Review of ratoon stunting disease (RSD) control for the Innisfail Babinda Cane Productivity Services (IBCPS)

Report Submitted

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THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

Dr. Anthony Young
Senior Lecturer in Crop Protection
The University of Queensland
Gatton Campus, 4343
anthony.young@uq.edu.au
0499 292 390

*Due to improved diagnostics and management practices, **this disease affects fewer than 5% of crops**. When the disease does occur, it can cause losses of 5-60%. Losses are greatest when the cane is moisture stressed and even with good irrigation, losses can range from 10 to 30%.*

Ratoon stunting disease. SRA Website, accessed 5th of December, 2018.

16%

Positive seedbeds for the IBCPS for 2017.

257,778 t of cane:

Estimated yield loss by IBCPS in 2017 owing to RSD (see pages 8-9) .

INTRODUCTION

Australian sugarcane growers have been living with unrecognised RSD for so long that poor cane performance is attributed to any number of factors before consideration is given to the main responsible factor. If you were to offer a grower a 20% discount on a new tractor, they would jump at the offer. If you then showed that that tractor would have more engine hours than another tractor, they would be delighted. However, this same thing occurs with RSD, but they do not recognise it. They don't know that they could improve their yields by 20%, because they've never known better. They don't know that they could achieve more profitable ratoons, because RSD is the norm, even though they might not realise they have the disease on their farm. They don't know that their weed control and soil health are deleteriously impacted by RSD, and has been for generations.

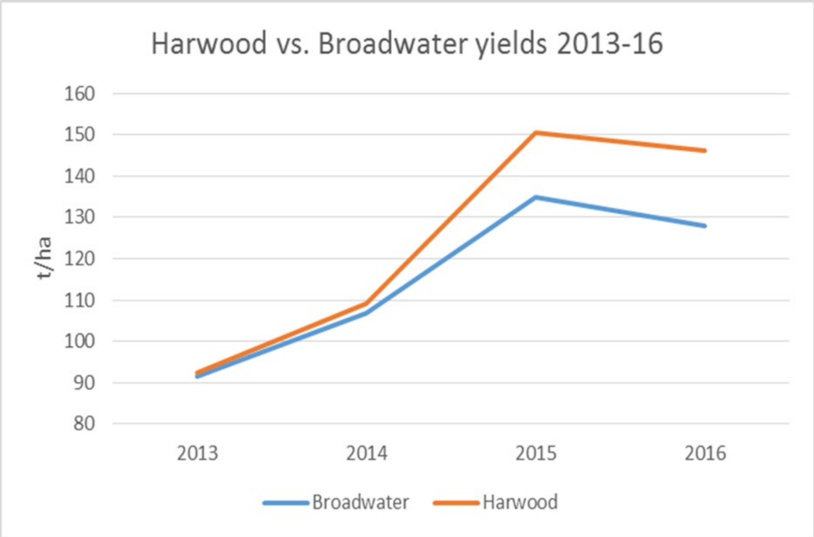
The cost of implementing a comprehensive control package for RSD is dwarfed by the benefits to the local industry.

I have had extensive experience in RSD management. I first learned of this invisible disease as a 16 year old planting sugarcane on my father's farm at Harwood, NSW. Following my undergraduate degree, I conducted my PhD research on RSD based at the BSES in Indooroopilly. Among my findings were that standard RSD diagnostics were poor and the disease was likely to be causing greater yield loss than the industry acknowledged. I concluded that RSD resistance should be deployed to control the disease. For five years I worked in the Queensland DPI&F as a Bacteriologist and Molecular Taxonomist. In 2011 I returned to Harwood as a BSES Extension Officer, and later in the same role but employed by the NSW Sugarmilling Cooperative.

During my four years at Harwood, I established the most extensive RSD control measures employed in Australia. This involved the development of LSB-qPCR as an advanced RSD diagnostic test, increasing the number of seedbeds tested (>700 per year), a tripling of the amount of clean seed distributed, transformation of the ASP plots for billet distribution, development and deployment of a billet delivery system, preferential recommendation of varieties based on RSD resistance, implementation of a mapping system to delimit RSD infections on farm maps, and an active and prolonged extension campaign to bring the growers with me. Did this effort have an impact?

In 2015, the year old component of our crop out-yielded that of the Burdekin: 120 t/ha. This in the southernmost, coldest sugar industry in Australia, without any irrigation. The total yield for 1YO and 2YO was 151 t/ha: the highest since the introduction of mechanical harvesting, and surpassed only by that of 1962 which followed large swathes of virgin land being brought into production. The following season, the combined yield was 146 t/ha, making 2015 and 2016 the highest consecutive yields on record. Likewise, the period 2015-2017 represents the highest yields for a three year period ever recorded at Harwood. But how much of this is attributable to RSD control? For the 2015-2016 period, Harwood yields were 13% higher than neighbouring Broadwater, which essentially shares the same grower demographics, variety mixture and proportion of 1YO to 2YO (see graph below). The difference is that Broadwater had not, at that stage, adopted the RSD control methods implemented at Harwood.

There has been an overall shift in the culture among Harwood growers. From a situation where 15% of ASP output was in the form of billets, we now enjoy almost complete billet distribution. This streamlined approach frees up significant resources associated with wholestalk distribution and planting. The clean seed uptake for Harwood has remained high, with the 2018 distribution of 890 t the second highest on record, and eclipsing the combined output of Broadwater and Condong. Even though Harwood has consistently used the highly sensitive LSB-qPCR test since 2015, RSD detections in seedbeds have dropped below 4%. This is from a high of 27% detections from 100 fields in 2015, as determined by LSB-qPCR. From the same fields, the then industry standard of EB-EIA/PCM detected only 3% infection: how many undiagnosed plant sources have led to persistent RSD infections?



The problem with RSD is that it is invisible, and it is impossible to specifically identify the yield losses associated with infection. For example, not every stool in an infected crop will be infected. Different varieties will have different yield losses. Weather conditions will have an impact, with the greatest losses in drier years. You cannot say that RSD is costing you this specific amount of yield loss. It can be difficult at times even to convince growers that RSD exists. Yet, as shown in Harwood, and in other places where growers have better RSD management programs, if you combat RSD the profits will flow. Throughout this review, specific recommendations are made in **red**.

Specific Action Summary

1. **Avoid plough-out replant.**
2. **Increase clean seed uptake.**
3. **Systematise the order of planting operations.**
4. **Phytosanitation.**
5. **Discontinue HWT for growers.**
6. **Improved diagnosis.**
7. **Map tested fields.**
8. **Request further SRA support for delimiting the impact of RSD in Australia.**

IBCPS Current Situation

With 16% of prospective seedbeds testing positive in 2017, it can be safely assumed that RSD is having a massive impact on the productivity and sustainability of the IBCPS sugar industry. When it is considered that seedbeds represent the best-of-the-best cane available, then it can be expected that the situation in commercial fields is much worse. There is a high degree (40%) of replant in the IBCPS area, which is both a reflection of the yield-eroding impacts of RSD, and a major factor that promotes its continuing impact. Clean seed output/uptake needs to be dramatically increased. More extensive seedbed and commercial field surveys need to be conducted using the best diagnostic platform available.

How to control RSD

Successful control of RSD requires a complete change in the culture across the range of stakeholders, including farmers, contractors and millers. This involves:

1. Improving grower awareness
2. Provision of disease-free material
3. Screening of prospective seedbeds with the best technology available
4. Mapping RSD incidence to reduce transmission
5. Preferential recommendations of varieties with greater resistance
6. The highest levels of phytosanitation practice available
7. The abandonment of hot water treatment of grower-supplied material
8. Eliminating replanting without a fallow period

Importantly, like other sugarcane productivity areas in Australia, IBCPS needs to engage with SRA to drive a cost-benefit analysis of the RSD impact in Australia, and the potential for novel solutions. The following provides detailed information on specific actions that will improve RSD management in IBCPS.

FIELD MANAGEMENT

Eliminate replant

Prevention is the most effective control of RSD, and prevention starts with a fallow. Growers should be discouraged at all times from replanting. There is a statistically-significant higher incidence of RSD in replant versus fallow plant (Maguire et al. 2009, Young et al. 2012). A moment's reflection should reveal that in many instances this indicates that RSD was present in the crop that was ploughed out. A further moment's reflection would show that RSD contributed to the poor performance of the previous crop, which led to the decision to plough it out in the first place. Infected volunteers are an important transmission route, and some evidence suggests that healthy cane can acquire RSD from infected stubble of the previous crop (Anthony Young unpublished data).

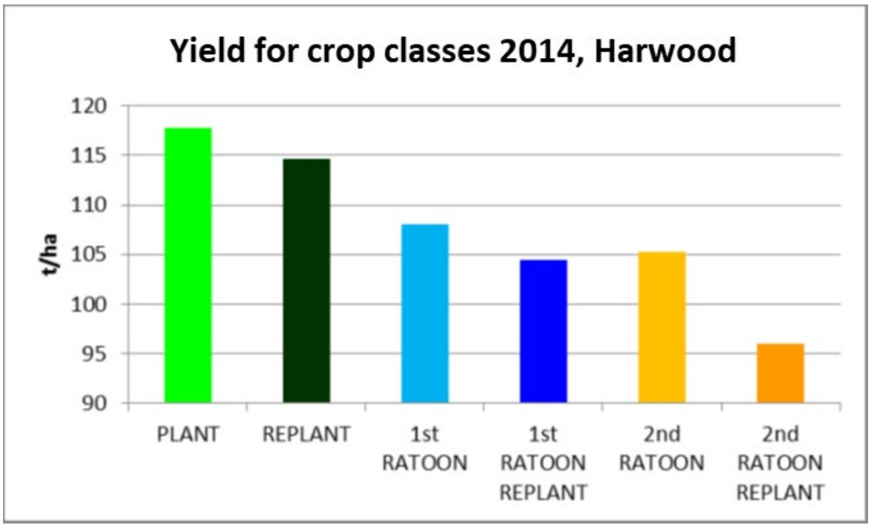
A major issue for IBCPS is the high proportion of replant versus fallow plant. As shown in the table below, over a five year period, over 40% of everything planted was replant. Of concern, in 2018 this was over 50%. It may be conjectured that the high amount of replant is the root cause of the RSD problem in the IBCPS area. This needs to change.

Year	PL	RP	Total	%RP
2014	3317.85	1965.47	5283.32	37.2
2015	2407.34	1665.71	4073.05	40.9
2016	2069.18	1289.35	3358.53	38.4
2017	1867.14	935.22	2802.36	33.4
2018	1750.97	1885.17	3636.14	51.8
Total	**11412.48**	**7740.92**	**19153.4**	**40.4**

Many replant growers will maintain that the soil is good enough and doesn't require a fallow, or that they have been doing it for so many years and there's no problem. Some will claim that they need the cash flow and that there are no suitable legume cash crops. In short, like so much change, there will always be more reasons not to than to. However, when farmers are convinced about the bottom line, change occurs rapidly.

An analysis of yield in relation to crop class was undertaken for the 2014 crop at Harwood (see graph below). As may be expected, plant after fallow out-yielded replant. Significantly, the trend continued through the ratoons, where ratoons after replant performed worse than the ratoons after fallow plant. Interestingly, the 2nd ratoons from fallow plant out-yielded the 1st ratoons from a replanted crop. What is of interest is that the majority of replant occurs in the more fertile riverbank alluvial soils, but even the higher natural productivity of these soils failed to deliver the yield benefits of a fallow. In addition to soil health benefits of a fallow, better RSD control leads to better yields throughout the crop cycle.

It is recommended that IBCPS analyse yield performance in relation to crop class and present the results to the growers.



Growers need to actively control volunteers in their fallow. It is always good practice to plant a leguminous fallow, for example soybeans, mungbeans, lablabs, peanuts *etc.* However, in the wet tropics it may not be possible in most instances to harvest the crop. Still, this will lead to offsets in fertilizing costs, as well of course as better control of RSD, soil health benefits, and increased profitability throughout the ensuing sugarcane crops over the complete cycle. Volunteer control is best achieved through application of a grass-specific product such as Verdict. Growers who employ a fallow have greater opportunity to control other grassy weed species such as guinea grass, Johnson grass, nutgrass and paspalum.

An active extension campaign is required to break the replant cycle. This needs to be supported by financial modelling that shows the long-term benefits for growers.

Order of operations

Clean seed uptake can be compromised if no consideration is given for the order of operations. *Lxx* can survive on surfaces for 4 months, but not longer. Likewise, although attempts at sterilizing harvesters and planters should be promoted, it is practically impossible to completely sterilize this equipment owing to the inaccessibility of different components (Taylor et al. 1988). Previously at Harwood, growers would plant their own cane, and then at the end of the season plant their clean seed. This was seen as another opportunity for infection. Therefore grower practice has changed significantly as growers now plant their purchased clean seed before anything else on the farm.

Following this, they should plant out the clean seed they grew the year before, and then, if required, plant from less certain sources.

For this system to work in the IBCPS region, it will be necessary to open the plots prior to the general commencement of planting, and to make clean seed available for the duration of the planting window. This necessarily involves weekend work and appropriate staffing allocation.

One common method by which RSD enters farms is when contract planters arrive with billets sourced from another farm. Most growers will, in order to save plants, ask the contractors to run the billets in. This practice should be completely eliminated. Planters should arrive clean and empty, and leave in the same condition.

Always plant clean seed first, then seed from the previous year's ASP purchase, then from less certain sources.

CLEAN SEED

Size of Approved Seed Plots

The best way to combat RSD in the short to medium term is the output of high volumes of clean seed. The key concept is to pour in so much clean seed at one end that clean came comes out the other. Unless there is a seismic shift in the uptake of tissue-cultured plantlets, there is an urgent need to expand the size of the ASP and distribution operations.

An average of 3,311 ha was planted each year in the IBCPS area over the past 5 years. Although it is estimated that some 15% of that area was stick planted, for the sake of convenience, let's assume that the whole area is billet planted. In most areas, it requires 10 t of billets to plant a hectare. Thus an average planting year in the IBCPS area would require 33,110 t of plants. If we assume that a crop grown for plants averages 75 t/ha, then a total of 441 ha of plants is required. If this area was to be planted with clean seed obtained the previous year, a total of 4,410 t of clean seed would be required, requiring 59 ha of ASP (at a yield of 75 t/ha). As this is six times the size of the current IBCPS ASP plots, and as invariably growers will want more of one variety than another, it is unrealistic that this can be achieved in the short term.

However, if IBCPS were to enter into a lease arrangement with a grower to source an additional 20 ha of fallow land (in addition to the current 10 ha of ASP), this would facilitate production of up to half of what is required. That is:

30 ha x 75 t/ha = 2,250

If growers can ensure that they keep their plant cane clean (see Order of Operations, Diagnostics and Phytosanitation sections), they can safely source clean seed from the 1st ratoon of their previous year's ASP-sourced seedbed. This would facilitate, as close as possible, the provision of enough clean plants to plant the entire area within three years.

It is recommended that IBCPS increase ASP plantings to at least 30 ha.

Assisting growers with their clean seed requirements

As part of this review, a clean seed calculator has been developed which may be able to assist IBCPS growers determine how much clean seed they need to purchase in a given season so as to be able to plant their fallow blocks the following season.

It is recommended that IBCPS assist growers with the clean seed purchasing decisions.

Design of Approved Seed Plots

An obvious barrier to uptake of clean seed is the unavailability of desired varieties. In some respects this is guesswork, because a defect might be found in a variety that was popular the previous year, and so demand will drop; or a new variety might enjoy outstanding results and demand will then outrun supply. Within these unavoidable constraints, IBCPS can analyse variety request data to help establish ASPs that reflect grower demand. For example, if 25% of all orders in 2018 were for Q208, then the ASP planted that year should have approximately 25% Q208. Judgement calls will need to be exercised, where variety proportions can be varied depending on general grower attitudes. However, in the main, if ASPs are planted in relation to grower demand, it is likely that there will be less waste of ASP cane sent to the mill.

There is also a tendency for PSCs to increase propagation of new varieties at the expense of proven varieties. A classic case is SRA1, which filled plots throughout Australia but has turned out largely to be a failure owing to its low fibre characteristics. There is always some excitement in the grower community about getting the latest variety. However, any cursory inspection of the varieties released over the past 30 years shows that the majority of varieties have a limited impact on the industry. Growers do not need ten varieties: they need one or two good ones that can be depended on to grow well in their conditions. As such, it is recommended that priority be given in ASPs to known quantities: varieties that growers are willing to purchase and propagate on their ground.

ASPs should be planted largely in proportion to that year's seed orders.

Clean seed production

As previously stated, to improve RSD control, IBCPS needs to increase the amount of clean seed produced and distributed. To improve germination, the standard practice at Harwood is to cut the whole stalks and then season them for 5 days, HWT at 50°C for 3 hrs, then season for another 5-10 days prior to planting. Alternatively, in NSW the SRA breeders adopt a 10 min pre-treatment the preceding day, followed by the full 3 hr treatment (Cattle et al. 2014). The prevailing conditions in the IBCPS area may require some adjustment to the treatment parameters, but the 3 hour HWT should not be varied.

Cost of Clean Seed

It is in the best interests of the entire IBCPS area to make clean seed as affordable as possible. Data from the Herbert (Stringer et al. 2016) and Harwood (Young 2017) demonstrates an increased yield of 13% following improved RSD control measures. Although (as stated in the Introduction), it is impossible to solely attribute these increases to improved RSD management, in both cases this 13% increase directly followed augmented RSD control. If this was to be translated in the IBCPS area, this would amount to an increased cane tonnage of 257,778 t in 2016:

1.13 x 1,982,905 t = 2,240,683 t.

2,240,683 t – 1,982,905 t = 257,778 t.

At a cane price of $30/t after harvesting, this amounts to $7.7 million of lost revenue. If we are highly conservative and claim that RSD is causing only half of the 13% yield loss, that equates to $3.9 million of lost revenue. And for the sake of argument, if RSD is only causing a tenth of the estimated 13% yield loss, thus is still approximately $800,000 dollars of lost revenue. This clearly shows that any investment by IBCPS in RSD control will pay significant dividends.

Thus the monetary value of clean seed output is completely dwarfed by the productivity benefits. Fundamentally, the IBCPS area should produce as much clean seed as possible and bring the cost down as close to the cost of competing seed (*eg.* farmer to farmer) as possible. Another benefit of driving the costs down is it will further disincentivise growers from having their own cane HWT.

More resources need to be directed towards controlling RSD in the IBCPS area: this will more than pay for itself.

Billet availability

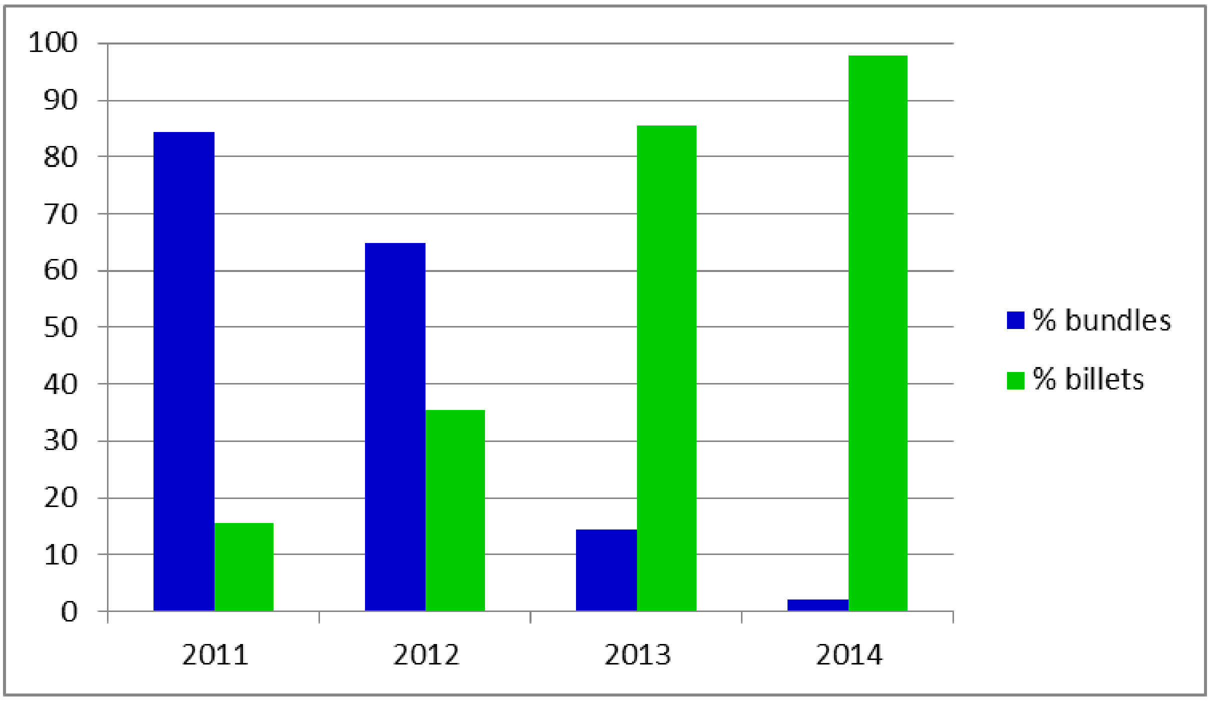
As most growers billet plant their cane, billets should be available from plots immediately upon commencement of distribution. IBCPS should consider the purchase of a dedicated harvester for the plots. At Harwood, a 2nd hand rubber-rollered Toft 6000 was purchased for $20k in 2013. This is still in operation. Depending on the course taken for the expansion of the ASP plots, consideration needs to be made into how IBCPS can make billets available to growers without the possibility of introducing the disease via contaminated harvesting equipment.

Billet distribution should be investigated as a way of promoting clean seed uptake.

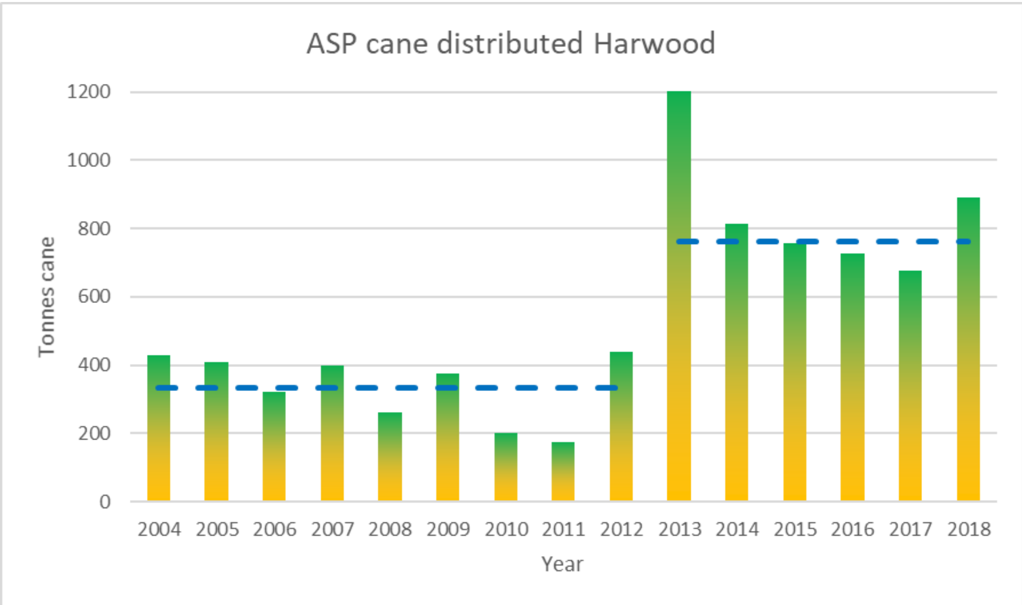
Billet delivery

One obstacle to clean seed uptake is the distance from the plots. This was overcome at Harwood by the design and manufacture of a dedicated billet delivery system ($30k). This particular unit can be affixed onto a flatbed truck and facilitated delivery of 6 t of cane at a given time, which typically amounted to 2 t into each of the planter and two chaser buggies. Using a tarping system, the grower could purchase up to three varieties at a time. This removed one of the barriers to adoption of clean seed, as growers could get what they wanted when they wanted and where they wanted it.

The availability of billets from the commencement of distribution, as well as the ability to deliver billets, led to a rapid and lasting change in the culture of clean seed plots. This is shown in the graph below.



Following the implementation of the new system in 2013, a record of 1,204 t of ASP cane was distributed. The Mill, in what amounts to a misguided intervention, raised prices in 2014 so that Harwood was in line with Broadwater and Condong. This was a big mistake because it led to decreased uptake. However, this has been somewhat turned around this year with a total of 890 t distributed for a >10,000 ha industry.



It is recommended that IBCPS investigate the opportunity for billet delivery among its growers.

HWT for growers

This was one of the first practises I stopped when I started as an Extension Officer at Harwood. Most importantly, **IT DOES NOT WORK**. Various studies (for example, Koike et al. 1982 and Victoria et al. 1986) have demonstrated that HWT does not kill ALL of the bacteria. You will ALWAYS get disease carryover (even though you may not be able to detect it). Therefore, as I mentioned to the growers, I won't HWT your cane because it's wasting your time and mine. HWT cane for growers unnecessarily ties up resources and is ineffective at combatting RSD.

It is recommended to eliminate HWT for growers.

Tissue culture

The availability of tissue cultured (TC) plantlets will facilitate rapid uptake of new varieties. However, it requires some amendments to farming practice and access to a TC planter. TC should be continued to be promoted, but not wholly relied on for RSD control.

Tissue culture uptake may take pressure off ASP distribution operations and should be further explored.

PHYTOSANITATION

All previous efforts are undermined if harvesters and other gear re-introduce RSD into otherwise clean fields. In practice it is impossible to sterilize all gear between fields, but every effort should be made when moving harvesters, planters and buggies between fields. Sterilization should follow the standard practice.

IBCPS should continue to engage with contractors in relation to phytosanitation.

DIAGNOSTICS

Seedbed diagnosis

Accurate and timely diagnosis of prospective seedbeds is a critical component of RSD control. With the exception of false-positives, which are rare, if a field tests positive then it should be mapped to prevent further spread of the infection through both planting and harvesting operations. It is important to note that no matter what test is being used, a negative result for the field in no way guarantees that the field is free from disease. This is because it is impossible to sample every stalk in a field, and it is entirely possible that a diseased field will yield stalks that, by chance, are unaffected. There are a range of diagnostic techniques available for RSD in Australia. In order of sensitivity, these are:

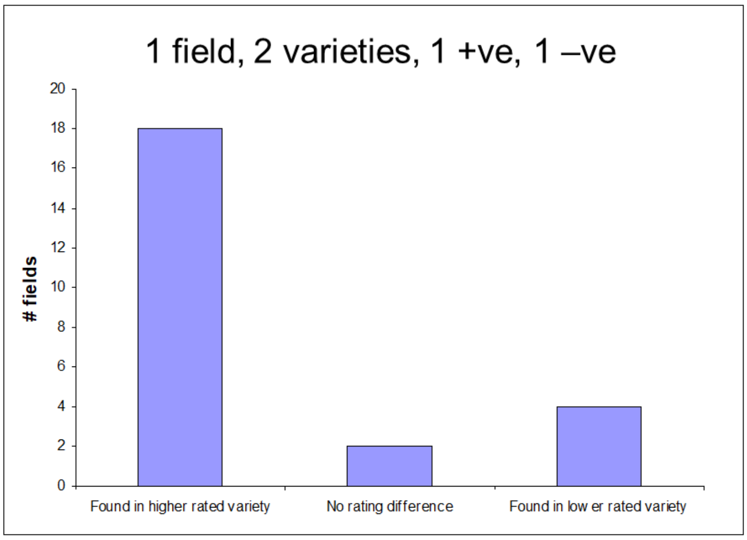
1. Slicing to reveal internal symptoms at lower nodes;
2. Phase contrast microscopy (PCM) of expressed xylem sap;
3. Evaporative-Binding Enzyme Immuno Assay (EB-EIA) on expressed xylem sap;
4. Conventional Polymerase Chain Reaction (PCR) on expressed xylem sap;
5. Loop mediated isothermal amplification (LAMP) on expressed xylem sap;
6. Quantitative PCR (qPCR) on expressed xylem sap;
7. qPCR on leaf sheath biopsy samples (LSB-qPCR[1]).

[1] The author declares a potential conflict of interest because he developed LSB-qPCR. It has been validated against EB-EIA, PCM, conventional PCR on LSB samples, and PCR on expressed xylem sap, where it showed

It is understood that SRA personnel are also working on developing a sugarcane core punch method and sugar stream test, but the utility and accuracy of these tests are not known.

Seedbed diagnosis is problematic for a number of reasons. As noted above, there is no guarantee that RSD will be detected even if it's present. This is in part due to necessarily small sample numbers, as well as the actual sensitivity and robustness of the diagnostic test applied. However, there are several steps that can be taken to help facilitate RSD detection.

If you are sampling a field with a mixture of varieties, target the variety with the highest RSD susceptibility. Data from Harwood showed that for 24 fields where two varieties of known RSD susceptibility were tested and one variety was positive and the other negative, 75% of the time RSD was found in the more susceptible variety, while 17% of the time it was in the less susceptible variety (the remaining 8% of the time there was no difference in nominal RSD susceptibility). Therefore it is best to target the more susceptible variety. In addition to greater likelihood of infection, susceptible varieties have higher *Lxx* titres, and so the disease spreads more rapidly in them than resistant varieties, leading to a greater chance of sampling an infected stalk. Furthermore, it is easier to detect higher titres than lower titres, so it is possible that positive samples from resistant varieties (which support lower *Lxx* titres), may have returned false negative results using the EB-EIA/PCM technique.



There is an industry perception that it's best to sample the four corners of a field in order to target the likely entry points for RSD. While this is intuitive, it is not necessarily correct: certainly it is untested. This question is likely to be addressed during trial work in early 2019 as part of an SRA project on RSD diagnostics.

Part of rationale of sampling the four corners is because those are the possible entry points for harvesters and planters. However, if the harvester is effectively sterilised, this should have no bearing on the presence of RSD in the corner where the harvester entered. In terms of the planter, RSD could be present anywhere within the field if a single stool of infected cane is harvested for billets. This has been demonstrated by a situation at Harwood in 2014 where three stools of Badila (grown as part of

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more sensitive detection than any technique. This method is being further studied as part of a 2 year SRA project. At the time of writing, no other technique offers the sensitivity of LSB-qPCR (Young et al. 2016).

a museum collection, and hidden in the ASP) where accidentally harvested for plants. Fortunately Badila has a distinctive colour and morphology that differs from the variety Empire (among which it was planted), and subsequent rogueing operations found stools of Badila randomly distributed among the Empire. Incidentally, this is considered the first and only time in history that Badila has been billet-planted in Australia. Be that as it may, there was no indication of more Badila in the four corners than anywhere else in the field.

Previous cane inspection teams at Harwood would sample a proportion of volunteers (when present) during seedbed inspections. However, as it is more likely that volunteers will have RSD, they should be targeted. These are the simplest way for RSD to enter a field. It is hoped that if IBCPS growers can eliminate replant, this will be a moot point. However, as that is not likely to happen in a single season, seedbed inspectors should target volunteers.

If volunteers are present in a seedbed, sample them intensively.

For LSB-qPCR sampling, in order to test as many fields in a day as possible, it is recommended to simply walk along the headland and collect samples from the first stool in every row. Where possible, target weaker, smaller stalks, as these are more likely than stud stalks to be infected. Even with this basic sampling strategy, more infected fields were identified than using conventional sampling and EB-EIA/PCM and PCR diagnostics. As per the optimised LSB protocol, 50 LSBs are pooled per field. It has been shown that RSD can be diagnosed by at least 2 infected LSBs in 48 uninfected (Young et al. 2016), while more recent work has narrowed that to a single infected LSB in 49 uninfected LSBs.

It is recommended that IBCPS engage with the current RSD Diagnostic Project Team to trial the LSB-qPCR method in early 2019.

Delimitation of Infection

In order to effect the culture change required by IBCPS growers, it is essential to more clearly define the RSD problem. This will involve an extensive stratified survey using LSB-qPCR or whatever molecular assay is proven to be the most effective for diagnosing RSD. The survey will be conducted on a cross section of fields that represent the proportion of each variety grown, the crop classes (including plant, replant, and ratoons from plant and replant), the management (farmers), and sub-districts. In this way, a more accurate understanding of the yield impacts of RSD in the IBCPS area can be determined.

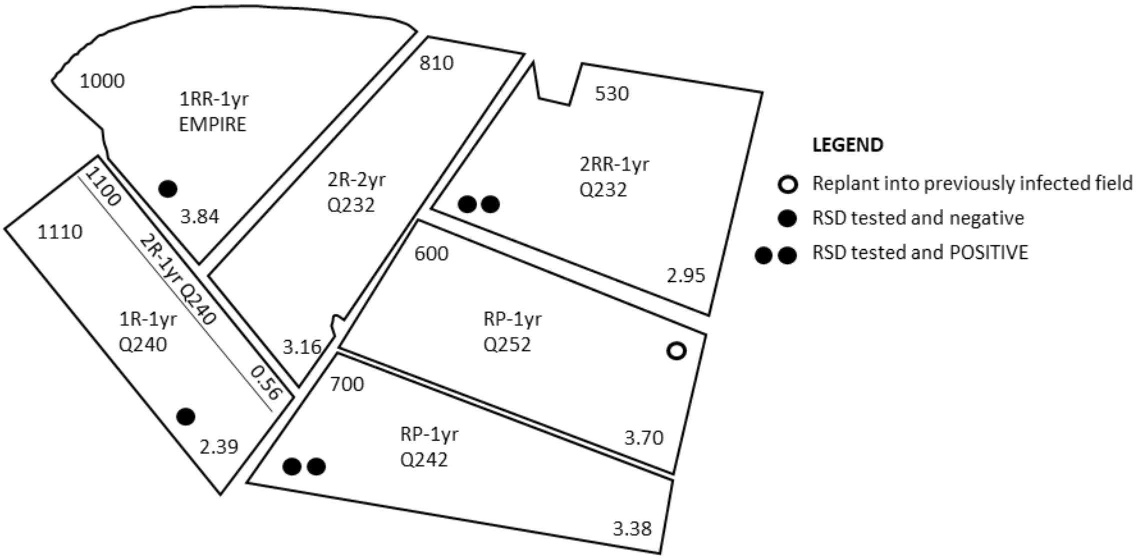
IBCPS to undertake a stratified survey for RSD.

Mapping infections

A major reason for the persistence of RSD is inadvertent spread during planting and harvesting operations. A simple system was introduced to combat this at Harwood whereby a new layer was added to grower farm maps (see example below). A single black dot on a field indicated that it was tested and the results were negative. These single dots are removed each season unless the field is re-tested for RSD. The presence of two black dots indicated that the field was tested and tested positive. These black dots remained with the field for the life of the crop. An open black dot indicated a replant crop that was replanted into a previously-infected field.

This system allowed the farmers to see at a glance what fields had been inspected the previous season, and what their RSD status was. Thus it became an important extension tool. It also prevented the usual occurrence of a grower saying that the field tested negative two years previously, so it should be clean. Importantly, this has become a useful tool for several planting contractors serious about RSD control. These contractors will not agree to plant the cane unless the farmer can show them their farm map.

It is recommended that IBCPS explore mapping options which include detailed crop class and RSD status.



INDUSTRY RESPONSE

Cost-benefit analysis of RSD management

It is a measure of how long the Australian sugar industry has been living with RSD (knowingly or otherwise) that there has never been a cost-benefit analysis of the impacts of RSD in our industry. This analysis should be supported by an industry-wide survey of the incidence of RSD, an assessment of the actual RSD-associated yield losses of a selection of varieties under different weather conditions, and a calculation of the resulting estimated yield losses. This 'bottom-line' figure could be used to guide an industry-wide response to RSD.

IBCPS should request SRA to conduct an independent analysis of the impact of RSD in Australia[2].

RSD resistance

There have been several phases of debate on the best way to manage RSD. These have chiefly focussed on the utility of resistant varieties, and extend back to the 1980's when Brian Roach concluded that resistance should be part of Australia's management of RSD. Roach's work demonstrated that RSD-resistance has high broad and narrow sense heritability that is largely transmitted from the maternal line. Thus lowering the overall susceptibility of Australian clones could be achieved by using resistant female parents. Unfortunately this line of enquiry was not pursued by BSES, which persisted with the view that RSD only occurred in less than 5% of fields so the cost of producing RSD-resistant varieties outweighed the benefits. During my PhD I also concluded that RSD resistance should be pursued in Australia. I renewed this call in 2012 after I commenced as a an Extension Officer in Harwood. The reasons for this, in brief, are as follows:

[2] I was unsuccessful in a SRA funding application to fund such a project in 2016.

1. Resistant varieties suffer less yield loss when infected;
2. There is a lower transmission rate within infected resistant varieties, meaning there is less spread;
3. More profitable ratoons will be achieved with resistant varieties;
4. More ratoons leads to less soil-health impacts of plough-out and re-establishment;
5. HWT is more effective for resistant varieties than susceptible varieties;
6. HWT-resistant strains of *Lxx* are likely to evolve and will further compromise the efficacy of HWT;
7. Resistance is largely conferred by the female parent, so achieving RSD resistance is a simple matter of prioritising resistant female mother canes.

There is a long-held meme that the inclusion of RSD resistance will cripple varietal output. This has been effectively contested by Comstock et al. 2001, who showed that elite but otherwise susceptible varieties could be retained in a program that selected for RSD resistance.

Our current understanding of RSD susceptibility is based on the number of infected vascular bundles in the cane, which is translated as higher bacterial titres in expressed xylem sap, determined by relative EB-EIA readings. This process should be updated with qPCR detection and quantification. This would involve individually sampling all stalks arising from several infected stools to determine the numerical variation in *Lxx* present among stalks and stools. Yield loss estimates could be determined concurrently using control (uninfected) stools. This is important because it is quite possible for 'field-resistance' or 'tolerance' to occur, where a cane can be heavily infected (in terms of *Lxx* titre), but not suffer a concomitant yield impact. Combining the actual yield-loss estimates for different varieties with the incidence determinations will facilitate a clearer estimate of the actual losses to RSD not just in the IBCPS area, but throughout the Australian sugar industry.

IBCPS should request SRA review the process of determining RSD susceptibility of varieties.

In Australia, RSD susceptibility ratings are typically produced *after* a variety has been released, if at all (Young et al. 2012). Growers should be made aware of the RSD susceptibility of their varieties so they can make informed decisions. For example, if a grower has to select from two eligible varieties for their situation, they should be able to select the variety that has the highest resistance. RSD susceptibility should be determined *prior* to the release of a variety, so that if in all other respects two varieties are equal, the one with greater resistance is released preferentially. By doing this, the Australian industry will waste less resources propagating 'flash-in-the-pan' canes which are promising when released, but buckle under pressure from RSD.

IBCPS should request SRA to reconsider incorporation of RSD resistance in the plant improvement program.

CONCLUSIONS

Recognising that RSD is a problem is the first step toward improving productivity in the IBCPS area. Without an integrated approach that incorporates all available management tools, it is likely that RSD will persist, as it has done for over 60 years. The basis for improved RSD management is a well-resourced extension campaign. In order to change the culture, growers need to buy in to the program.

Given the rewards available, the culture within a productivity area can change remarkably quickly. The key short-term objective is to greatly expand the volume of clean seed available for uptake. This will take significant resourcing and will require grower buy in. Seedcane costs should be kept as low as possible. Within two years of a dramatic increase in ASP output, growers will experience increased productivity which will entrench improved and lasting participation in ASP uptake. The role of tissue-cultured plants needs to be further explored.

An RSD survey will help better delimit the incidence and impacts of the disease. This should use the best diagnostic technique available and target fields representative of seedbeds and commercial crops.

Greater integration between IBCPS and Mill data is essential to prevent further spread of the disease. This should include detailed incidence and crop class data on farm maps.

Further efforts are required to ensure that planting and harvesting contractors are not introducing RSD from one farm to another. Growers will need to take the time to supervise decontamination activities. Under no circumstances should planting material from unknown provenance be introduced onto farms.

Many of the problems faced by IBCPS are the same as those faced by other areas throughout the Australian sugar industry. Although we have known about RSD since it was discovered in January 1945, it is still having an impact. With more sensitive diagnostics now available, it is appropriate that IBCPS and other Productivity Services Companies engage with SRA and experts at a high level to determine whether or not industry-wide approaches are required to better manage this disease.

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