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Incidence and economic effects of ratoon stunting disease on the Queensland sugarcane industry

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Abstract Ratoon stunting disease (RSD) has had a significant influence on productivity and profitability in the Australian sugarcane industry for at least the last 76 years. There have been few attempts to objectively quantify the incidence and economic influence of the disease across the industry. Most Cane Productivity Service (CPS) groups routinely monitor RSD in plant sources and, in some cases, in commercial crops. Surveys by 12 Queensland CPSs were conducted in 2017-2020 with sampling of different proportions of commercial crops (5-25% of farms) in each region. The latest molecular technology was adopted to assay samples. RSD incidence varied between 0 and 60% in commercial crops and 0 and 41% in plant source inspections. The data suggest that implementation of the three pillars of RSD management (disease-free seed-cane, equipment sanitation and planting into fallow ground devoid of volunteers) were essential to minimise RSD incidence. Failure to adequately address any one of these pillars often compromised RSD management. An economic analysis suggested that RSD led to an annual loss of $25m in the study areas in the 2019 crop. This is significant, but it is unlikely to be the largest single disease constraint on productivity.

Key words Surveys, incidence, economic effects, regions, importance

INTRODUCTION

Ratoon stunting disease (RSD) is acknowledged as a major disease around the world, following its initial recognition in Australia in the summer of 1944 (Steindl 1961; Davis and Bailey 2000). Much knowledge about RSD has accumulated over the years, including on diagnosis, yield loss, transmission, management and the causal agent (*Leifsonia xyli* subsp. *xyli* or Lxx); this will not be fully reviewed in this paper (Steindl and Hughes 1953; Steindl 1961; Gillaspie and Teakle 1989; Davis and Bailey 2000). The disease has been difficult to manage in the field because it presents no characteristic external symptoms, other than non-specific crop stunting and reduced yield (Steindl 1961). Defining plant disease status relies on the application of an appropriate assay (Croft *et al.* 2012).

Cane Productivity Services (CPSs), and similar institutions, have generally been the agencies that monitor RSD within the Australian sugarcane industry. Their focus is on inspection of farmers' plant sources (plant source inspections or 'PSI') and on providing healthy planting material from disease-free central nurseries (approved seed plots). However, in recent years CPSs have also conducted surveys of commercial crops to investigate the incidence of RSD within individual mill areas and regions.

In this paper, we explore the commercial incidence of RSD across most of the Queensland sugarcane industry, to gauge the effect this 'invisible' disease is having on commercial productivity and profitability. Not every Australian mill area is represented; Young *et al.* (2020) addressed losses in New South Wales and there were no data for Maryborough and Rocky Point Mill areas.

METHODS

RSD assay technologies

- Symptoms: when ratoon stunting disease (RSD) was first identified, no external symptoms were associated with diseased plants; the only parameters linked to the disease were red nodal markings in older cane and a pink blush just below the growing point in young cane (Steindl 1961). The discovery of the causal agent and associated research led to a progression of much more precise and reliable assays.
- Slicing: a few industry technicians still slice cane as a diagnostic tool, with sighting of the red nodal tissues as the key identifier. Slicing is employed so that farmers can be advised 'on the spot' of the disease status of their cane. Though useful early in the history of RSD, such symptoms are now acknowledged as relatively unreliable. The technology is not recommended for routine commercial application.
- Phase-contrast microscopy (PCM): is an 'older technology' that involves collection of xylem sap from stalks cut in the field. The number of stalks from which sap is collected varies with the crop area and adopted sampling strategy; more samples provide a higher probability of detection, but at higher labour cost. The xylem sap is expressed by applying air pressure to the cut end of a stalk, with sap collected as it exudes from the other end; this is placed into a tube for transport to the local laboratory. The sap is examined at 1,000x magnification using phase-contrast optics and a positive result recorded if even a single characteristic bacterium (Lxx) is seen (Gillaspie *et al.* 1973; Teakle *et al.* 1973).
- qPCR DNA-based assay: DNA assays offer a highly sensitive, modern, quantitative and specific test (up to 1,000x more sensitive than PCM) (Grisham *et al.* 2007); the assay has been adapted and applied in various ways across the industry. Several methods are used to collect plant material:
  - xylem: the xylem sap collection method is identical with that used with the PCM assay (Croft *et al.* 2012). The extracted sap is cooled and dispatched to the SRA RSD assay laboratory before being subjected to qPCR assay. A positive result is recorded when the Cq value is below a maximum threshold.
  - LSB (leaf sheath biopsy): the method was developed by Young *et al.* (2016) and uses circles of leaf sheath tissue, generally collected from the fifth leaf below the top visible dewlap. The leaf sheath circles are placed in water to allow the bacteria to diffuse out of the cut vascular bundles before the extract is cooled and dispatched to a RSD qPCR laboratory. The advantage of this method is that many more tissue samples can be collected per unit of time, and, accordingly, 50 stalks are sampled per crop (rather than 16 with xylem sap).

Although there is a higher Lxx bacterial titre in the xylem sap than the leaf sheath (Croft *et al.* 2012; Bailey 1977), sampling a more stalks with LSB provides a countering improvement in detection sensitivity.

RSD surveys

Some CPSs conduct annual commercial crop RSD surveys in their mill area; others undertake occasional surveys to periodically gauge the extent of the disease. Part of the routine activities of all CPSs is to test grower plant sources (PSI). Table 1 provides information on surveys and PSI undertaken in each mill area/region. Details of the major varieties within each region and the applied RSD assay are also listed; the latter is important as it provides a guide on relative detection sensitivity. Data from Maryborough and Rocky Point Mill areas were not available.

Table 1. Details of RSD inspections and assays undertaken in each mill area/region and data on the major varieties grown (PSI = plant source inspections).

Mill/Region	Major varieties	Survey	PSI	qPCR		PCM
				Xylem	LSB	
Mossman	Q208$^{\phi}$, Q183$^{\phi}$, Q240$^{\phi}$	Yes	No	+		
Tableland	KQ228$^{\phi}$, Q208$^{\phi}$, Q183$^{\phi}$	No	Yes	+		
Mulgrave	Q208$^{\phi}$, Q253$^{\phi}$, Q250$^{\phi}$	Yes	Yes	+		
South Johnstone	Q200$^{\phi}$, Q208$^{\phi}$, Q253$^{\phi}$	Yes	Yes		+	
Tully	Q208$^{\phi}$, Q200$^{\phi}$, Q250$^{\phi}$	Yes	Yes	+		
Herbert	Q208$^{\phi}$, Q253$^{\phi}$, Q232$^{\phi}$	No	Yes	+		+
Burdekin	Q240$^{\phi}$, KQ228$^{\phi}$, Q183$^{\phi}$	Yes	No	+		
Proserpine	Q240$^{\phi}$, Q208$^{\phi}$, Q183$^{\phi}$	No	Yes	+		
Mackay	Q208$^{\phi}$, Q240$^{\phi}$, Q242$^{\phi}$	No	Yes	+		
Plane Creek	Q208$^{\phi}$, Q183$^{\phi}$, Q240$^{\phi}$	No	Yes	+		
Bundaberg	Q240$^{\phi}$, KQ228$^{\phi}$, Q208$^{\phi}$	Yes	Yes	+		
Isis	Q240$^{\phi}$, KQ228$^{\phi}$, Q208$^{\phi}$	Yes	Yes	+		

RSD incidence was calculated according to the following method: i. % farms: if a single crop on a farm returned a positive RSD result, that entire farm was considered diseased; ii. % crops: if a single part of a designated crop returned a positive RSD result, then the entire crop was considered diseased, even if other parts of that same crop returned a negative result (this may happen when different varieties are planted into the same block and tested separately); iii. % tests: this refers to the total number of RSD assays conducted in each district/region and the percentage that returned a positive RSD assay result.

Economic effects

Previous research has quantified yield losses in diseased versus healthy crops (Steindl 1961) and these data were used to predict probable yield losses in each region across the industry. The effect of RSD on yield varies with climate and management; the greatest losses occur in relatively dry climates where there is minimal or no irrigation. Ample supply of water tends to mitigate against the effects of the disease (Gillaspie and Teakle 1989).

Industry data for the 2019 crop (QCANESelect®) were sourced to provide information on the proportion of plant and ratoon crops in each mill area/region; we assumed that similar crop-cycle proportions existed in calculations using 2017 and 2018 RSD data. Also sourced were the mean crop yields for plant and ratoon crops for the same mill areas/regions (Table 2).

Yield-loss estimates considered the following factors: crop cycle status, variety, local climate, irrigation and previous yield-loss trials. Assumed mean losses in each district provide only a general indication of the effects of RSD since the weather in any one season, and any one part of the mill area, will influence crop losses. Assumed mean losses for each district are detailed in Table 2, with separate estimates for both plant and ratoon crops.

Table 2. Proportion of crops as plant or ratoon in each mill area/region and mean plant and ratoon crop yields (2019 data). Yield-loss estimates assume 100% of the crop is infected.

Region/Mill area	Proportion as plant or ratoon crops (%)		Mean crop yields (t/ha)		Assumed yield losses (%)	
	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon
Mossman	12.4	87.6	91.5	77.8	20	35
Tableland	17.2	82.8	111.1	86.4	10	15
Mulgrave	17.5	82.5	85.4	73.7	20	35
South Johnstone	15.1	84.9	76.7	69.4	12	20
Tully	15.3	84.7	75.1	74.4	12	20
Herbert	14.0	86.0	83.9	70.0	20	35
Burdekin	21.6	78.4	141.5	109.8	10	15
Proserpine	16.2	83.8	86.8	71.0	20	35
Mackay	14.2	85.8	83.2	71.2	20	35
Plane Creek	21.0	79.0	78.1	69.5	20	35
Bundaberg	18.6	81.4	84.8	67.8	15	30
Isis	13.5	86.5	83.0	72.4	15	30

The value of the economic loss from RSD (V) was calculated using the following: i. 2019 mean crop yields (Y_c), given in Table 2; ii. estimated 'healthy' mean crops yields (Y_o) (as if no RSD was present in the area – presented as 'yield without RSD incidence' in Table 4); iii. estimated 'diseased' crop yields (Y_1) based on the estimated RSD-associated yield losses accompanying the disease in each mill area/region (presented as 'yield with RSD incidence' in Table 4); iv. the area affected by RSD (A) (presented in Table 4, calculated as the average harvested area in each region multiplied by the RSD incidence in that region); and v. local cane prices (P) (calculated from local CCS data and world sugar prices). The percentage RSD-diseased crops data were used to calculate monetary losses.

$$Y_0 = \frac{Y_c}{(1-I) + [I/(1+L)]}$$

$$Y_1 = \frac{Y_0}{(1+L)}$$

$$V = PA\,(Y_0 - Y_1)$$

RESULTS

Summary results from the mill area/regional surveys and PSI are outlined in Table 3. The data indicate a very large variation in disease incidence across mill area/regions. High crop incidences were evident in both the Mossman and South Johnstone Mill areas, with moderate levels (10-25% farms diseased) in the Mulgrave, Herbert, Proserpine and Bundaberg regions. Several mill areas (Tableland and Plane Creek) recorded no RSD; the disease has not been detected in the Plane Creek Mill area for over 12 years.

RSD incidence in PSI varied on occasions from survey data in the same mill area; in some, a higher RSD incidence was recorded with PSI. Isis Productivity Board staff suggested that the actual RSD incidence in Isis was no more than 1.5% diseased crops, even though PSI data indicated a much higher incidence.

Table 3. Proportion of RSD diseased crops in plant sources (PSI) and in surveys assessing sugarcane disease status in mill areas/regions across the Queensland sugarcane industry.

Mill area	PSI / Survey	Year	Total farms	% RSD	Total crops	% RSD	Total tests	% RSD
Mossman	Survey	2020	91	60.4	140	54.3	141	54.3
Tableland	PSI	2018-2020	68	0	200	0	280	0
Mulgrave	Survey	2019	80	11.3	90	10.0	94	9.6
	PSI		34	14.7	68	11.8	78	10.3
	Survey	2020	155	26.5	279	33.0	350	26.3
	PSI		50	38.0	127	40.9	160	37.5
South Johnstone[1]	Survey	2019			1500	24.0		
	PSI	2019			951	18.6		
	PSI	2020			983	34.3		
Tully	Survey	2018	120	8.3	166	9.0	612	4.7
Herbert	PSI	2020	347	27.7	967	15.0	1375	11.8
Burdekin	Survey	2019	470	4.9	503	5.7	508	5.1
	Survey	2020	479	11.5	528	11.8	528	11.8
Proserpine	Survey	2019	91	15.4	172	13.4	219	11.4
	Survey	2020	121	23.1	261	16.1	412	12.1
Mackay	PSI	2018	1012	1.1	4860	0.3	5432	0.2
	PSI	2019	1125	1.0	4875	0.2	5678	0.2
Plane Creek	PSI			0		0		0
Bundaberg	Survey	2017	79	16.5	153	10.5	721	5.1
	Survey	2018	143	38.5	340	25.3	1786	14.2
Mean				19.2		16.2		13.3

[1]For the purposes of the economic calculations, 26% diseased crops was used for deriving economic losses for South Johnstone

The yield and economic impacts of RSD in each Mill area/region are outlined in Table 4. Losses varied enormously from $0 to over $4 million per mill area/region. As a proportion of the gross industry revenue (based on hectares cultivated to sugarcane), Mossman and South Johnstone Mill areas were the most seriously affected by RSD. By contrast, losses in the large cane-growing region of Mackay were minor. The overall revenue loss to the industry regions reported here was estimated at $25m.

DISCUSSION

There were striking differences in RSD crop incidence among the mill areas/regions. Some regions had very few, if any RSD-infected crops, including the Tableland, Mackay and Plane Creek Mill areas. These regions are characterised by either a long history of diligent implementation of the recommended RSD management strategies (use of disease-free seed-cane, sanitation of machinery cutting surfaces and planting into disease-free nursery/field sites) or strict attention to RSD management when sugarcane farming began in the area (Tablelands). Ensuring that crops start disease-free is important in reducing the initial amount of disease in plant crops; it then takes much longer for the disease to enter and spread to other healthy crops. The low RSD incidence in Mackay, a very large cane-growing region with a long RSD history (the longest in the world), illustrates that recommended RSD management principles may lead to effective disease control. Though the reported data are from plant source inspections, Mackay CPS staff are confident the data also reflect commercial crop incidence.

Table 4. Yield impacts and value of economic losses from RSD using local CCS data and a sugar price of $AU400 per tonne.

Region/Mill area	Crop class	Yield with RSD incidence (t/ha)	Yield without RSD incidence (t/ha)	Area affected (ha)	Yield loss (t)	Value of economic loss ($)
Mossman	Plant	84	101	734	12,315	405,138
	Ratoon	67	91	5,189	121,803	4,007,070
	Total			5,923	134,118	4,412,208
Tableland	Plant	101	111	0	0	0
	Ratoon	75	86	0	0	0
	Total			0	0	0
Mulgrave	Plant	75	90	678	10,209	335,585
	Ratoon	60	81	3,195	66,768	2,194,765
	Total			3,873	76,977	2,530,350
South Johnstone	Plant	70	79	845	7,145	234,685
	Ratoon	60	73	4,752	57,456	1,887,273
	Total			5,597	64,600	2,121,957
Tully	Plant	68	76	403	3,272	116,478
	Ratoon	63	76	2,230	28,068	999,100
	Total			2,632	31,340	1,115,577
Herbert	Plant	72	86	1,184	16,976	615,288
	Ratoon	54	73	7,271	137,298	4,976,245
	Total			8,455	154,275	5,591,534
Burdekin[1]	Plant	130	143	1,729	22,478	902,601
	Ratoon	97	112	6,275	91,267	3,664,733
	Total			8,003	113,745	4,567,334
Proserpine	Plant	74	89	549	8,156	303,099
	Ratoon	55	74	2,838	54,518	2,026,011
	Total			3,387	62,674	2,329,110
Mackay	Plant	69	83	19	266	9,903
	Ratoon	53	71	116	2,142	79,665
	Total			135	2,408	89,568
Plane Creek	Plant	65	78	0	0	0
	Ratoon	51	70	0	0	0
	Total			0	0	0
Bundaberg	Plant	76	88	728	8,322	323,664
	Ratoon	55	72	3,184	52,907	2,057,675
	Total			3,912	61,230	2,381,339
Isis[2]	Plant	72	83	27	290	11,420
	Ratoon	56	73	171	2,868	113,096
	Total			3,336	56,236	124,516
Total						25,263,493

[1]Burdekin losses were estimated on the current incidence of RSD largely in one mill area. Actual losses across the region may be smaller than those listed.

[2]Isis 'survey data' were considered by local staff to reflect the seeking out of RSD on affected properties and not a real estimate of RSD across the district – hence an estimate only of disease incidence was used in these calculations.

In contrast, there were very high incidences in both the South Johnstone and Mossman Mill areas. In the South Johnstone Mill area, there is a relatively large number of smaller farmers; there is also an associated propensity for a 'plough-out/replant' farming system (Spannagle unpubl. data). Located in the Wet Tropics, it is difficult to ensure stool death in the short space of time between plough-out and replant, so many farmers have planted disease-free seed-cane/commercial crops into fields containing excessive volunteer diseased-stool populations. This has led to escalating RSD incidence, with new crops infected mechanically (via harvesters) from diseased volunteers within the planted crop. Local extension on RSD management has been intense in the last couple of years in both the South Johnstone and Mossman Mill areas.

In the Herbert 68% of 2020 RSD PSI detections were associated with the variety Q253⁽ᵇ⁾ (L Di Bella, unpublished); the variety appears to be highly susceptible to the disease.

The current RSD incidence does not necessarily reflect the failure of RSD management principles, nor does it represent the current emphasis on RSD management provided by local extension staff, but rather the longer-term history of RSD extension and management within the area. If RSD management is neglected, a serious and costly disease epidemic is likely to result. Strong affirmative action is then needed; this has been successfully undertaken many times in the Australian industry. In several of the districts where the current incidence is high, one or other of the recognised essential management strategies was either ignored or poorly applied.

The results reported here mostly reflect qPCR assay of survey/PSI samples. Unpublished data suggest that Lxx detection has improved significantly with the adoption of a molecular assay (versus the anti-serum-based technology) (Young *et al.* 2020). Several other types of Lxx assays are still used within the industry, including PCM and slicing cane. These older assays, though potentially offering quicker turn-around times, should be avoided if Lxx detection is to be maximised.

An interesting outcome of this study was the relative RSD incidence in PSI versus commercial crop survey data. There is an assumption that inspection of plant sources, presumably the cleanest sugarcane in a region, would reveal lower disease levels than commercial crops. Commercial crops are more likely to be exposed to RSD infection via contaminated cutting equipment (harvesters/cultivation equipment/planting equipment) or from crop establishment from RSD-diseased plant sources. Our data suggests instead that RSD incidence in CPS PSI RSD data may be as high, or higher than in surveys of commercial crops (though this is not always the case). CPS staff quite often seek out RSD on diseased farms, leading to a bias toward RSD-infected cane. This was the case with the 2019 Mulgrave PSI data. Unless the specific circumstances surrounding PSI/datasets are identified, poor interpretation or incorrect assumptions are liable to be made.

The economic study, based on mean yields for each mill area/region in 2019, suggests that RSD is causing economic losses of close to $25m/annum in the areas related to this study across the Australian industry. The losses varied significantly with individual mill area/region and were not dependent on RSD incidence alone. Any crop losses in the Burdekin will be of higher value, given their cane yield and high CCS. However, full irrigation leads to lower losses, so the economic effects may be reduced (for a given incidence) by irrigation. The reported calculations for the Burdekin are probably on the higher-side of the actual losses experienced.

Australian industry losses from RSD are not as great as for some other major Australian diseases. Pachymetra root rot industry surveys were reported by Magarey *et al.* (2013). Industry data suggest that for the same mill areas/regions reported in this paper, 9 of the 12 areas had 50% or more farms infested by pachymetra root rot. In some, over 80% farms were affected. This is far-higher than for RSD. Individual crop losses associated with pachymetra root rot may be just as high, depending on disease severity; economic losses of over $50m/year have been attributed to pachymetra root rot. *Pratylenchus zeae* (root-lesion nematode) is found on an even higher proportion of farms; economic losses caused by all parasitic nematodes have been estimated at around $80m annually (Blair and Stirling 2006).

The strong limitation imposed on Australian sugarcane yields by poor soil health has been highlighted in a number of previous studies (Magarey 1996; Garside *et al.* 1997; Blair and Stirling 2006) that included experimentation on soil fumigation, rotation and fallowing. The need for improvement in the health of soils/root systems is no surprise, given that the industry is based on a sugarcane monoculture, and in many cases a variety monoculture. Magarey *et al.* (2011) highlighted the economic danger of this situation from a disease management perspective. While RSD continues to have a significant influence on industry profitability, it is not the economically most debilitating disease.

Some regions are suffering financial losses from RSD because of failed historical management programs. In every case, there is now a much more intense focus on RSD management; RSD incidence is expected to decline in these regions over the next 5-10 years. Implementation of the recommended RSD management pillars will be essential if further significant losses are to be avoided. Bhuiyan *et al.* (2021) addresses the possibility of resistance as a management tool; economic and practical justification for this approach currently appears to be lacking.

RSD remains a central focus for disease management in the Australian sugarcane industry and emphasis should continue to be placed on the disease, as suggested by Young and Knight (2020).

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