row position as the previous planting.

Cane yield and oospore levels were measured at harvest of the Q208Φ plant crop (all sites) and a first-ratoon crop (Experiment 1) after approximately 12 months growth, as described above.

Data analysis

We first used analysis of variance procedures (ANOVA) on a combined dataset, across trials. The interaction between cultivar and site was highly significant for oospore counts in all crops ($P<0.0001$), therefore data were analysed separately for each site and crop. All oospore count data were analysed using a negative binomial generalised linear model. Cane yields (t/ha) were analysed using a linear mixed model (ASReml-R) (Butler *et al.* 2009). Pairwise comparisons of predicted means used the Tukey's HSD test ($P=0.05$). Linear regression analyses were carried out in order to relate: a) pre-plant oospore levels to oospore levels at harvest of the Q208Φ crops; and b) pre-plant oospore levels to cane yield (t/ha) in the Q208Φ crops.

RESULTS

Pachymetra levels under different cultivars

Experiment 1 – Southern region field trial

All resistant cultivars had significantly lower oospore levels than intermediate and susceptible cultivars (Table 1) at the Yandaran trial site. Levels in intermediate cultivars were not significantly different to those in susceptible cultivars. Oospore levels under the intermediate cultivar Q232Φ were significantly higher than oospore levels under another intermediate cultivar, Q200Φ, and all resistant cultivars. Cultivation of this site resulted in dilution of within-row oospore levels by a mean of 80%.

Experiment 2 – Herbert region field trial

Pachymetra levels in the cultivar trial at Abergowrie were significantly lower than *Pachymetra* levels at the Yandaran trial. Oospore populations varied among treatments ($P=0.0049$). Both Q232Φ and Q208Φ had significantly higher oospore populations than Q200Φ (Table 1). *Pachymetra* levels were diluted by a mean of 3% due to cultivation of the Abergowrie site.

Table 1. *Pachymetra* oospore levels under different clones in cultivar trials located at Yandaran, Abergowrie and Marian prior to cultivation.

Clone	*Pachymetra* resistance		*Pachymetra* oospores/g soil		
	Category	Rating^	Yandaran	Abergowrie	Marian
Q183Φ	Resistant	1	25.1[a]	11.9[ab]	12.2[a]
Q242Φ	Resistant	2	23.6[a]		
Q238Φ	Resistant	3	45.9[a]		22.6[a]
KQ228Φ	Intermediate	5	474.3[bc]		133.2[b]
Q200Φ	Intermediate	5	290.7[b]	5.4[a]	72.2[b]
Q208Φ	Intermediate	5	462.4[bc]	39.6[b]	173.3[b]
Q232Φ	Intermediate	5	799.6[c]	51.2[b]	
Q240Φ	Intermediate	5	418.1[bc]	10.2[ab]	
Q253Φ*	Intermediate	5		19.0[ab]	
QN05-1339*	Susceptible	7		23.0[ab]	
QN05-178*	Susceptible	7		39.2[ab]	
Q155	Susceptible	9	349.4[b]		
Q171	Susceptible	9	593.3[bc]		

^ *Pachymetra* resistance rating, where 1=highly resistant and 9=highly susceptible.
*Resistance ratings of unreleased clones are based on fewer ratings than commercial cultivars.
Means followed by the same letter(s) are not significantly different among treatments at a significance level of P=0.05, according to a Tukey HSD test.

Experiment 3 – Central region field trial

Pachymetra levels in the cultivar trial at Marian were significantly lower than *Pachymetra* levels at the Yandaran trial, but were not significantly different to oospore levels at the Abergowrie trial. Mean oospore levels under the cultivar trial at Marian varied among cultivars at a significance level of P<0.0001. *Pachymetra* populations under the resistant cultivars Q183Φ and Q238Φ were significantly lower than under the intermediate cultivars KQ228Φ, Q200Φ and Q208Φ. Oospore levels under intermediate cultivars were not significantly different (Table 1). Cultivation resulted in dilution of oospore levels within the row by a mean of 57% prior to replanting with Q208Φ.

Pachymetra oospore dynamics under subsequent crops of Q208Φ

Experiment 1 – Southern region field trial

Pachymetra levels generally increased in plots with lower pre-plant oospore levels and decreased in plots with higher pre-plant oospore levels by the end of the Q208Φ plant crop (Figure 1A). Oospore levels varied among plots previously planted to different cultivars at the end of the plant crop of Q208Φ (P<0.0001). *Pachymetra* levels increased (4–8 times greater) under the Q208Φ plant crop in plots where resistant cultivars were grown previously, but were still significantly lower than where intermediate or susceptible cultivars were grown previously. Oospore populations decreased or showed little change during the Q208Φ plant crop in most treatments where intermediate cultivars (mean decrease of 0.6%) or susceptible cultivars (mean decrease of 16%) were grown previously. The relationship between oospore levels under the Q208Φ plant crop and pre-plant oospore levels was highly significant (P=0.0020). *Pachymetra* populations under the Q208Φ plant crop were greater than predicted (based on the regression analysis in Figure 1A) in plots where Q200Φ was grown previously; however, oospore levels were not significantly higher in plots where Q208Φ was grown previously. Oospore levels were significantly lower than predicted under the Q208Φ plant crop in plots where Q171 was grown previously.

Pachymetra oospore populations measured at the end of the Q208Φ plant crop increased by approximately 50% by the end of the first ratoon. Inoculum levels increased in all cultivar treatments in the first ratoon (Figure 1B), unlike the plant crop (where oospore populations generally increased in plots where resistant cultivars were grown previously and showed little change under other treatments). Oospore levels at the end of the first ratoon varied among treatments at a significance level of P=0.004. Oospore populations remained significantly lower in plots where resistant cultivars were grown previously (mean 57.3 oospores/g soil), compared to under plots where Q232Φ was grown previously (162.9 oospores/g soil). *Pachymetra* levels under different cultivar treatments in the Q208Φ first ratoon were highly related to oospore levels under the Q208Φ plant crop (P=0.0005). Inoculum levels under the Q208Φ first ratoon were higher than predicted based on the regression in plots where Q171 or Q240Φ

were grown previously, and lower than predicted in plots where Q200ᶲ was grown previously. Oospore populations under the ratoon crop remained as predicted in plots where Q208ᶲ was grown in both plantings.

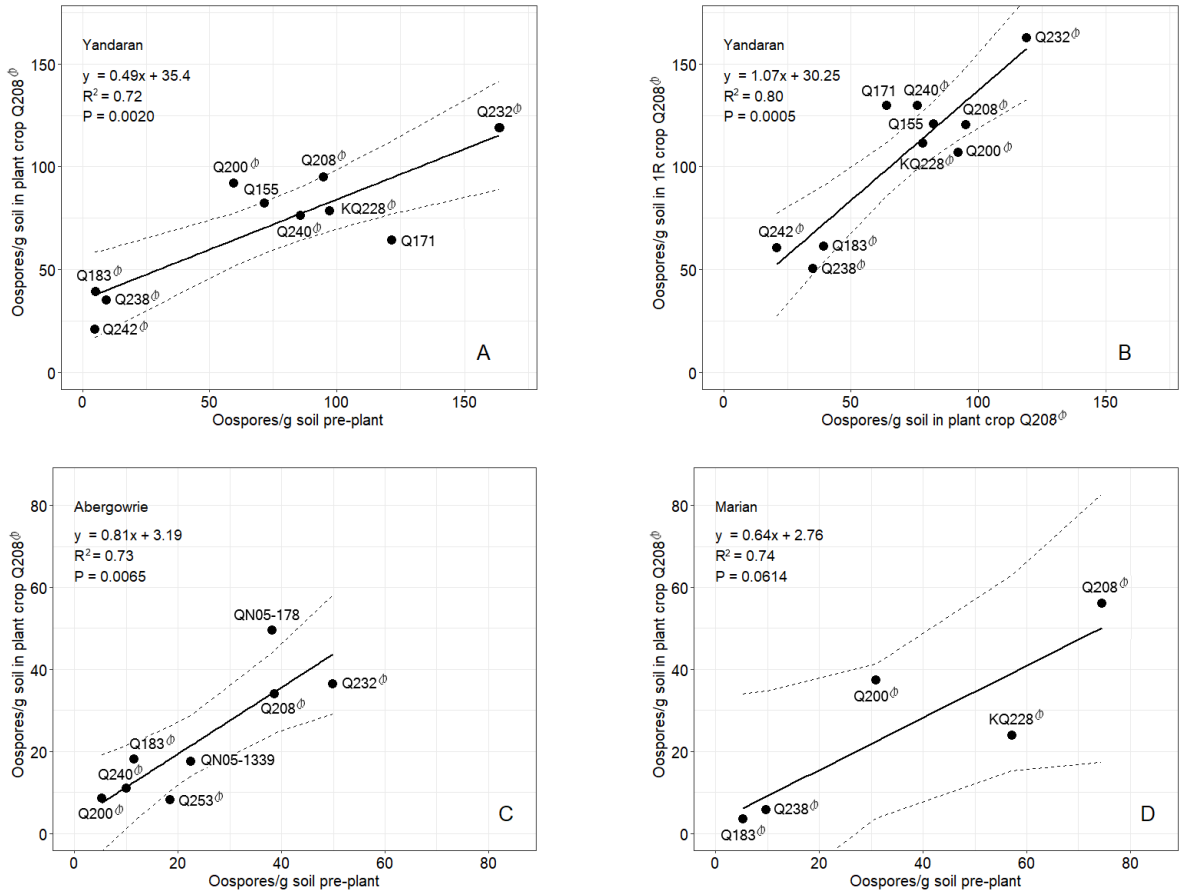

Figure 1. Regression of final and initial *Pachymetra* oospore levels under Q208ᶲ plant and first-ratoon crops in field experiments located at Yandaran (A, B), and plant crops at Abergowrie (C) and Marian (D). Data labels indicate the cultivar grown in the previous planting. Broken lines indicate 95% confidence intervals. Axes of graphs (C) and (D) are scaled to half that of (A) and (B) due to lower oospore levels at these sites.

Experiment 2 – Herbert region field trial

Pachymetra levels varied at the end of the Q208ᶲ plant crop among treatments (P=0.0087, Figure 1C). *Pachymetra* populations increased under the Q208ᶲ plant crop in plots where the resistant cultivar Q183ᶲ (56% increase) or the intermediate cultivar Q200ᶲ (62% increase) had been grown and decreased or showed little change in most other treatments where intermediate or susceptible cultivars were grown previously. Oospore levels at harvest of the Q208ᶲ plant crop were related to pre-plant oospore levels (P=0.0065). *Pachymetra* levels in plots where Q208ᶲ was grown following Q208ᶲ were as predicted by the regression. Oospore populations in plots where QN05-178 was grown previously were higher than predicted; while oospore populations in plots where Q253ᶲ was grown previously were lower than predicted.

Experiment 3 – Central region field trial

Inoculum levels varied significantly among plots of the previous cultivars at the end of the plant crop of Q208ᶲ (P<0.0001). Oospore populations decreased in most treatments under the Q208ᶲ plant crop. *Pachymetra* levels increased under the Q208ᶲ plant crop in plots where Q200ᶲ was grown previously (increase of 21%). Oospore counts under the Q208ᶲ plant crop decreased by 58% in plots where KQ228ᶲ was grown previously. *Pachymetra* levels remained significantly lower in plots where resistant cultivars were grown previously, compared to plots

where intermediate cultivars had been grown previously. Inoculum levels at harvest of the Q208ϕ plant crop were related to pre-plant oospore levels ($R^{2=}$0.74, Figure 1D), however this relationship was only significant at P=0.0614. *Pachymetra* levels were as predicted for all treatments.

Relationship between cane yield of Q208ϕ and *Pachymetra* levels

Experiment 1 – Southern region field trial

The relationship between pre-plant oospore levels and cane yield in the Q208ϕ plant crop at Yandaran was significant (P=0.0049, Figure 2A). Based on the regression, yield losses of 21% are incurred at an inoculum density of 120 oospores/g soil. Cane yield in plots where Q208ϕ had been grown previously in the cultivar trial was close to the predicted cane yield, based on a regression between pre-plant oospore counts and cane yield across all treatments. Cane yield of the Q208ϕ plant crop was significantly higher than predicted in plots previously planted to Q240ϕ and KQ228ϕ, and lower than predicted in plots previously planted to Q155 and Q171.

Cane yield of the Q208ϕ first ratoon was not related to oospore levels at the end of the Q208ϕ plant crop (Figure 2B). The differences in cane yield of Q208ϕ among treatments with the highest and lowest oospore counts reduced in the first ratoon, compared to the plant crop.

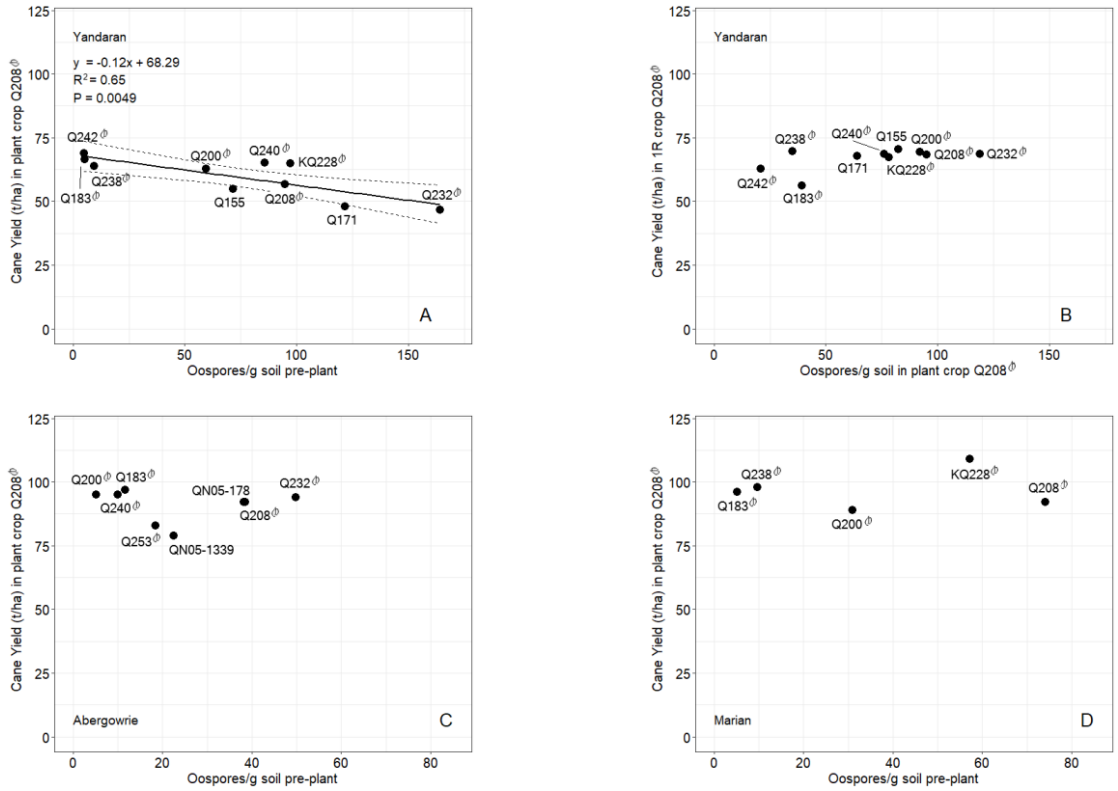

Figure 2. Regression of Q208ϕ cane yield and initial *Pachymetra* oospore levels in plant and first-ratoon crops in field experiments located at Yandaran (A, B), and plant crops at Abergowrie (C) and Marian (D). Data labels indicate the cultivar grown previously in the cultivar trial. Broken lines indicate 95% confidence intervals. X-axes of graphs (C) and (D) are scaled to half that of (A) and (B) due to lower oospore levels at these sites.

Experiment 2 – Herbert region field trial

High cane yields (mean 91 t/ha) were produced in the Q208ϕ plant crop at Abergowrie with heavy lodging. Cane yield of the Q208ϕ plant crop was not related to pre-plant oospore levels under different treatments (Figure 2C). No significant differences in cane yield occurred among the different treatments under the Q208ϕ plant crop (Tukey HSD, P=0.05).

Experiment 3 – Central region field trial

Heavy lodging occurred in the Q208ϕ plant crop at Marian. Cane yield in the plant crop Q208ϕ was not related to pre-plant oospore levels (Figure 2D). There were no significant differences in cane yield of the plant crop Q208ϕ among any of the cultivar treatments (Tukey HSD, P=0.05). High cane yields (>90 t/ha) occurred in most treatments, despite the different *Pachymetra* levels under different treatments.

DISCUSSION

Our results are generally consistent with the current guidelines used to provide recommendations to growers for management of pachymetra root rot. Current recommendations estimate: nil to low yield loss at less than 40 oospores/g soil; moderate yield loss at 40–70 oospores/g soil; and high yield loss at greater than 70 oospores/g soil in intermediate cultivars (Plunkett and Magarey 2014). In our study, 7–12% yield losses were predicted at 40–70 oospores/g soil based on the regression between cane yield and oospore levels in the Q208ϕ plant crop (Experiment 1). This is similar to estimates in previous research (Magarey 1995). Moderate-high yield losses were incurred in Experiment 1, estimated at 12% in the Q208ϕ plant crop (at a mean of 71 oospores/g soil) and 18% in the Q208ϕ first ratoon (at a mean of 105 oospores/g soil), based on the regression between cane yield of the Q208ϕ plant crop and pre-plant oospore populations. The increase in oospore levels under the plant and first-ratoon crops of Q208ϕ (Experiment 1) and subsequent yield losses demonstrate that improved management of pachymetra root rot (through oospore monitoring and cultivar selection) could have considerable productivity gains.

Pachymetra oospore levels and cane yield in the plant crop Q208ϕ varied among plots where different intermediate cultivars were grown previously in relation to *Pachymetra* oospore levels present prior to planting Q208ϕ. This relationship is consistent with other studies, which have demonstrated that *Pachymetra* is a significant factor reducing cane yield (Magarey 1991b, 1994; Bhuiyan *et al.* 2016). The overall results from our study do not support the hypothesis that *Pachymetra* has become more aggressive where the same cultivar has been grown for more than one crop cycle. This conclusion is made based on the following:

a) Oospore levels in plots planted to Q208ϕ following Q208ϕ were not significantly higher than predicted, based on a linear regression between final and pre-plant oospores/g soil, compared to other cultivar treatments.
b) Cane yield in plots planted to Q208ϕ following Q208ϕ was not significantly lower than predicted, based on a linear regression between cane yield of Q208ϕ and pre-plant oospores/g soil, compared to other cultivar treatments.

Previous studies have shown a significant negative association between *Pachymetra* oospore population and cane yield losses in the Northern (Magarey and Bull 2008) and Central regions (Magarey *et al.* 2003). Ours is the first study to show a similar negative association between *Pachymetra* oospore population and yield in the Southern district. The consistent association between *Pachymetra* oospore population and yield across different environments increases our confidence that *Pachymetra* is an important factor limiting cane yield. However, soils are a very complex environment with many interactions among plants and biological, nutritional and physical factors and we only examined the association of cane yield and *Pachymetra* oospore populations. Previous studies have investigated the association of other soil pathogens, *Pythium arrhenomanes* (Croft and Magarey 1984) and plant-pathogenic nematodes (Bhuiyan *et al.* 2016), and soil compaction (Burgess and Calcino 1996) on cane yield. Soil health will continue to be an important area for future research.

High *Pachymetra* levels occurred under Q232ϕ, which is rated intermediate in resistance to *Pachymetra* (Experiments 1 and 2). It is possible that the size of the root system in differeent cultivars is a contributing factor in the number of oospores produced. Susceptible cultivars have poor root systems with few roots due to a high level of *Pachymetra* infection, whereas intermediate cultivars are more likely to have a lower percentage of rotted roots and a larger root system; therefore, intermediate cultivars could produce higher oospore populations than susceptible cultivars. This would explain the high cane yields and high oospore populations in cultivars such as Q232ϕ. Monitoring of *Pachymetra* levels in ratoon crops is important, in order for growers to make informed decisions of when to remove crops and when to plant resistant cultivars. Field trials should be routinely conducted in order to assess long-term dynamics of *Pachymetra* populations under new cultivars that have been rated to have intermediate resistance to pachymetra root rot.

Our results highlight the importance of resistant cultivars for the management of pachymetra root rot. Higher cane yields were achieved where Q208ϕ was grown following *Pachymetra*-resistant cultivars, compared to plots where Q208ϕ was grown following most intermediate or susceptible cultivars. In Experiment 1, mean yield losses in the plant crop of Q208ϕ were estimated at 17% (95 oospores/g soil) in plots where Q208ϕ was grown previously. Losses were up to 29% where Q208ϕ followed Q232ϕ in the plant crop (164 oospores/g). These yield losses are

significant, particularly in context of the current pressure placed on industry from other diseases, climatic conditions and rising production costs. Only 35% of cultivars grown in Australia are rated as highly resistant to *Pachymetra* (SRA 2018). Intermediate cultivars have shown better performance on poor soil types than resistant cultivars, which could explain low adoption rates of resistant cultivars on these soils. In 2017, the top 10 performing cultivars (based on tonnes sugar per hectare) on soil types where *Pachymetra* is an issue in the Herbert region consisted of mostly intermediate cultivars (SRA 2018). Agronomic field trials could be conducted to assess the performance of advanced clones on poor soil types prior to release, in order to select resistant cultivars with high productivity on *Pachymetra*-conducive soil types.

Resistant cultivars are critical to reducing and maintaining *Pachymetra* levels below economic thresholds; however, current resistant cultivars often do not perform better than intermediate cultivars on poor soil types where *Pachymetra* is an issue. There is a need for the development of more resistant high-performing cultivars that are suited to *Pachymetra*-conducive soil types. This is critical in order to reduce yield losses being suffered in subsequent crops of intermediate cultivars in these soil types. Breeding of highly productive cultivars with resistance to *Pachymetra* should remain a high priority for the Australian sugar industry. The use of molecular markers to screen parents and experimental clones in the early stages of breeding programs for *Pachymetra* resistance could accelerate the number of resistant cultivars tested in advanced-stage field trials (McIntyre *et al.* 2005). *Pachymetra*-resistance markers should be a high priority for research in this area.

High *Pachymetra* populations at the Yandaran site provided the best opportunity to investigate cultivar-related changes in *Pachymetra* levels and subsequent cane yield losses in the Q208$^{(f)}$ plant crop. The impact of oospore populations under different cultivar treatments on cane yield of the following crop of Q208$^{(f)}$ was not demonstrated at the Abergowrie and Marian sites. Mean pre-plant oospore levels were 24 oospores/g soil (Experiment 2) and 35 oospores/g (Experiment 3). The poor relationship between pre-plant oospore levels and cane yield at these sites is consistent with current management recommendations for pachymetra root rot, which estimate that nil to low yield losses could be expected in intermediate cultivars at inoculum levels less than 40 oospores/g soil. It is possible that the soil type and environmental conditions at these sites are less conducive to pachymetra root rot. *Pachymetra* levels under susceptible and intermediate cultivars in the ratoon cultivar trial at Abergowrie were lower than mean oospore levels reported in surveys of the Herbert growing region (Holzberger *et al.* 2016).

Our results clearly demonstrate the residual soil-borne effect of different cultivars in the subsequent Q208$^{(f)}$ crop. Further research is required to understand the cause of high oospore levels under some intermediate cultivars. Industry losses due to *Pachymetra* may be reduced by selecting resistant cultivars for release that are suited to *Pachymetra*-conducive soils.

ACKNOWLEDGEMENTS

Funding for this research was provided by Sugar Research Australia Limited and CQUniversity. We acknowledge Dr Shamsul Bhuiyan, Michael Turner and the SRA plant-breeding staff involved in establishing the original cultivar trials and the efforts of harvesting contractors and all SRA staff involved in this project work. Thank you to our cooperative growers, John Steemson, Geoffrey Low and Albert De Boni, who hosted field trials used in our study.

REFERENCES

Bhuiyan S, Croft B, Wong E, *et al*. (2016) Effects of pachymetra root rot and nematodes on some elite sugarcane clones in Australia. *Proceedings of the Australian Society of Sugar Cane Technologists* 38: 54–64.

Burgess DJW, Calcino DV (1996). The effect of furrow-compaction on germination and yield of sugarcane planted under wet soil conditions. *Proceedings of the Australian Society of Sugar Cane Technologists* 18: 209–212.

Butler D, Cullis B, Gilmour A, Gogel B (2009). *Mixed models for S language environments, ASReml-R reference manual*. Queensland Department of Primary Industries and Fisheries: Brisbane.

Croft B (1989) A technique for screening sugarcane cultivars for resistance to pachymetra root rot. *Plant Disease* 73: 651–654.

Croft B, Bull J, Greet A (1998) A simple and efficient method of rating sugarcane clones for resistance to pachymetra root rot. *Proceedings of the Australian Society of Sugar Cane Technologists* 20: 276–279.

Croft B, Magarey R (1984) Pathogenic fungi associated with northern poor root syndrome of sugarcane. *Proceedings of the Australian Society of Sugar Cane Technologists* 6: 55–61.

Croft B, Magarey R, Whittle P (2000) Disease management. In *Manual of Canegrowing*. (Eds DM Hogarth, PG Allsopp) pp. 263–289. Bureau of Sugar Experiment Stations, Indooroopilly.

Dick M, Croft B, Magarey R, Clark G (1989) *Pachymetra*, a new genus of the Verrucalvaceae (Oomycetes). *Botanical Journal of the Linnean Society* 99: 97–113.

Holzberger G, Magarey R, Di Bella L, Bull J, Nielson R (2016) Pachymetra root rot survey in the Herbert river district 2014–2015. *Proceedings of the Australian Society of Sugar Cane Technologists* 38: 65–71.

McIntyre C, Whan V, Croft B, Magarey R, Smith G (2005) Identification and validation of molecular markers associated with pachymetra root rot and brown rust resistance in sugarcane using map- and association-based approaches. *Molecular Breeding* 16: 151–161.
Magarey R (1989a) Development of sampling strategies for *Pachymetra chaunorhiza*, a sugarcane root pathogen. *Phytopathology* 79: 1306–1309.
Magarey R (1989b) Quantitative assay of *Pachymetra chaunorhiza*, a root pathogen of sugarcane in Australia. *Phytopathology* 79: 1302–1305.
Magarey R (1991a) The effect of varietal resistance on the epidemiology of pachymetra root rot. *Proceedings of the Australian Society of Sugar Cane Technologists* 13: 95–102.
Magarey R (1991b) *Pachymetra Root Rot of Sugarcane*. PhD thesis, University of Queensland, St Lucia.
Magarey R (1994) Effect of pachymetra root rot on sugarcane yield. *Plant Disease* 78: 475–477.
Magarey R (1995) *Pachymetra Root Rot Research in the Mackay District 1984–1995*. Bureau of Sugar Experiment Stations, Indooroopilly.
Magarey R, Bull J (2008) Yield losses caused by pachymetra root rot in northern Queensland: 10 years of breeding selection trial data. *Proceedings of the Australian Society of Sugar Cane Technologists* 30: 145–154.
Magarey R, Bull J (2011) The relationship between glasshouse and field-derived resistance ratings for pachymetra root rot. *Proceedings of the Australian Society of Sugar Cane Technologists* 33: 162–168.
Magarey R, Bull J, Lonie K, Tomasin W (2008) Dynamics of *Pachymetra* spore populations: the effects of site and varietal resistance. *Proceedings of the Australian Society of Sugar Cane Technologists* 30: 295–302.
Magarey R, Bull J, Royal A (2013) Surveys assessing the incidence and severity of pachymetra root rot in the Australian sugarcane industry. *Proceedings of the Australian Society of Sugar Cane Technologists* 35: 160–167.
Magarey R, Mewing C (1994) Effect of sugarcane cultivars and location on inoculum density of *Pachymetra chaunorhiza* in Queensland. *Plant Disease* 78: 1193–1196.
Magarey RC, Sarich CE, Turner JD, Bull JI (2003) Influence of pachymetra root rot resistance on yield losses in central Queensland. *Proceedings of the Australian Society of Sugar Cane Technologists* 25: 8 pp.
Plunkett G, Magarey R (2014) Resistant varieties are the only solution to pachymetra root rot. *Cane Connection* pp. 9–10.
Queensland Government (2018) Queensland Globe. https://qldglobe.information.qld.gov.au (accessed 30 October 2018).
Sugar Research Australia (2018) QCANESelect Regional Reporting. http://tools.sugarresearch.com.au/QCANESelect/Regional Reports/RegionalReportCriteria.aspx (accessed 19 September 2018).