BSES Limited

FINAL REPORT – SRDC PROJECT BSS302

EPIDEMIOLOGY STUDIES INTO SUGARCANE SMUT

by

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SUMMARY

- Sugarcane smut was first detected in Queensland in June 2006. Though known overseas, important questions remained about what would happen in Queensland; these were - how fast will the disease spread across each district; how quickly will the disease build up in susceptible crops; what yield losses are likely in these crops? Answers to these questions became the objectives of this three-year project.
- Epidemiology studies in Bundaberg-Isis were first funded (December 2006) by BSES. SRDC funding extended these studies to the Herbert / Mackay areas.
- Smut spread was assessed by selecting non-infested farms across the Herbert, Mackay and Bundaberg-Isis districts and inspecting them on a regular basis. The speed of infestation of these farms indicated how fast the disease was spreading. In addition, industry data on farmer-reported smut-infested farms were accessed; these also provided information on the speed of spread. Extrapolation of the data suggested smut would infest all farms in the Herbert, Mackay and Bundaberg-Isis districts within 20-30 months from first detection.
- Smut escalation in diseased crops was assessed by recording increases in smut-infested stools in individual highly susceptible crops over time. 7-11 fold increases in infested stool populations were seen across Queensland; this compares to 1-2 fold increases in Louisiana. This information enabled farmers to decide when to terminate infested crops.
- Spread and escalation data, coupled with industry variety data, were used to predict the peak and severity of the epidemic in the Herbert, Burdekin and Bundaberg-Isis areas. Peaks were predicted in 2009-2010 (Herbert / Bundaberg-Isis) and 2012 (Burdekin)
- The influence of resistance on incidence / severity was assessed in a variety trial planted in Mackay. Data showed rapid infestation and escalation in plots of highly susceptible varieties. In contrast, varieties rated <8 showed limited disease incidence and severity. The varieties distributed by industry to replace smut-susceptible varieties in late 2006 performed well and were affected only to a very minor degree by smut.
- Yield loss studies initially focused on selecting a diseased commercial crop of a highly susceptible variety and weighing cane affected by low, medium or high disease levels; yield in plots was related to percent infested stools and smut severit. In a highly susceptible crop, very significant losses (30%) were associated with high infestation levels and moderate-high disease severity. In another approach, mill harvest data were used to assess crop cycle yield trends in susceptible varieties. By comparing ratoon crop cycle yield responses both in the presence of smut, and without smut (pre-vs post-2006), whole mill area effects of the disease on yield were gauged. It was difficult to show large yield losses in factory data, though trends for lower yield were seen in Herbert 2009 and 2010 crops of the highly susceptible varieties Q157 and Q174[Φ]. Generally low losses reflect the success of the management strategies implemented by industry after the smut incursion; large yield losses in badly infested crops of highly susceptible varieties were on-the-whole avoided through the termination of heavily-infested crops.
- A review of the recommended plough-out threshold suggests that 5% infested stools in highly susceptible varieties is too low in east coast production areas; a more realistic figure is 15%. This figure will vary depending on a number of factors:
    i. the favourability of the environment to smut, and

ii. how long it will take, on a whole farm basis, to transition from highly susceptible to more resistant varieties, The threshold will therefore vary depending on farm and district factors.

- A review of the resistance needed in commercial crops to minimise yield losses re-emphasises that the most important strategy is to discard varieties rated >8 as quickly as possible. Varieties of slightly lower susceptibility are likely to remain high yielding in current plantings. A much higher level of resistance is needed in the Ord River area, where the environment strongly favours smut. Acceptable levels of resistance will vary with district (environment) in Queensland and NSW.
- The influence of the smut management strategy adopted by the Queensland sugarcane industry on economic outcomes was compared to a non-variety solution. This indicated that losses would have been 10-fold (>$400m) if highly susceptible varieties had not been discarded and more resistant replacement varieties grown commercially.
- The curvilinear relationship between disease incidence (untransformed data) and resistance rating in resistance screening trials is evidenced in field observations. A slight decrease in susceptibility (7 instead of 9) leads to a significant drop in smut incidence in commercial fields; at the other end of the rating scale, there is very little difference in field disease incidence in varieties at the resistant end of the spectrum (1-3 ratings). The commercial yield losses expected in varieties rated 7, 8 and 9 will therefore vary considerably (relatively small in 7, very large in 9).

1.0 BACKGROUND

Sugarcane smut is a major disease world-wide, causing very significant yield and germplasm losses wherever it has occurred. The disease was first recognised in Africa in 1877 and has an on-going strong history of spread around the world. Smut is known from overseas studies to be influenced by the environment. It seemed only a matter of time before an Australian incursion was detected as this country remained one of the last to be smut-free. Smut was found for the first in Australia in 1998 in the Ord River area of Western Australia. Rapid spread and build up in this very favourable environment saw the disease drastically decrease the yield of highly susceptible varieties; the industry removed these varieties as fast as physically possible. Pre-emptive research by BSES enabled the resistance of Australian commercial varieties to be assessed in Indonesia between 1998 and 2006. A large percentage of varieties was found to be susceptible highlighting the vulnerability of east coast production areas to smut. The finding of smut in June 2006 in the Childers area therefore immediately drew a very strong industry response; cane farmers urgently wanted to know how fast smut would spread in their districts, how quickly the disease would escalate in their crops and what yield losses could be expected. With the main management strategy being the planting of resistant varieties, farmers had to decide when to terminate susceptible crops and to replant with more resistant canes so that yield losses and costs were both minimised. Given that up to 80% of crops in some districts were planted to susceptible varieties, these questions were critical for maintaining profitability.

Smut was found in three production areas in 2006: Bundaberg-Isis (June), Mackay (November) and the Herbert (December). BSES initiated epidemiology studies in November 2006 seeking to answer industry-related questions. Methods were devised, plans initiated and some results obtained before SRDC funding became available; this allowed the work to be extended to the Mackay and Herbert districts. The project was initially funded for the period 1 January 2007-1 May 2010, but was later extended to 1 December 2010.

2.0 OBJECTIVES

Start-up objectives for the three-year project were:

Overall: Optimise industry transition from susceptible to resistant commercial varieties, with minimal losses resulting from direct or in-direct crop effects, thus maximising industry profitability.

Sub-objectives

1. Determine the speed at which smut builds up and spreads in crops in Southern, Central and Herbert districts. Little was known about smut epidemiology in Queensland; speed of disease escalation controls when farmers should replace susceptible crops with resistant varieties. Sub-optimal changeover will result in reduced yields leading to severe financial losses
2. Extend this information to both growers and millers to increase their understanding of the disease. Extension of the results will reduce the inappropriate planting of varieties in smut-affected districts. Smut spread in each district will vary with climatic factors such as temperature and rainfall; large variations across the production area will affect smut severity in the major cane-growing districts, warranting the need for the proposed research.

Early accomplishment of objective milestones led to an August 2008 review of the project; milestones were subsequently redefined to include the research activities listed below.

3. Modified activities:
    - Model the progress of the epidemic in the Herbert, Mackay and Bundaberg-Isis districts so that industry will become aware when the epidemic will peak and subsequently subside.
    - Select adjacent strips of 'I' and 'R' varieties and assess how the 'I' varieties will withstand the smut epidemic
    - Complete inspections on the variety trial planted in the Mackay area, assessing smut escalation as influenced by resistance.
    - Provide more detailed extension of project results in each of the study areas to ensure farmers are aware of the latest results with smut.

An additional opportunity arose to assess the effect of smut on yield; this was explored in addition to the SRDC-agreed objectives / activities listed above.

Each objective was achieved as summarised below.

Objective 1A: Determine the speed at which smut spreads in crops in Southern, Central and Herbert districts.
Networks of healthy farms (40+) were selected across the Bundaberg-Isis, Mackay and Herbert districts either in late 2006 or in late-2007 (after SRDC project funding became available and staff were engaged in the Herbert and Mackay districts). At least three susceptible crops on each selected farm were chosen and these were monitored at least three times per year. Finding an infested stool in any of these crops resulted in the whole farm being classed as infested. Smut-infestation of farms in these networks provided real-time evidence on how smut was spreading across districts; this also enabled a comparison of spread in the Herbert, Mackay and Bundaberg-Isis areas. A second approach utilised records maintained by Productivity Service staff of farmer reports of smut on their farms; these records also provided an indication of the speed of spread across districts. Mathematical analyses of these data suggested that smut spread in the Herbert appeared to be faster than in the Mackay and Bundaberg-Isis areas; all farms were predicted to be infested in the Herbert by October 2008, in Mackay by February 2009 and in Bundaberg-Isis by April 2009. This information provided farmers with a good understanding of when smut was expected to reach their farm.

Objective 1B: Determine the speed at which smut escalates in highly susceptible crops in Southern, Central and Herbert districts.
Selected crops of highly susceptible (9-rated) varieties were monitored at least three times each year and the location and number of infested stools recorded. Smut escalation rates were then quantified. Escalation rates varied quite markedly; the most rapid escalation occurring when smut-infested planting material was used to establish a crop. Scattered infested stools facilitated rapid spread to new stools from local spore dispersal. Escalation rates were approximately 7-11 fold per annum; 10 infested stools found in a crop in year 1 escalated to approximately 100 stools in year 2 and 1,000 stools in year 3 (this is well above the previously suggested plough-out threshold of 5% of stools). This compares to rates of 1-2 fold in Louisiana (Jeff Hoy, personal communication). In some crops rates were significantly lower or higher, depending on the local environment and individual crop conditions.

Objective 2: Extend this information to both growers and millers to increase their understanding of the disease.
Over 90 seminars on the findings from this epidemiology research were presented to industry during the course of this project; these were at specific smut meetings in the Herbert, Mackay or Bundaberg-Isis areas but also included Brisbane and all the other cane-growing regions. There was keen interest in project outcomes in the 2007-2008 period with intense questioning about project findings as farmers anticipated the spread of smut to their

own farms (Figure 29 details number of presentations x month). Forums included specific smut information meetings, shed meetings, annual general meetings of Productivity Service groups, special SRDC-organised seminars – such as regional meetings and a SRDC-seminar in Brisbane, BSES Field Days and the project review meeting held in Mackay in August 2008. In addition, five papers have been published / drafted for conferences of the Australian Society of Sugar Cane Technologists. ASSCT papers enabled industry-wide extension of the latest research results.

Objective 3A: Modelling the smut epidemic in each of the main infested regions.

A simple Excel model was constructed incorporating data on: i. the proportion of the variety supply to local sugar factories constituted by resistant (R), intermediate (I) and susceptible (S) varieties (both real data from previous years and predicted data for future years), and ii. expected smut severity in these crops (based on project and industry staff assessments) using three severity categories (low, medium, high severity).

A major controlling influence in the model is the proportion of the crop planted to highly susceptible varieties and the speed of smut spread and build-up within these crops. Information on the latter two components was gathered in project activities, while data on variety composition within a district was predicted by industry staff. Modelling for the Herbert, Burdekin and Bundaberg-Isis areas suggested individual epidemics would peak in:

i. Herbert: 20009-2011;
ii. Burdekin: 2012; and
iii. Bundaberg-Isis: 2010.

This information enabled farmers and industry to assess how to manage the disease and when to expect the most severe yield losses.

Objective 3B: Select adjacent strips of 'I' and 'R' varieties and assess how the 'I' varieties will withstand the smut epidemic

Studies examining the reaction of 'R' and 'I' canes in propagation plots / commercial crops were undertaken in each of the study areas. In the Herbert, focus was on the important replacement variety Q208[A]. This cane has been planted widely in every Queensland production area to replace the more susceptible commercial canes. Initial reports suggested relatively high levels of smut infestation in a few crops of this variety (up to 9% infested stools); project inspections in the Herbert clearly showed that the disease did not escalate in succeeding ratoon crops – in some cases even decreasing in incidence. This was an important outcome for the Queensland industry as it suggests that the current smut epidemic will not threaten the commercial viability of this variety. In Mackay, project staff compared disease levels in Q138 with those of other susceptible and intermediate-rated canes. Data from these inspections in May 2010 indicated that smut did not pose a huge threat to this variety; Q138 has temporarily been re-instated for commercial cultivation in the central region. In Bundaberg-Isis, inspections of strips of varieties of differing resistance were undertaken regularly, again confirming the resilience of Q208[A] in this smut epidemic. Project staff in each region were consulted by their local industry about their knowledge of smut infestation in the new commercial replacement varieties.

Objective 3C: Complete inspections on the variety trial planted in the Mackay area, assessing smut escalation as influenced by resistance.

A variety trial containing R, I and S varieties was planted in the Mackay area in 2007. This provided an opportunity to determine the level of resistance needed to tolerate the smut epidemic. Project staff made regular inspections leading up to end of the project. Data showed that the highly susceptible varieties (9-rated, such as Q157) rapidly became infested; almost all stools were infested within 18 months. Disease severity in plots of Q157 also increased quickly with consequent yield losses. There were marked differences between 9-rated canes and those rated even slightly more resistant (7-rated, but still classified as susceptible, for instance Q138). These data suggested that eliminating the most highly susceptible varieties (9 rating) was of prime importance in managing the smut epidemic. Of significance to industry, intermediate varieties such as Q135 and Q183[Ⓓ] performed very well and will be suitable for continued cultivation, even during the peak of the epidemic. The trial will be maintained beyond the project period and harvest results used to relate resistance and yield.

Objective 3D: Assessment of smut associated yield losses.
Yield loss research was not part of the original project but with the early achievement of the initial project objectives, there was opportunity for crop loss research. Yield losses were quantified in two ways: i. relating plot yields to smut incidence and severity in a single crop in a badly affected district, and ii. by analysing district factory data on the yield of susceptible vs other more resistant varieties; the latter was undertaken using whole crop cycle yields both before and during the smut epidemic. The premise is that if the disease is seriously affecting yields, district data for highly susceptible varieties should provide evidence of significant losses. Such evidence was seen with Q124 yields during the orange rust epidemic in 2000.
Individual crop plot research showed that smut decreased the yield of a crop of Q157 at Abergowrie by an average 27% and that maximum losses would have been >60%. District factory analyses showed some influence of smut on the highly susceptible varieties but this effect was not nearly as marked as the influence of orange rust on yields in the year 2000. The latter result is evidence of the success of disease management strategies adopted by local industry, where badly smut-affected crops were terminated before large yield losses became evident.

3.0 METHODOLOGY

The methodology employed in project activities is generally outlined in papers written for the Australian Society of Sugar Cane Technologists (Magarey et al., 2008, 2009, 2010 and 2011 (draft paper)).

Project staff: SRDC-funding enabled a research assistant to be employed in each of the Herbert, Mackay and Bundaberg-Isis areas and casual field staff to form an inspection team under the supervision of these research assistants. Toward the latter end of the project, the research assistant in Mackay ceased employment with BSES and relevant Mackay inspections were undertaken by project staff from either Bundaberg-Isis or the Herbert.

Data recording: databases for each district were established using Access software to enable efficient data interrogation. Updated versions of the databases were transferred regularly to Tully ensuring the project leader was kept up-to-date with project data. Results included spatial (GPS) data plus a range of other relevant information.

Spatial mapping: soon after the smut incursion, BSES purchased Mapinfo software and the project information officer (Mrs Lonie) became proficient in its use. Spatial data and associated mapping proved ideal in extending project outcomes, with spread and smut location maps easily interpreted by farmers, technical staff and project participants. Regular map updates were presented in the many extension activities associated with the project.

Smut spread:
Method 1: Details of the method used to examine smut spread across the Herbert, Mackay and Bundaberg-Isis areas are detailed in Magarey et al., 2008. Briefly, a network of previously smut-free farms was selected in November 2006 (Bundaberg-Isis), and October 2007 (Herbert and Mackay). Crops of the highly susceptible varieties (Q157, Q158, Q205[Ⓓ]) only were selected in order to gauge how fast smut was capable of spreading; these varieties were those of maximum commercial interest. The farm network in each area included a regular and diverse spacing of farms across the whole district. Three crops per

farm were regularly inspected; when smut was found on a farm, monitoring ceased and a positive result recorded for that farm. The proportion of smut-infested farms over time was used to assess the speed of smut spread. Monitoring was continued until all farms became infested.

Method 2: Productivity Service Company (PSC) and BSES Limited staff were regularly asked by farmers to identify smut on their farms. A record was kept by PSC staff of which farms were infested and when. Early in the smut incursion, there was keen farmer and industry interest in reporting smut, meaning these *ad hoc* data provided a real assessment of smut spread. Toward the latter part of the spread phase, this ceased to be the case so gathering additional data was not meaningful. Data for the Herbert, Mackay and Bundaberg-Isis areas were accessed providing a second means for predicting smut spread. Mathematical predictions made using method 1 were then compared with those using method 2.

Smut escalation: example highly susceptible crops with low infestation levels were selected in each district and were monitored 3-times per year. The research assistant plus a team of casual field staff walked every fourth cane row recording smut incidence with a hand-held GPS instrument (later a wrist-mounted GPS); infested stools were also identified by tying a different coloured flagging tape (at each inspection) to each stool. Data were downloaded and smut escalation monitored using both spatial maps and total infested-stool counts. Data on primary vs secondary whips were also recorded.

Modelling of the smut epidemic: Data from the smut spread and escalation studies were combined with real and predicted industry data on the proportion of the variety supply to each factory constituted by R, I and S varieties to make predictions when the smut epidemic would peak in each district (largest area x severity). To undertake this modelling, industry staff were asked to supply variety data for preceding years along with their predicted estimates for the following 3-4 years. Project data were then used to predict the severity of smut in the remaining crops of susceptible varieties. The epidemic was deemed to have peaked when the weighted area x severity parameter reached a maximum. The model took account of smut in R and I rated canes but their contribution to the weighted smut parameter was very small. Graphs of these predictions were produced for the Herbert, Burdekin and Bundaberg-Isis areas.

Variety comparison inspections: An important issue during the smut epidemic was ‘how do different varieties compare in their ability to withstand smut infestation’? Methods were needed that quantified both % infested stools and smut severity. Smut infestation assessment was simple, based on the percentage of stools showing any level of smut (one or more whips). Smut severity was a little more problematic but was based on a scale developed in resistance screening trials in Bundaberg. The severity scale used is outlined below: -

***Scores*: 0** = no smut whips in the stool; **1** = one or a few whips, but the majority of the stalks are healthy with no whips (up to 15% stalks with whips); **2** = between 15-45% of stalks with whips; yield loss not large as a number of stalks remain healthy; **3** = between 45-70% stalks with whips; some grassiness in the stool, significant yield losses; **4** = only one or two (if any) healthy stalks remain; the stool is very grassy and yield losses very large.

Mackay variety trial: A trial containing 10 varieties that varied greatly in smut resistance was planted in the Mackay area in 2007, so providing an opportunity to determine the level of smut resistance needed to minimise yield losses. Plots comprised four rows by 10 m with six replicates. Project staff regularly inspected trial plots recording information on infestation and severity for each variety. In 2009, some stools were cut by hand and information on stalk populations, smut severity and stalk weight analysed to determine the influence of the disease on yield. Logistics meant that not all varieties could be assessed in this manner; data were gathered for Q157 (9) and Q138 (8). The field trial was harvested in 2008 and 2009 by machine as per normal plant breeding selection trial methods (incorporating a weigh truck and the measurement of plot yields) but weights were not significantly affected by smut in these harvests. However, when smut was expected to have affected yields significantly (in 2010) the farmer unexpectedly harvested the trial area without notifying BSES. It is hoped to retain this site for assessment and harvest in 2011. Results obtained then will indicate more precisely what level of smut resistance is needed to minimise yield losses. Trial plot severity data were mapped and this highlighted differences among the varieties.

Yield loss research: two different approaches were used to assess smut-related yield loss effects. This included the effect on individual stools in the Mackay variety trial and an assessment on a whole crop in the Abergowrie area in the Herbert district. In the Mackay variety trial, stools of Q157 (HS) with severity scores of 0, 1, 2, 3 and 4 were selected, stalk populations quantified and whole stools cut and weighed by hand. The results were analysed using Spearman's rank correlation coefficient.

In assessing whole crop yield losses, a badly affected crop of Q157 was identified in the Abergowrie district, Herbert River. Two types of analyses were undertaken. i. *Stool disease severity characterisation*: assessments were made of stools in each severity category (0-4 basis) in terms of stalk number, proportion exhibiting smut whips, average weight of stalks per stool and total harvest yield per stool. Ten representative stools of each severity category were selected randomly within the crop and assessed for yield effects; data were analysed using Spearman's rank correlation. ii. *Estimation of the relationship between plot severity and commercial yield*: commercial yields were estimated from selected 'plots' marked within the crop. In the latter analysis, areas were identified where disease severity was low, medium or high. Two-row x 10 m plots (seven in total) were marked and severity assessments made on every stool within each of these plots. All sugarcane material was harvested within the plot area and the commercial crop yield measured using a bipod, grab and scales (hand harvested). This provided data on whole plot yields; an average disease severity score was calculated for these same individual plots. The results from the seven plots were further analysed by correlating average stool severity within each plot with commercial yield. Spearman's rank correlation analysis was undertaken to examine the significance of the correlation between smut severity and commercial yield.

In addition, 20 plots (1 row x 7 metres) were selected, marked and all stools within these plots assessed for smut severity. Plots were selected in a zigzag systematic pattern across the cropping area to provide a representative assessment of smut severity in the commercial crop. Average smut stool severities for each plot, plus the overall mean disease severity, were calculated from individual stool severity scores. The relationship between crop yield and smut severity in the seven weighed plots was used to predict smut yield losses for the whole field (crop) of Q157.

Variety management solution: finally, a comparison was made to show how the adopted smut management strategy, using resistant varieties, compared to a 'non-variety' solution – what would have happened if smut was allowed to run its course with the same suite of susceptible varieties. A set of assumptions was adopted which included the following: i. the % susceptible varieties did not change during the period since the incursion, ii. smut built up as predicted from epidemiology studies, iii. smut spread occurred as indicated from the epidemiology work (Bundaberg-Isis totally infested by April 2009; Mackay by February 2009; Herbert by October 2008), iv. yield losses in HS canes constitute the major part of losses studies, v. Losses were also calculated assuming HS crops were planted each year, as per their 2006 percentage (the latter won't have increased the losses dramatically, but will have increased them).

4.0 RESULTS

With three teams monitoring a large number of crops over a three year period, a very large data base and many results were collected during the course of this project. Data have been archived in Access databases (one for each area). Example results only are presented below; these results have also been summarised in papers written for conferences of the Australian Society of Sugar Cane Technologists. The four papers are reproduced in the Appendix.

4.1 Smut spread

4.1.1 Herbert

Project farms

- Smut spread quickly through the project farm network in the Herbert area. The map below (Figure 1) shows the Herbert region with the majority of the farms infested by the end of March 2008. Maps were used extensively to illustrate smut spread in many project presentations to industry.

Figure 1 – smut infestation of the network of previously disease-free farms in the Herbert district as at 31 March 2008. All farms were infested by late 2008.

Farmer smut reports

- Records from farmer smut reports were analysed mathematically in early 2008 and a curve fitted enabling a prediction as to when all farms in the Herbert would be smut-infested (Figures 2 and 3). These curves were also fitted to data from the Mackay and Bundaberg-Isis regions. The results suggested that all Herbert farms would become infested by October 2008.

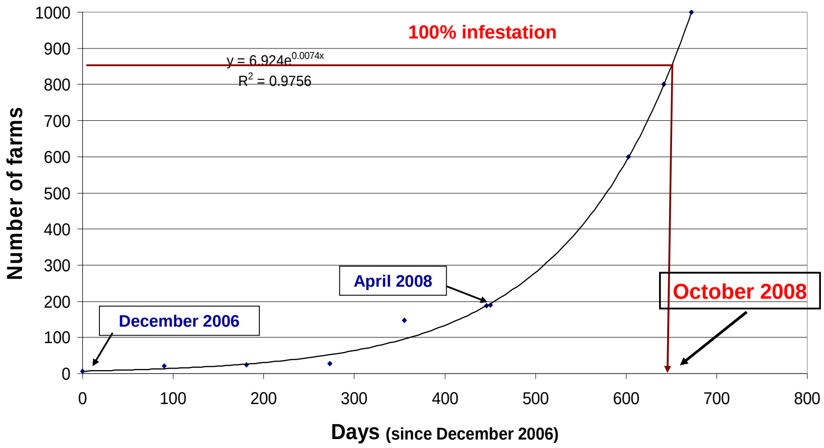


Figure 2 – Data from farmer reports of smut were also used to predict when all farms in the Herbert would become smut-infested; the prediction was October 2008. There was no disagreement from industry or service groups to this prediction and general agreement later that this indeed happened.

Figure 3 – Farmer reporting of smut was also converted into maps to graphically illustrate how quickly the disease was spreading. The top map shows all the known smut-infested farms in March 2007, while the lower one showing rapid spread to many new farms by March 2008, just 12 months later.

4.1.2 Mackay

- *Project farms:* Smut also spread quickly through the Mackay project farm network. The map below shows the Mackay region with the majority of the farms infested by the end of March 2008 (Figure 4). Initially the north coast area showed more rapid spread (near the site of the initial smut find) but later it spread quickly over the entire region.

Figure 4 – smut infestation of the network of previously disease-free farms in the Mackay district as at 31 March 2008. All farms were infested by early 2009

Farmer smut reports

- Records from farmer smut reports were analysed mathematically and a curve fitted early in 2008 to predict when all farms in the district would become smut-infested (Figures 5 and 6). The results suggested that all farms would become infested in Mackay by February 2009.

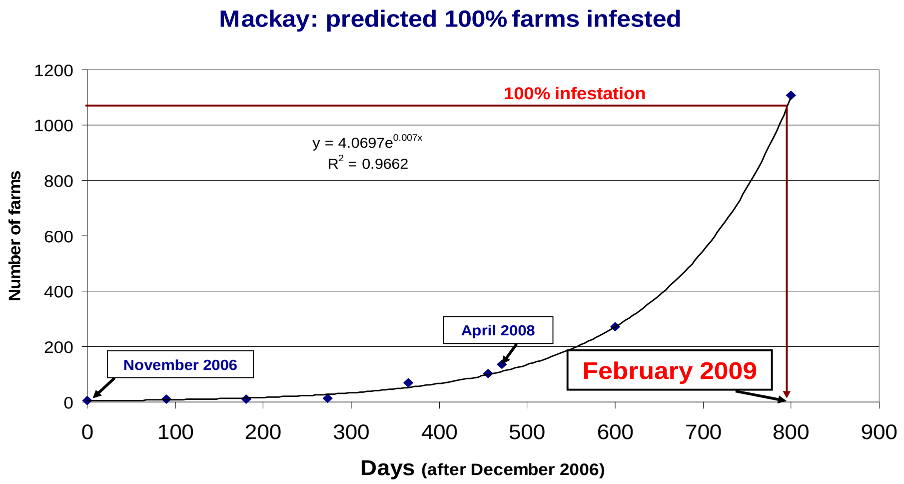


Figure 5 – Data from farmer reports of smut in the Mackay area enabled a prediction that all farms would become infested by February 2009

Figure 6 – Maps for the Mackay farmer reports are outlined above; again the top map shows the situation in March 2007, while the lower one provides details on the March 2008 situation. Spread appeared to be slower in Mackay than in the Herbert.

4.1.3 Bundaberg-Isis

Project farms

- Smut did not spread quite so quickly through the project farm spread network. The map below shows the Bundaberg-Isis region with the many project farms infested by the end of March 2008 (Figure 7).

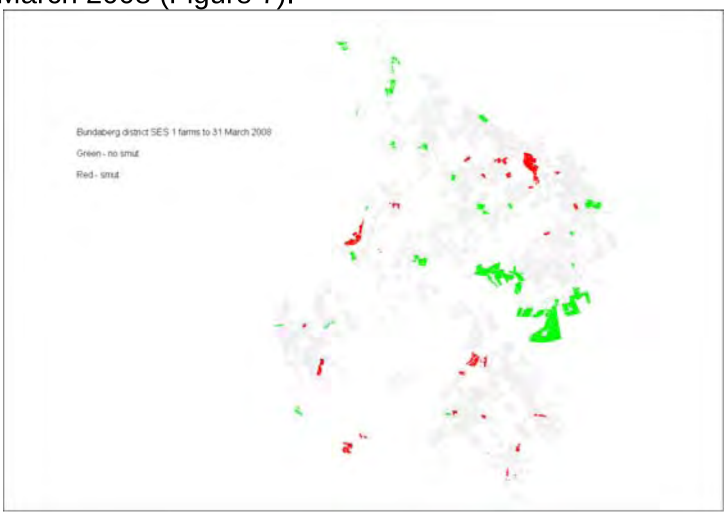


Figure 7 – smut infestation of the network of previously disease-free farms in the Bundaberg-Isis district as at 31 March 2008. All farms were infested by early 2009.

From the project network farms predictions were also made as to when all district farms would be infested. These data suggested April 2009 for the Bundaberg-Isis region (Figure 8).

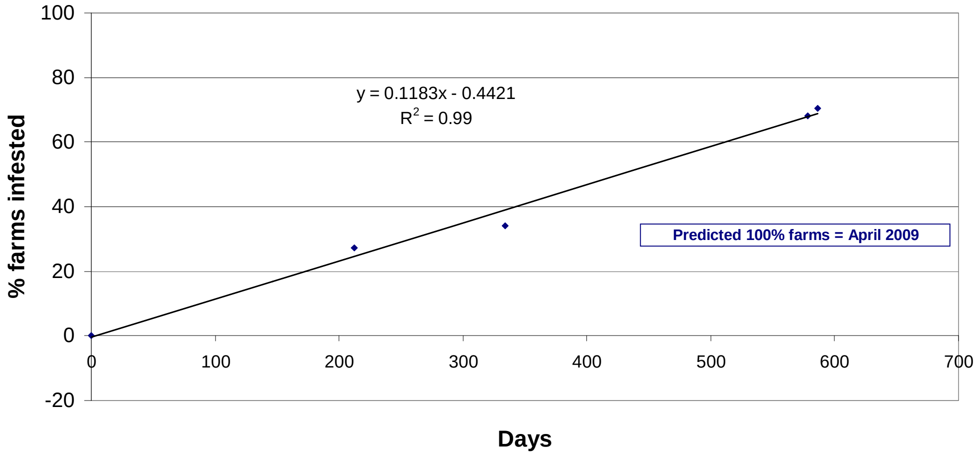


Figure 8 – predictions as to when all farms in the Bundaberg-Isis region would become smut infested were made using infestation rates of farms in the smut-free farm network selected in November 2006. This suggested 100% infestation by April 2009.

Farmer smut reports

- Records from farmer smut reports in the Bundaberg-Isis region were again analysed mathematically and a curve fitted in early 2008 (Figure 9). From these data the prediction for all farms to be infested was also April 2009 – consistent with the smut-free farm network data.

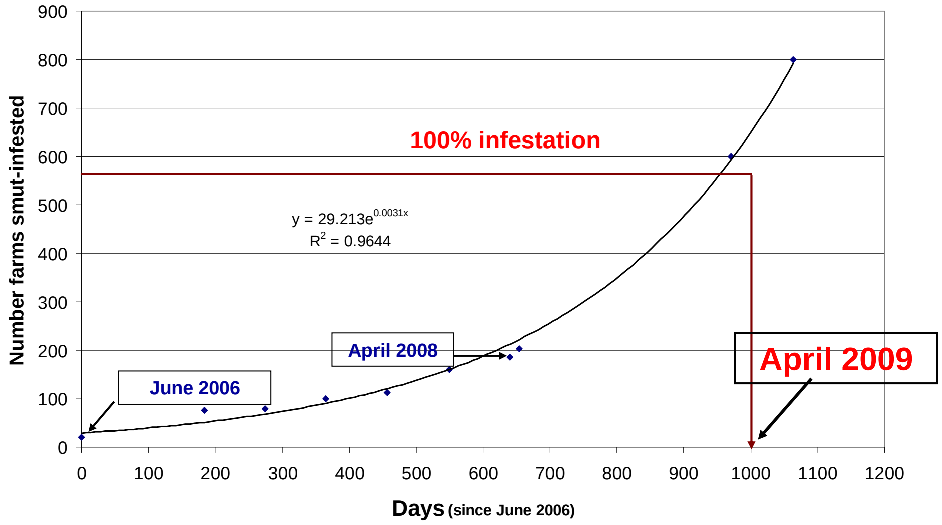


Figure 9 – predictions as to when all farms in the Bundaberg-Isis region would become smut infested were also made using farmer reports of smut infestation on their farms. The prediction was consistent with those made from the project smut-free farm network monitoring - April 2009.

- A comparison was made late in 2007 of the predictions from farmer report records in each major district (Herbert, Mackay and Bundaberg-Isis). Predictions on the increase in reported infested farms are outlined in Figure 10. These show that the spread was faster in the Herbert, compared to Mackay and Bundaberg-Isis. Maps showing disease spread on these farms are presented in Figure 11.

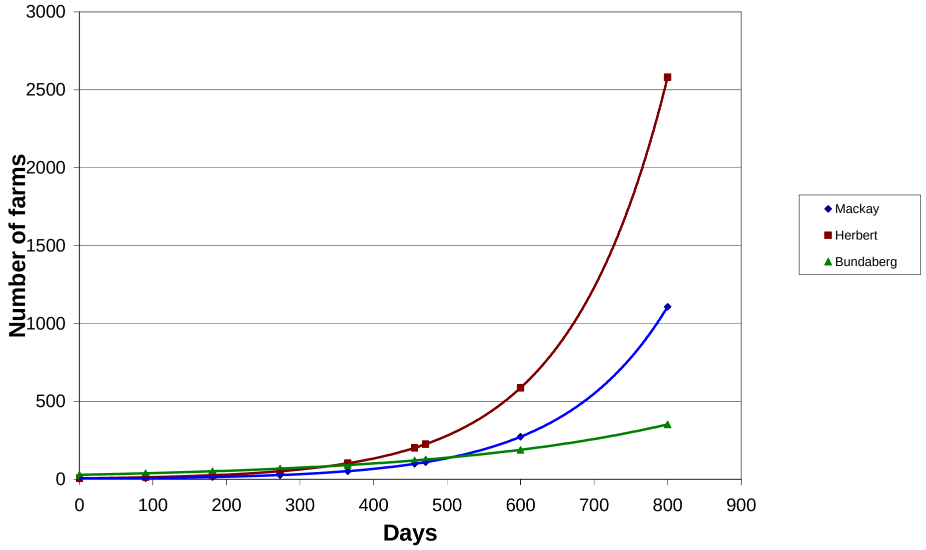


Figure 10 – predictions made early (late 2007) as to when all farms in the three study regions would become smut-infested suggested faster spread was occurring in the Herbert than in Mackay and Bundaberg-Isis

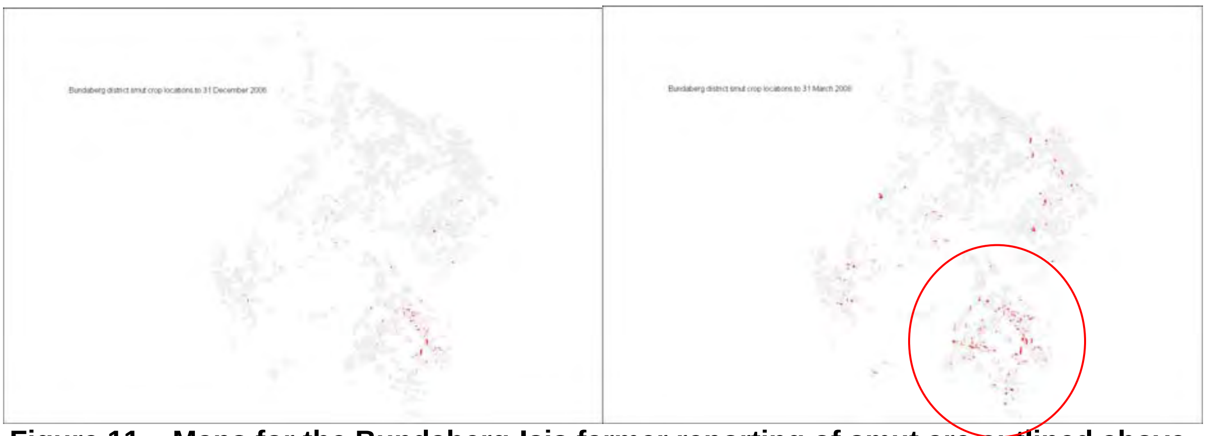


Figure 11 – Maps for the Bundaberg-Isis farmer reporting of smut are outlined above; again the top map shows the situation in March 2007, while the lower one provides details on the March 2008 situation. Note the higher concentration of smut-infested farms in the area where smut was first detected in Queensland (red circle) – in the Isis mill area. Only later did smut spread more quickly around the Bundaberg city area and in the Millaquin-Bingera mill areas.

4.2 Smut escalation

4.2.1 Herbert

Monitoring of susceptible crops

Monitoring of the stools infested in susceptible crops (principally Q157 and Q174[b]) was undertaken using GPS technology. Escalation rates were calculated from the increase in infested stool numbers in these crops (Figure 12).

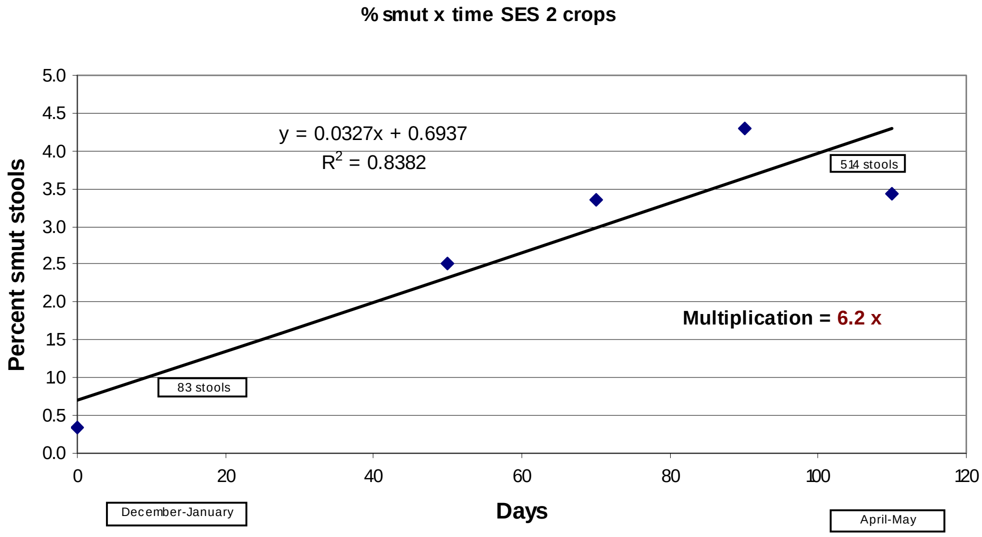


Figure 12 – The increase in infested stool numbers in susceptible Herbert crops is detailed in the above graph. The average increase in these crops was 6.2 fold per annum. The percent increase varied considerably between crops depending on whether crops had been established with infested planting material and other issues.

Primary vs secondary whips

There are two forms of whips in infested susceptible crops – those arising at the apex of growing shoots (primary whips) and those arising from the apex of side-shoots on standing mature stalks (secondary whips). Data on whip formation was recorded in susceptible crops in the Herbert. Figure 13 shows how primary and secondary whips developed during the 2008 growing season. Secondary whips only formed once mature stalk material was present in a standing crop. In the Herbert, this corresponded to April in 2008.

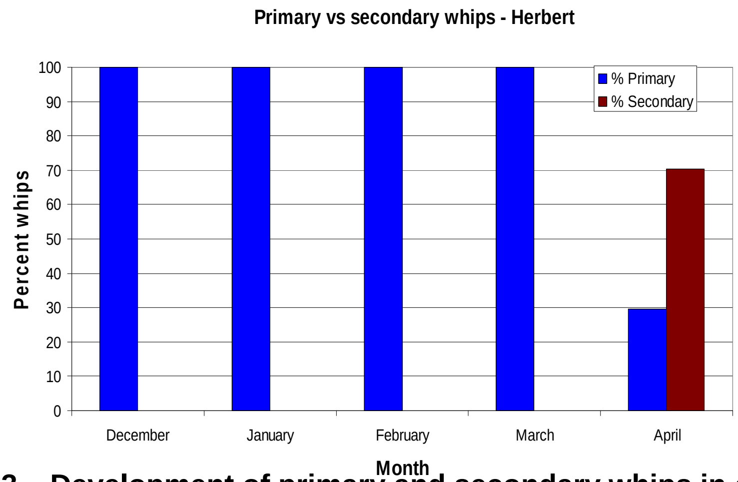


Figure 13 – Development of primary and secondary whips in crops of highly susceptible crops in the Herbert. Secondary whips only developed in April or later. Secondary whips are produced as side-shoots on standing mature stalk material.

4.2.2 Bundaberg-Isis

Monitoring of susceptible crops

Monitoring of the stools infested in susceptible crops (principally Q205$^{\Phi}$) was undertaken using GPS technology. Escalation rates were calculated from the increase in infested stool numbers in these crops (Figures 14, 15 and 16).

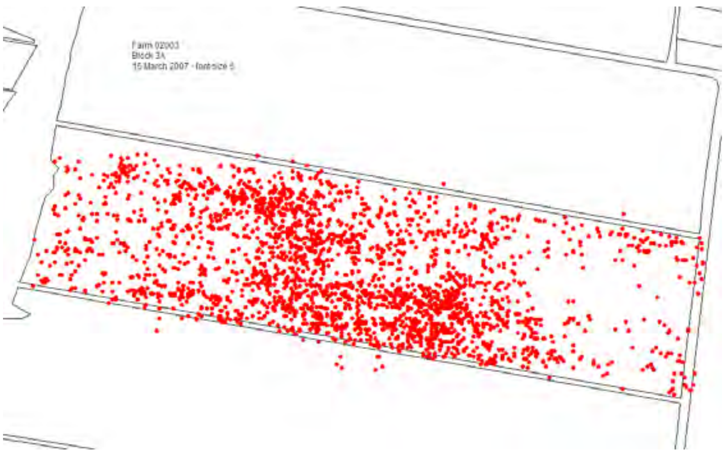


Figure 14 – The spatial map of a crop of Q205$^{\Phi}$ in the Bundaberg-Isis area showing the distribution of smut-infested stools in a badly diseased crop. Maps like this were produced for many crops in Bundaberg-Isis, Mackay and the Herbert areas.

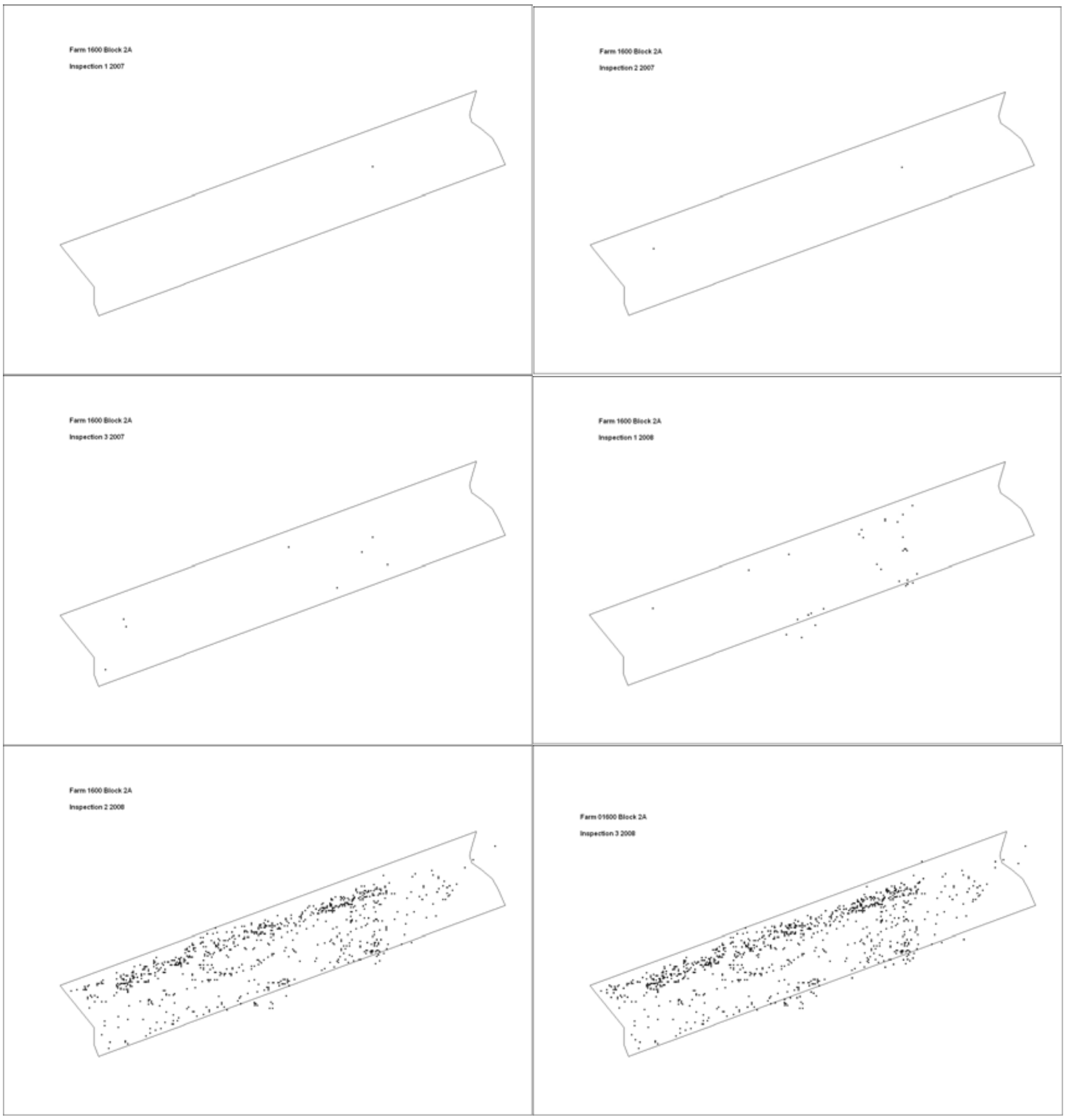


Figure 15 – The maps above show how smut may escalate in a single highly susceptible crop of Q205$^{\phi}$ in the Bundaberg-Isis area with the increase in smut infested stools represented by the black dots; the maps cover an 18 month period from early 2007 to just before harvest in 2008. A massive increase in infested stools can be seen during this period and this illustrates the potential for the disease to spread and escalate within infested highly susceptible crops

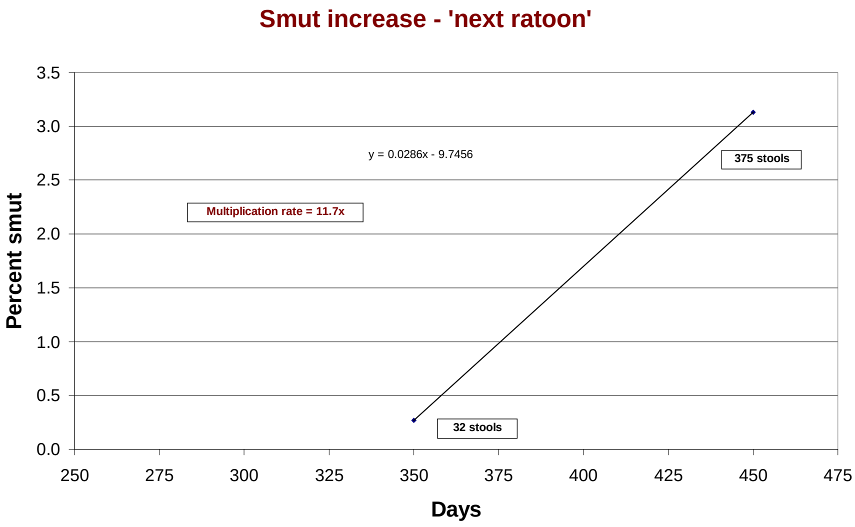


Figure 16 – The increase in infested stool numbers in a highly-susceptible Bundaberg-Isis crop of Q205$^{\phi}$ is illustrated in the graph. In this crop the escalation rate was calculated 11.7 fold per annum. Escalation rates varied markedly depending on local crop conditions.

The types of smut whips (primary vs secondary) observed in susceptible crops in the Bundaberg-Isis area during the growing season are outlined in Figure 17.

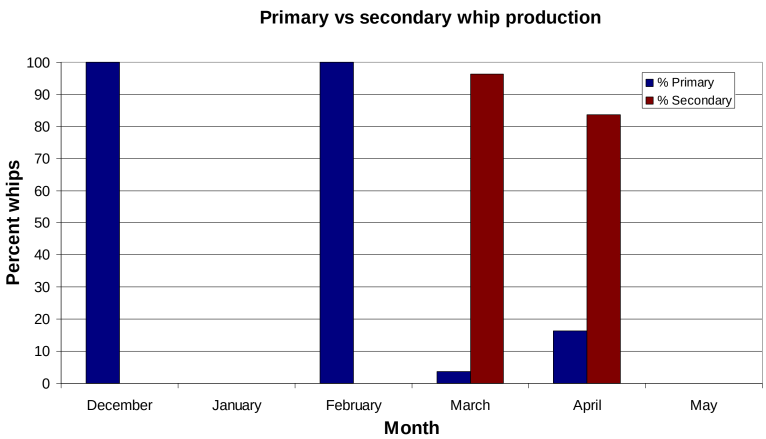


Figure 17 – Development of primary and secondary whips in highly-susceptible crops (Q205$^{\phi}$) in the Bundaberg-Isis area. Secondary whips developed earlier in Q205$^{\phi}$ in Bundaberg-Isis compared to the Herbert. Variety-specific influences may have been to reason for this response.

4.3 Epidemic modelling

Modelling of the epidemic in the different districts provided information on when the peak in the smut epidemic was to be expected in each area. The peak in smut intensity is very much dependant on the percentages of the highly susceptible varieties grown in each area and how quickly each district transitioned to more resistant varieties.

Modelling suggested that the Herbert district would suffer the highest levels of smut and that the epidemic would peak in 2009-2010 (Figure 18). A similar time-line was predicted for the Bundaberg-Isis area, but at lower intensity, while the Burdekin would peak later (in 2012) at much lower disease intensities. Reasons for the lower intensity in the Burdekin lie in two factors:

i. the disease was found there later; and
ii. this facilitated a more advanced transition to resistant varieties before the disease escalated – meaning that smut will never reach the intensity that it did in the Herbert, Mackay and Bundaberg-Isis areas.

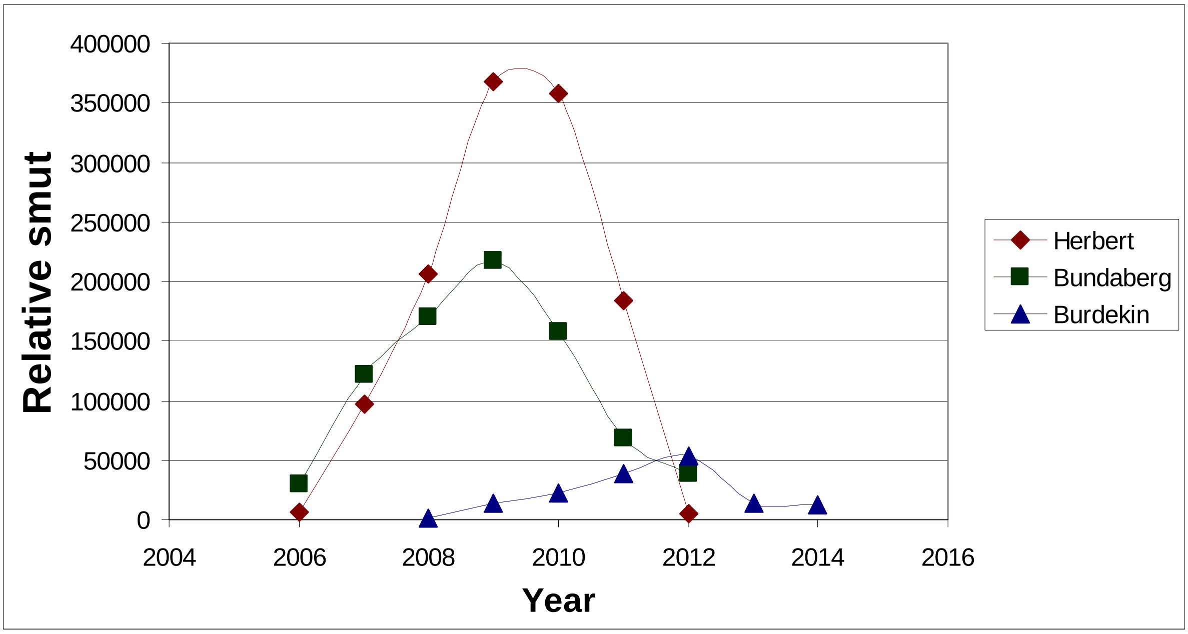


Figure 18 – Predicted peaks in the smut epidemic in the Herbert, Burdekin and Bundaberg-Isis areas. The magnitude of the smut peaks correspond with the percentage of the area cropped to highly-susceptible varieties and the severity of the disease in these crops. The Burdekin area had already largely transitioned to more resistant varieties when smut was first found in the district – so the peak is very significantly lower in that area.

4.4 Strip comparison of varieties

4.4.1 Susceptible vs highly susceptible varieties

4.4.1.1 Q186$^{\Phi}$, Q187$^{\Phi}$, Q204$^{\Phi}$ (S) vs Q157 and Q174$^{\Phi}$ (HS) - Herbert

Example data only are presented below on how varieties of differing resistance are withstanding the smut infestation pressure. In the Herbert, comparisons were made between susceptible (S, rated 7-8) and highly susceptible (HS, 9-rated) varieties in 2009. Examples of S canes include Q186$^{\Phi}$ and Q187$^{\Phi}$; Q186$^{\Phi}$ had been a useful late maturing cane in the Herbert and more northerly districts constituting up to % of the variety supply in 2006 when smut was first found in the Herbert district. Q187$^{\Phi}$ was never as popular but has a similar smut rating. Figure 19 illustrates the difference in smut infestation of stools within crops of Q186$^{\Phi}$ (S) and Q174$^{\Phi}$ (HS) planted in Macknade. There were large differences in the extent of infestation. This was also the case with Q187$^{\Phi}$ (S) vs Q174$^{\Phi}$ (HS) as illustrated in Figure 20.

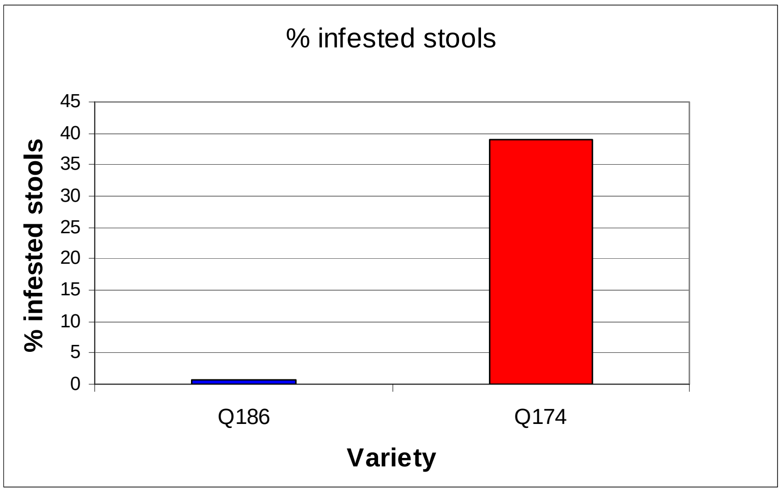


Figure 19 – Differences in smut infestation of crops of Q186$^{\phi}$ (S) and Q174$^{\phi}$ (HS) planted adjacent in the same block in the Macknade area of the Herbert district. This illustrates the large differences in these varieties across the Herbert and show how slight differences in rating can have a large impact on infestation levels.

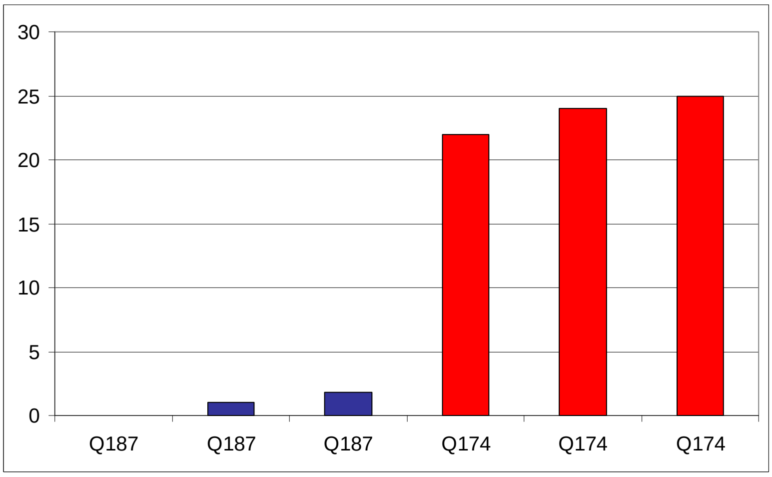


Figure 20 – Differences in smut infestation of crops of Q187$^{\phi}$ (S) and Q174$^{\phi}$ (HS) planted side-by-side in the Herbert district. This again illustrates the large difference in infestation seen in S and HS varieties across the Herbert. The different columns in the graph represent three assessments in the same crops.

Further comparisons between S and HS varieties were made in detailed inspections undertaken in the Herbert in May-June 2010. Data were collected comparing smut infestation and severity in the worst affected crops of Q186$^{\phi}$, Q204$^{\phi}$ (S), Q157 and Q174$^{\phi}$ (HS) crops; these were spread across the district. Later (October 2010), the same crops were –re-inspected with a view to undertaking yield loss assessments (Table 1).

Farmer	Variety	% stools infested	Severity
1	Q186$^{\Phi}$	85.3	2.05
	Q157	18.6	0.22
2	Q186$^{\Phi}$	69.5	1.55
	Q174$^{\Phi}$	98.9	3.29
3	Q186$^{\Phi}$	41.2	0.62
	Q174$^{\Phi}$	96.7	2.48
	Q204$^{\Phi}$	12.9	0.16
	Q174$^{\Phi}$	100.0	2.76
4	Q186$^{\Phi}$	19.5	0.20
	Q174$^{\Phi}$	52.5	0.97
5	Q204$^{\Phi}$	17.6	0.25
	Q174$^{\Phi}$	100.0	2.88
6	Q204$^{\Phi}$	47.2	0.86
	Q174$^{\Phi}$	98.6	2.78
7	Q186$^{\Phi}$	85.8	2.29
	Q174$^{\Phi}$	100.0	3.12

Table 1 – Differences in smut infestation in paired crops of Q186$^{\Phi}$, Q204$^{\Phi}$ (S) and Q157 and Q174$^{\Phi}$ (HS) planted side-by-side in the Herbert district. This again illustrates differences in infestation in S vs HS varieties in the Herbert.

When differences in infestation and severity were considered concurrently (weighted parameter providing an indication of the average severity in each stool - maximum score of 4), the differences between S and HS varieties became more pronounced (Table 2). The weighted parameter provides an indication of what can be expected on average in individual stools of each variety. The data for Q174 suggest that the effect of smut was approaching an extreme position with large and very significant yield losses.

Variety	% stools infested	Smut severity	Weighted parameter (max=4)	% maximum score
Q186$^{\Phi}$	53.9	0.79	0.43	10.6
Q174$^{\Phi}$	82.7	2.25	1.86	46.4
Q204$^{\Phi}$	25.9	0.42	0.11	2.7
Q174$^{\Phi}$	99.5	2.81	2.79	69.8

Table 2 – Differences in smut infestation in paired crops of Q186$^{\Phi}$, Q204$^{\Phi}$ (S) and Q174$^{\Phi}$ (HS) planted side-by-side at seven farm sites across the Herbert. This again illustrates differences in infestation and severity in S and HS varieties in the Herbert. An average severity rating of less than 1 suggests no or minimal smut yield effects.

In September 2010, some of the same crops were re-inspected with a view to undertaking yield loss assessments in S vs HS crops. It was hoped to locate lightly and heavily-diseased sections of each crop and to determine yield losses within each section. Visual observations suggested that in all inspected crops of Q174$^{\Phi}$, 100% of stools were infested with an average severity rating of 3 or above (stools significantly grassy and many smut whips); we could not locate lightly diseased sections of the crop. In contrast, it wasn't easy to locate whips in the worst-affected crops of Q186$^{\Phi}$; the indications were that the whips seen in earlier inspections were small and arose from tillers around the periphery of the affected stools; some of these had since disappeared. Severity ratings in the crops of Q186$^{\Phi}$ were around 1 (very minor smut effects). We could not locate sufficient disease In Q186$^{\Phi}$ crops to represent moderate or heavily-diseased comparisons.

4.4.1.2 Q138 (S) vs Q157 (HS) – Mackay

In the Mackay area, Q138 has been a variety suited to the poorer soils and areas suffering from more adverse growing conditions. Less smut has been seen in this variety than anticipated given its S rating (7). A survey was undertaken in May 2010 to quantify smut incidence and severity in representative crops of this, and other varieties, compared to Q157 in the Mackay area. Data on % infested stools are shown in Table 3.

Variety	Resistance rating	# crops inspected	% infested stools
KQ228$^{\Phi}$	2	4	0.00
Q200$^{\Phi}$	3	3	0.00
Q226$^{\Phi}$	3	3	0.00
Q183$^{\Phi}$	4	5	0.00
Q208$^{\Phi}$	4	22	0.01
Q135	5	2	0.00
Q138	7	6	0.02
Q196$^{\Phi}$	7	10	2.14
Q209$^{\Phi}$	7	5	0.00
Q157	9	10	18.98
Q170$^{\Phi}$	9	5	0.00
Q205$^{\Phi}$	9	6	8.21

Table 3 – Differences in smut infestation in a range of varieties in commercial crops in the Mackay area during a survey conducted in May 2010

These data show that there was very little smut found in Q138 (only 5 stools in total) and this was considerably less than found in Q157. In the Mackay variety trial very little smut was seen in the HS Q205 $^{\Phi}$; however in more general surveys of the Mackay district, significant infestations were observed. Q170$^{\Phi}$ appears to be unusual; very little disease was seen in this cane, even though it is rated 9. Other exceptions have been seen when reactions in the Mackay area have been compared to the Bundaberg-Isis district. Some research has been initiated into potential variation in strains of the pathogen.

4.4.2 Intermediate varieties – Q208$^{\Phi}$

The most important replacement varieties for the highly susceptible Q157, Q158, Q166$^{\Phi}$, Q174$^{\Phi}$ and Q205$^{\Phi}$ have been either the highly resistant KQ228$^{\Phi}$ and Q200$^{\Phi}$ or the intermediate rated variety, Q208$^{\Phi}$. The latter particularly has been very popular with farmers and is providing high yields and CCS; it will shortly be the major variety in Queensland, constituting a large proportion of district crops in the Herbert, Burdekin, Mackay and Bundaberg areas. Its resistance to smut is therefore of prime importance to the Australian sugarcane industry. Data from the Ord River area suggest that Q208$^{\Phi}$ may exhibit quite high levels of infestation (up to 30% infested stools) but that smut does not continue to escalate in Q208$^{\Phi}$ as it does in highly susceptible varieties; in fact it may decrease in incidence with ratoon crops. A significant component of epidemiology project inspections therefore sought to quantify how smut infestation of Q208$^{\Phi}$ compared with the more resistant varieties and whether it would support excessive levels of smut under high infection pressure. Inspections were undertaken in a number of districts, but observations from the Herbert only are presented.

Crops with the highest levels of infestation in the Herbert were identified and inspections continued over time. In addition, with one of these crops, a farmer obtained planting material from one of these crops to plant other Q208$^{\Phi}$ crops.

A crop with 9 percent infested stools was located in the Stone River area in early 2009. Planting material was taken from this crop and planted nearby. Both the ratoons arising from the original crop and the planted crop were both monitored. There was no sign of smut in the planted cane, nor was smut observed in the ratoons of the 9 percent infested crop.

4.4.3 Mackay variety trial

The Mackay variety trial was planted at the site where smut was first detected in the central district where relatively high disease intensity was being experienced. Smut infestation of varieties occurred from the plant crop through to the second ratoon during the project period. Figure 21 outlines data obtained in plant and first ratoon crops.

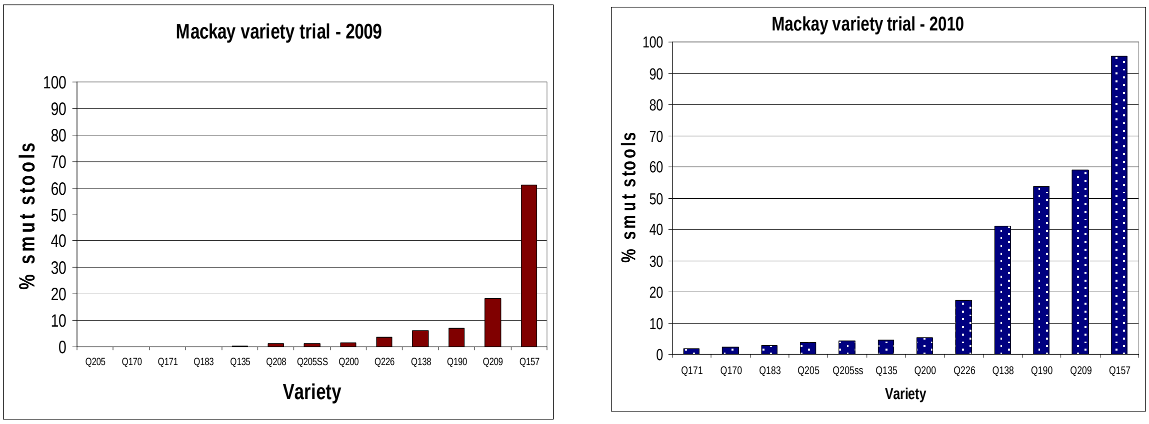
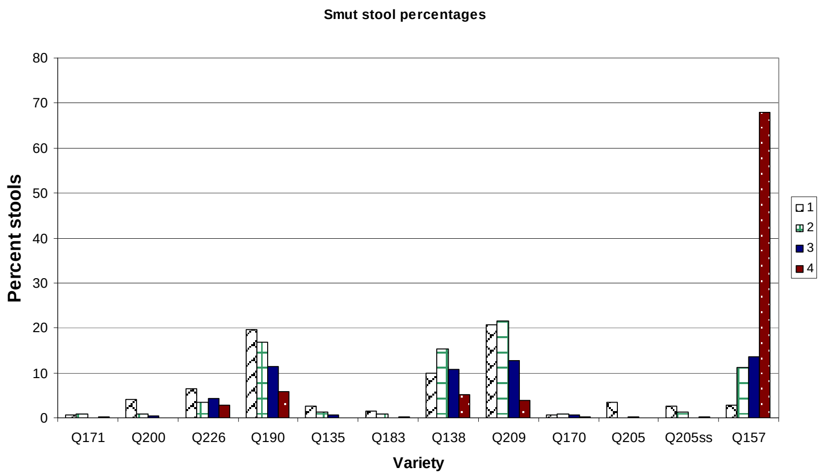


Figure 21 – Smut infestation (% stools infested) in varieties differing in resistance planted at Habana, Mackay in 2007; first ratoon data (top) and second ratoon (bottom) data are presented.

Smut severity is an important issue for cane farmers since high incidence but low disease severity does not lead to significant yield losses, while high incidence and severity may cause a financial disaster. Data for each of the varieties on maximum disease severity (score 4, which implies grassy stools and major yield loss) are presented in Figure 22.



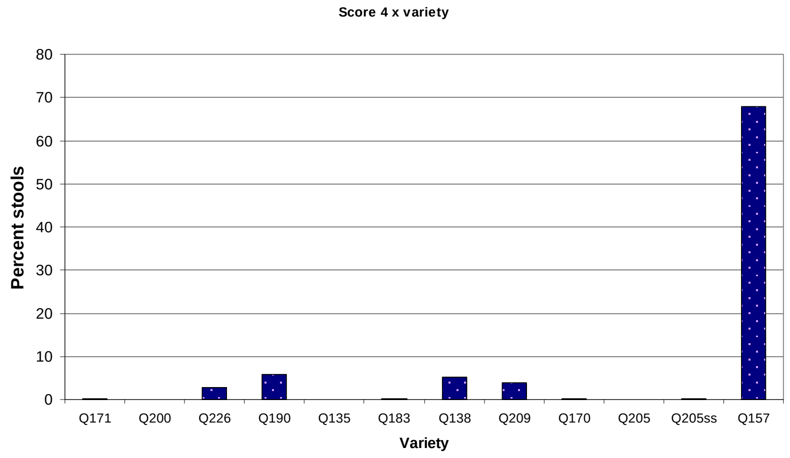


Figure 22 – Average smut severity scores for varieties in the Mackay variety trial (1-4 severity scores top; only the percentage of stools with severity score 4, below) in the second ratoon crop

These data again suggest that varieties of slightly lesser rating (7 or 8) suffer much lower smut severity compared to 9-rated canes.

In order to determine if the curvilinear rating system for smut (based on a disease incidence vs rating scale) is reflected in these data, disease incidence and severity in the Mackay trial were related to resistance using a power curve. The data for smut incidence (percent infested stools, first ratoon crop) are presented in Figure 23.

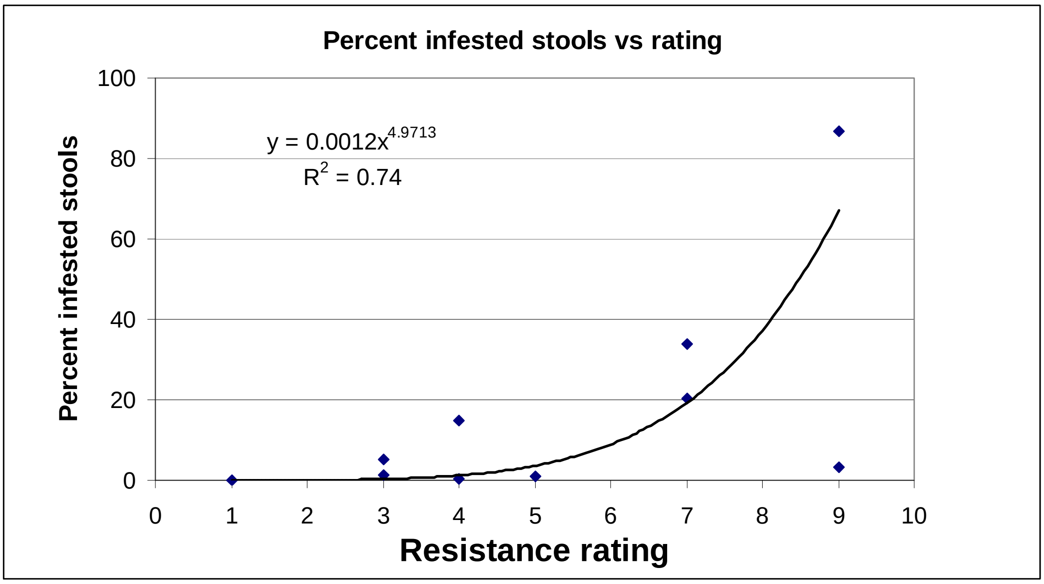


Figure 23 – The relationship between resistance rating and smut incidence in the Mackay variety trial using first ratoon data

There was an obvious exception in the data with Q170$^{\Phi}$ exhibiting very little disease even though rated 9 (HS). The curvilinear relationship between smut incidence and resistance rating had a regression co-efficient of 0.74; the application of a linear relationship resulted in an R^2 of only 0.38, indicating a poor fit to the data. These data suggest that there is a curvilinear relationship between ratings and disease incidence, at least in the early stages of crop infestation. Field observations thus match the method used to apply ratings in resistance screening trials.

Data for disease severity (Figure 22) also seem to suggest a curvilinear relationship between resistance and severity, though there are again obviously low figures for Q170[(b)].

4.5 Assessment of smut-associated yield losses

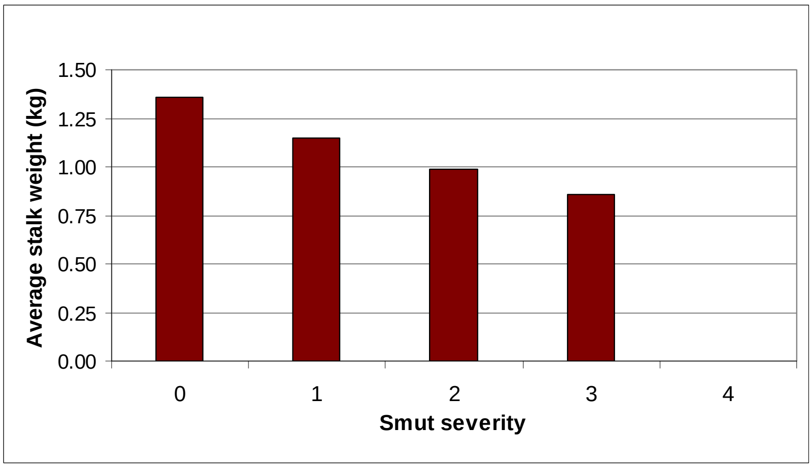
4.5.1 Effect of smut on individual stools

The relationship between disease severity and yield in individual stools of Q157 in the Mackay variety trial was analysed using Spearman's rank correlation (Table 4).

Table 4 – The results of Spearman's rank correlation analysis on the effect of smut severity rating on stool yield parameters in Q157, Habana, Mackay

Sugarcane yield parameter	Correlation coefficient (r)	Probability
Number of stalks in stool	-0.5732	p=0.0878
Total stool weight (kg)	-0.7059	p=0.0275
Average stalk weight (kg)	-0.9136	p=0.0005

The relationships between smut severity and yield components for Q157 in Mackay are illustrated in Figure 24.



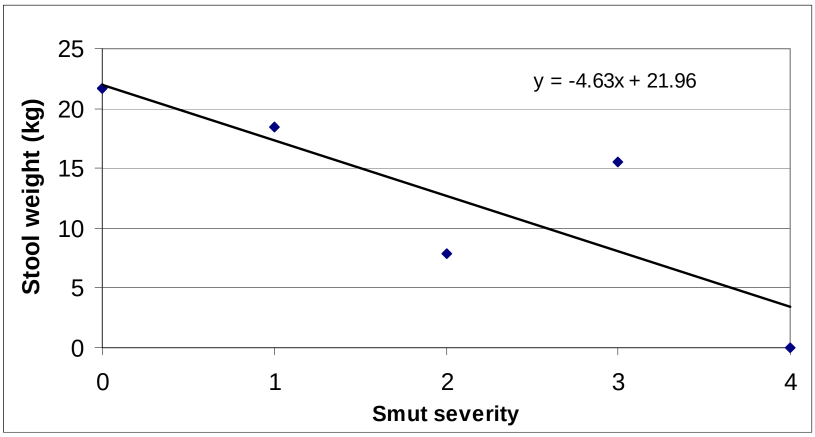


Figure 24 – The effect of smut severity rating (0-4 scale) on stool weight (top) and average stalk weight (bottom) in first-ratoon Q157 at Habana, Mackay

4.5.2 Yield loss in individual crops

Research into individual crop yield losses resulting from smut was undertaken in the Abergowrie area, Herbert district. Data relating disease severity and yield are presented in Figure 25. The data show that smut has a dominant influence on the yield of highly susceptible varieties, in tis case Q157, especially at high disease severity.

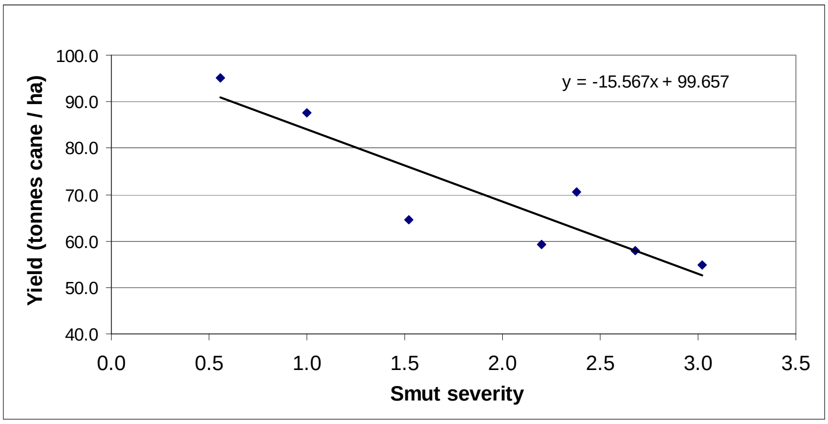
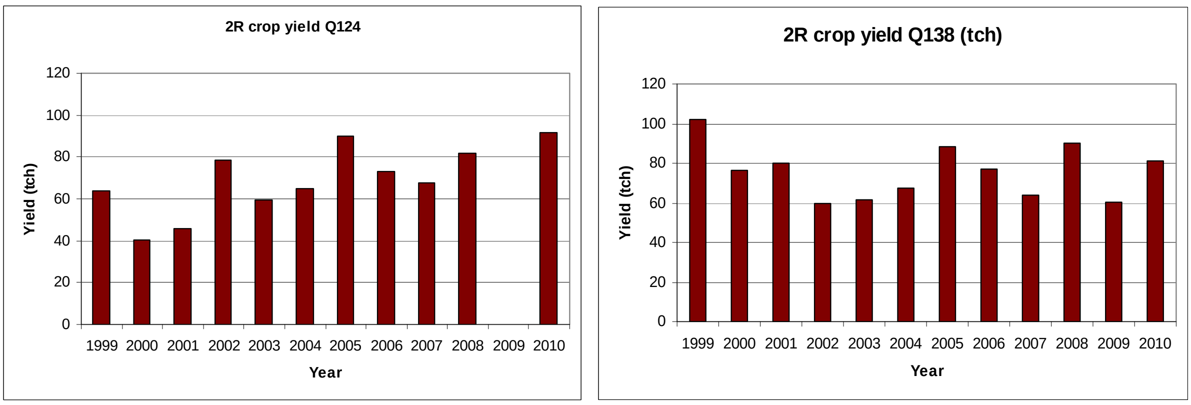


Figure 25 – Relationship between commercial yield and smut severity in Q157 at Abergowrie, Herbert River

4.5.3 Yield losses as evidenced in factory data:

Factory data were obtained from the Herbert River mills midway through the 2010 harvest season for the seasons 1999-2010. The data were analysed to determine if there were any trends in yield with smut susceptibility. It is difficult to detect such trends because of the interaction of a large range of factors that affect commercial yield. However, data extracted for Q124 indeed show how orange rust reduced the commercial yield of this variety in the years 2000 (especially) and 2001 (Figure 26). Yields in second ratoon crops in 2000 were roughly half those in the variety in 2002. There is no doubt therefore that very large effects of diseases may be detected by analysing such data. When data were examined for varieties of differing smut resistance ratings (only second ratoon data shown), there appeared to be no consistent reduction in yield in the 2009 and 2010 crops for I (Q124, Q135) crops nor for those varieties rated S (Q138, Q186[φ], Q204[φ]). However, lower yields were evident in Q157 and Q174[φ]. When the yield of all varieties was compared to their yield in the 2002 crop (2002 yield expressed as 100% for each variety), and the data for Q157 and Q174[φ] compared to the combined data from all other varieties, trends for reduced yield in the HS varieties seemed evident, while the yield of the other varieties remained constant (Figure 27).



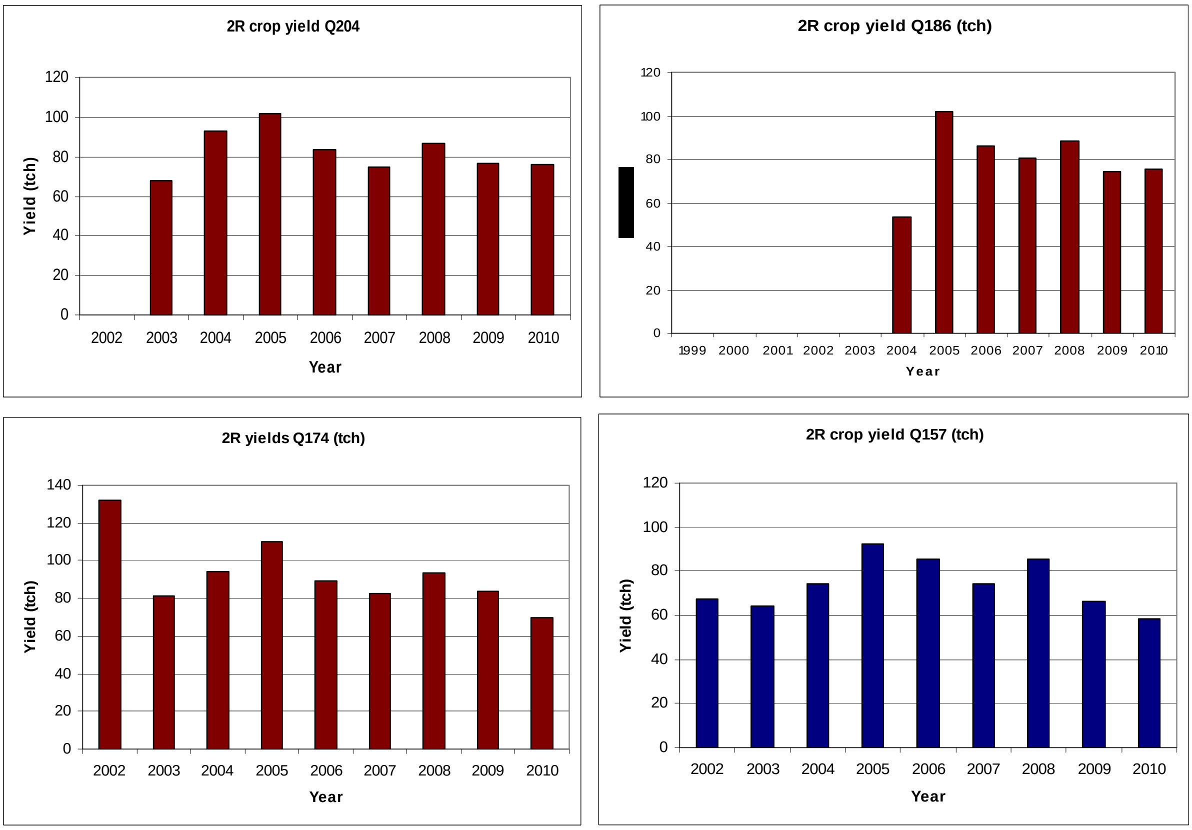


Figure 26 - Second ratoon yields (tonnes / ha) by year (2002-2010) in different varieties in the Herbert: Q124, Q135 (I), Q204$^{\phi}$, Q186$^{\phi}$ (S); Q174$^{\phi}$, Q157 (HS).

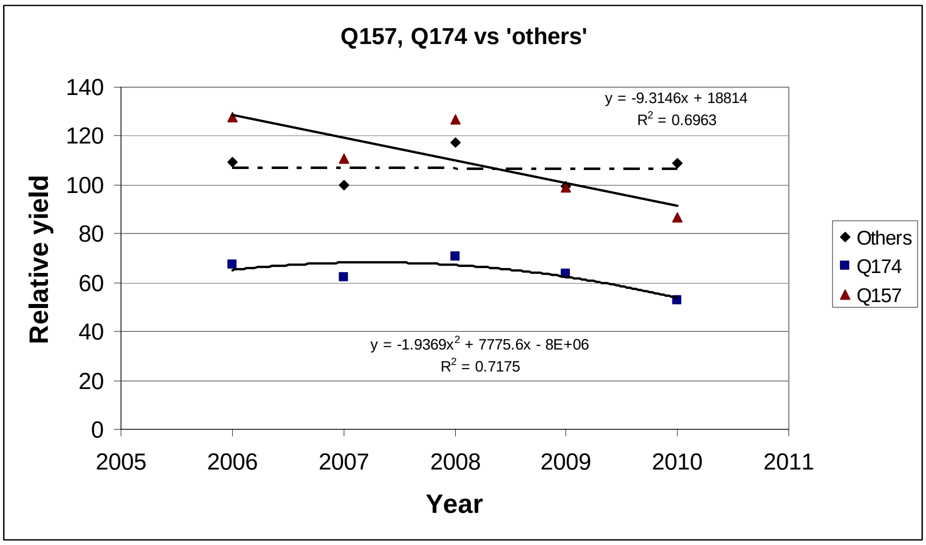
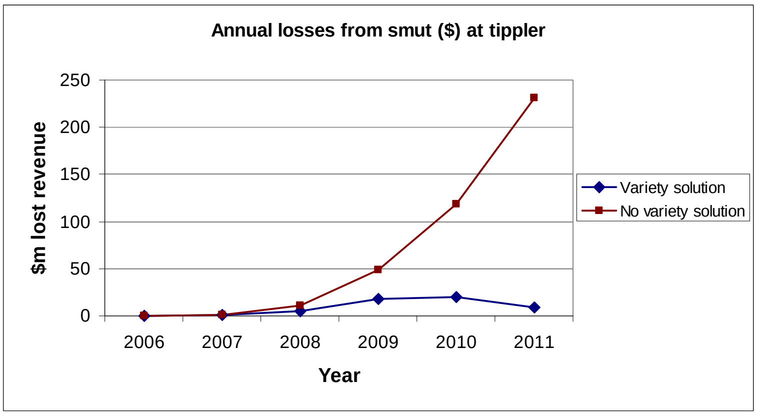


Figure 27 – Relationship between yield (tonnes cane /ha) of the HS varieties Q157 and Q174$^{\phi}$ in commercial crops in the Herbert (2006-2010) compared to mean data for the varieties Q200$^{\phi}$, Q204$^{\phi}$, Q138 and Q186$^{\phi}$.

4.6 Monetary losses from smut: variety vs no variety solution

The financial losses resulting from smut were estimated for the adopted management strategy as well as if it was assumed that a no change in variety strategy occurred. This quantifies what has been achieved in the combined industry management strategy. Calculations involved the whole of Queensland. Losses are illustrated in Figure 28.



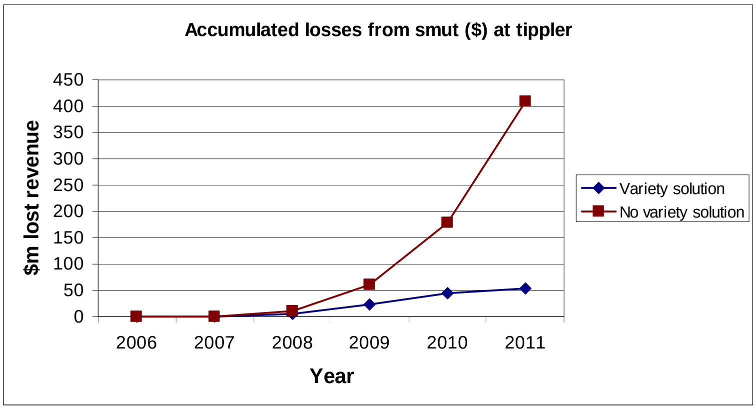


Figure 28 – Estimated financial losses from smut calculated as lost returns from the value of the sugarcane delivered to the tippler at the sugar factory in a 'variety' vs 'no variety' solution to the smut epidemic. The top graph shows annual losses, while the lower graph shows accumulated losses.

5.0 COMMUNICATION ACTIVITIES

Smut seminars

The transfer of project information was of prime importance – relaying answers to farmer's concerns. Over 90 seminars were presented by project staff on epidemiology research during the 3.5 year project period (an average of >2 / month); this doesn't include presentations made by non-project staff using project information (Figure 29). An interesting consideration is when demand for information peaked. Figure 30 shows presentations made by month and year. Some peaks in interest in smut lay in the latter half of 2006 (soon after the first smut detection) and then in late 2007-2008 and early 2009. Intense farmer interest coincided with rapid smut spread across districts; farmers were concerned when it would reach their farm, and the consequences of infestation. Later in 2008 (from personal experience) the urgency for information noticeably dissipated as farmers knew what to expect, had seen the disease, knew of the recommended management practices and were 'comfortable' with their variety transition program. Even though a large number of seminars were presented in early 2009, the intensity of interest had waned to some degree. The mid-year planting season (June-July) is when farmers and extension staff are too busy to stage seminars (there is important field work to do) thus there were very few seminars in this period in any year, even in 2008.

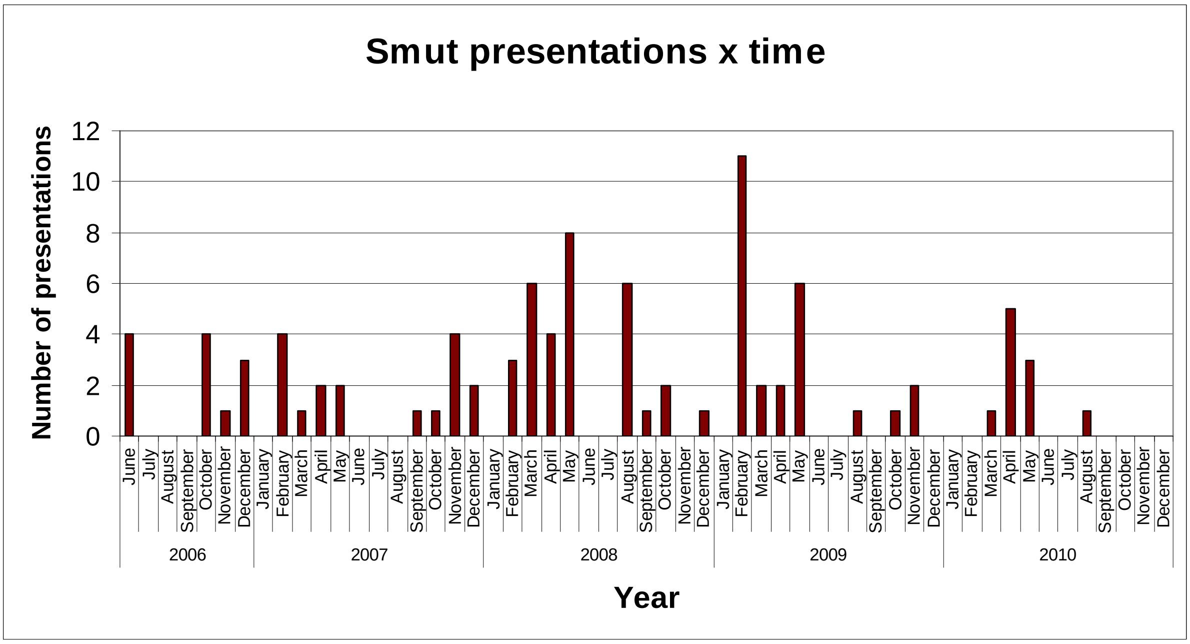


Figure 29 – Extension of results from the SRDC-funded epidemiology studies occurred throughout the course of the project. This graph shows the number of Powerpoint presentations made in each month following the first incursion in the Childers district in June 2006. Over 90 presentations were made in total.

6.0 OUTPUTS

Outputs from the project included:

- Five ASSCT papers that progressively presented information to industry on results from smut project work. This also provided opportunity to interact with industry on developments in the smut epidemic and management strategies (see Appendix 1).
- BSES Bulletin articles which provided another way of extending information to industry.
- An epidemiology newsletter that distributed key results to industry at the peak of the smut epidemic. This gave answers to the main questions posed by the farming community. Many other queries were answered in individual industry smut seminars in the different districts.
- Papers were written for other Proceedings / Journals, providing information to a wider audience.
- Project information was distributed to industry via two smut videos sent to all farmers.
- Radio interviews on ABC Rural programs also highlighted outcomes from the project.

7.0 EXPECTED OUTCOMES

Outcomes from the project include:

- Minimised direct losses from smut through better choice of varieties at the peak of the epidemic
- Maximised profitability resulting from the most appropriate termination of crops, given the level of smut on individual and district farms.
- Improved breeding and selection program activities, based on the level of resistance needed to

- minimise direct losses from the disease while maximising the use of high yielding germplasm.
- Better prediction of the losses caused by smut on an industry basis
- A better understanding of disease epidemiology in general and improved associated skills, such as the use of spatial software and databases.

8.0 FUTURE NEEDS AND RECOMMENDATIONS

There remains a need for the following research and extension:

- **Relating smut resistance to yield losses**. Potential to address this lies in:
    - ***Mackay variety trial***: where it is hoped to gather commercial yield data in the 2011 crop and to relate yield losses to resistance.
    - ***Commercial crop yields***: in the Herbert where varietal resistance and disease severity will be related to actual crop yields. It is expected that some farmers will persist in cropping susceptible varieties even though significant smut infection is present. Of interest will be the commercial yields in crops of susceptible (7-8 ratings) vs the highly susceptible (9 rated) canes in the 2011 crop. These data will provide information on optimal thresholds for smut resistance as applied to clones progressing through the selection program.
    - ***Wet tropics***: the smut epidemic is still developing in the wet tropics and New South Wales. Both areas are influenced by what is thought to be 'sub-optimal' environmental conditions. The continued spread and escalation of smut in susceptible crops in these areas should be followed so that revised recommendations may be made to farmers on thresholds for commercial crop resistance. This will assist with decisions on which varieties are added to the DEEDI-controlled Approved Variety list for each PPA.
- **Extension:** though peak need for information was mid-way through the project period, further extension is needed: -
    - ***Plant breeding***: there remains a need to continue the flow of information relating resistance and yield losses to the plant breeders. It is critical that the use of germplasm is fully exploited if commercial yields are to be maximised. Much data have been obtained already but there are further data that will shape the smut resistance selection program. Currently, all varieties are discarded from the program if they have a resistance rating >6 (most districts). This should be revised in light of findings from this project, and from work conducted in the near future.
    - ***Farming community***: as mentioned above, in some districts where the smut epidemic hasn't yet peaked, there will be a need for further information so that farmers can optimise their management of the smut epidemic.

9.0 DISCUSSION

A large amount of information on sugarcane smut, and its epidemiology, was known before the initial east coast smut incursion was detected in June 2006 (Bock, 1964; Ferriera and Comstock, 1989; Hoy, 1993, Lee-Lovick, 1978). Smut was the very first sugarcane disease described, recognised in Africa in 1877. The disease spread to almost all sugarcane producing countries around the world by the 1990s and was the subject of intense research for many years before it arrived in Australia. Research showed that spores produced on smut whips were the main means for disease spread but that the disease also spread via infested planting material. Hoy et al. (1991) showed that the vast majority (90%) of spores produced on whips were deposited within 10m of infested stools, with much smaller amounts transported further afield. He concluded that the highest inoculum deposition was directly beneath infested stools and at the base of stools in adjacent rows. Australian spore trapping research (Magarey et al., 2008, 2009) supports this, also showing the limited spread of most of the inoculum. Climate has a significant effect on the disease with the most severe smut occurring in hot, dry, irrigated farming systems while spread and escalation is slower under high rainfall conditions, resulting in lower disease pressures. A number of questions remained however for the Australian epidemic: how fast will smut spread, how quickly will the disease escalate in highly susceptible crops, and how will our varieties react to the disease under Australian environmental conditions? These issues were addressed in an SRDC-funded research project that spanned 2006-2010.

Project research showed that smut spread quickly across the study regions (Herbert, Mackay, Bundaberg-Isis), infesting all farms within 20-30 months of first detection. Although spread was rapid, it was slower than the spread of other sugarcane pathogens such as the rust fungi (*Puccinia melanocephala, P. kuehnii*). Spores of these fungi infest developing leaves, which present a much bigger target for inoculum than the auxillary buds infected by smut. For this reason, brown rust spread from Mossman to New South Wales in just 12 months while it probably took closer to 6 years for smut to spread to all farms in the Bundaberg-Isis region (assuming the initial undetected incursion was in 2003). This gave farmers time to transition out of highly susceptible, and into more resistant, varieties. Losses have been lower with smut, even though the disease is quite capable of devastating crops, because there was sufficient time to implement a management strategy before the epidemic peaked.

Smut escalation in highly susceptible crops was shown to be rapid with the disease transitioning from a minor outbreak to a major infestation (requiring crop termination) within 2-3 years. Studies on both spread and escalation answered the most important questions facing farmers and allowed them to formulate a management strategy centring on susceptible crop termination associated with the replanting of more resistant varieties. The adopted industry management strategy supported by BSES, canegrowers and local Productivity Service Companies was intense, required much hard work but worked very effectively.

Field observations on inoculum emanating from highly susceptible varieties, and the associated infestation of commercial crops, were consistent with research by Hoy et al. (1991) and Magarey (2008, 2009). Under Queensland conditions inoculum produced from HS canes is largely limited to the same crop, or to adjacent crops; there were limited effects of increased inoculum pressure >100m away. Some inoculum no doubt spreads beyond this immediate area but only a limited amount compared to the spores deposited locally. Evidence of this was seen in increased stool infestations in immediately adjacent rows of resistant, intermediate or susceptible crops planted next to a very heavily diseased, highly susceptible variety. Much lower disease levels were seen in rows of these same varieties planted further away. Disease pressure therefore decreases rapidly with distance from infested, highly susceptible crops.

Varietal resistance is a key management strategy for sugarcane smut and so our studies examined how varieties of differing resistance reacted to varying smut infection pressure. Project observations highlighted differences in disease levels in varieties assigned to the susceptible (7-9) category; those rated 7 and 8 generally showed much less disease under commercial cropping conditions than those rated highly susceptible (9). The quantity of inoculum produced in these canes was also far less. A survey of crops of Q138 (Mackay) and Q186[Φ] / Q204[Φ] (Herbert) showed that smut infestation and disease severity were substantially lower than in comparable highly susceptible varieties (such as Q157, Q174[Φ] and Q205[Φ]). The same differences were seen in the Mackay variety trial where disease levels quickly escalated in the HS Q157 compared to other susceptible canes (such as

Q138). Thus differences between S and HS crops in smut infestation levels and disease severity were observed under field conditions. There were exceptions, with Q170[Φ] and Q205[Φ] (rated 9) showing low disease levels in the Mackay variety trial; Q205[Φ] did show high infestation levels in the 2010 Mackay disease survey and Q170[Φ] has shown high levels of disease in the Bundaberg region.

A factor to be considered when comparing S and HS varieties is the method used to apply smut resistance ratings. There is a curvilinear relationship between rating and disease incidence in screening trials; a log transformation of the data is applied before ratings are assigned. A consequence is that as smut increases from near zero levels, small changes in incidence lead to relatively large changes in applied resistance ratings. At the susceptible end of the spectrum, a large change in disease incidence leads to a small change in the applied resistance rating. An implication is that a variety rated 9 (highly susceptible) suffers very much higher disease incidence than a variety rated 7; while a variety rated 3 suffers only slightly more than a variety rated 1. This effect has been evident in commercial fields in Queensland, where 9-rated varieties quickly suffer high disease levels, high disease severity and significant yield losses. In contrast, 7-rated canes under Queensland conditions show slower disease spread, disease escalation and smaller yield losses. A susceptible rating alone (7-9) is not sufficient to distinguish varieties that should be immediately eliminated from the industry and those which potentially could be grown commercially under less-favourable environments for smut. The distinction between susceptible and highly susceptible is therefore important. Varieties falling into the unacceptable HS category are 9-rated canes such as Q157, Q158, Q166[Φ], Q174[Φ] and Q205[Φ]. Those which have generally suffered very little from smut but are currently rated susceptible are Q138, Q186[Φ], Q188[Φ] and Q204[Φ]. This non-linear rating system needs to be taken into account when interpreting inoculum production, potential yield losses and resistance discard thresholds.

Artificial inoculation of varieties and natural spread trials in Bundaberg, where single rows of test canes are planted between heavily diseased rows of highly susceptible varieties show that under extreme infection pressure, smut may escalate in varieties rated S (7, 8) or even some more resistant varieties. Smut epidemiology considerations suggest that such high infection pressure would rarely, if ever, occur under commercial conditions in Queensland; though high levels were found in places such as the Ord River. Our Queensland observations showed that even at the peak of the smut epidemic, 7 and 8-rated varieties generally showed much lower levels of infestation and severity than seen in resistance screening or natural spread trials, indicating they were exposed to much lower levels of inoculum under commercial cropping conditions. The highest priority in the current smut epidemic is therefore to very quickly terminate crops of 9-rated varieties, since they are the ones that generate the highest inoculum pressure and are also most at risk from smut-associated yield losses.

The project generated a large amount of epidemiology data and further epidemiology analyses should investigate how variation in inoculum pressure with distance from an infection source governs spore deposition at the soil surface and on sugarcane buds (which leads to smut development in crops). These analyses will assist in interpreting resistance data and setting resistance thresholds for each district. There is considerable mathematical theory on disease epidemics and this could no doubt be employed to help quantify and explain variation in disease infestation and severity. SRDC has provided funding for a well-respected epidemiologist with excellent statistical and mathematical expertise to travel to Australia early in 2011. It is hoped he will provide assistance to further analyse smut data and so shed light on these observations.

Varieties rapidly propagated as replacement canes for the highly susceptible varieties have yielded well and have reduced the smut infection pressure in each district; these include Q200[Φ], Q208[Φ], KQ228[Φ] and Q232[Φ]. Their rapid adoption has significantly limited the losses from smut and is testament to the success of the industry smut emergency response plan. Overall, the epidemic will be considered by many farmers to have been more minor in farm profitability terms than they thought when smut was first detected in Queensland. This has been due to the rapid industry adoption of the smut management strategy, the ability of varieties of susceptible S (7-8, but not HS 9 rating) to tolerate the disease with minimal losses, and the later finding of smut in districts that we anticipated would favour the disease.

Some components of the smut management plan extended in 2006 should now be reviewed. In the original plan, a 5% infested stool plough-out threshold was set to provide a general indication to farmers when infested crops should be terminated to avoid significant yield losses. Where conditions highly favour a disease, spread and escalation will be rapid so low thresholds are needed. I suggest that the 5% threshold be revised and raised to a higher level for the east coast production areas with the environmental conditions prevailing in Queensland. Some individual highly susceptible crops were observed where infestation levels were high (>30% in cases), but severity was relatively low. These crops remained high yielding. Termination at 5% infested stools may have in these cases been un-necessary. Spread of inoculum from these crops into intermediate varieties did not appear significant, when smut infestations were in the 5-15% range. An issue to be considered for these thresholds is the timing of the smut assessment; the earlier the infestation is assessed during the season, the more significant is the disease incidence since there will be more time for disease escalation during the life of the crop. I believe the threshold could be raised closer to 15% infested stools when assessments are made pre-new year (under most Queensland conditions). Farmers in the Herbert generally did not terminate their crops when the 5% threshold was breached and losses only occurred in crops where stool infestations were very high (for instance >70%) - but more importantly, stool severity was also very high. The % infested stools cut-off must be linked to stool severity in order to predict when crops are to be terminated. In the Ord River, where conditions are highly favourable to smut, a low threshold was certainly needed.

Other considerations for ‘general rules’ include escalation rates; variations in the predicted escalation rates were also observed. 7-11 fold increases in highly susceptible crops were predicted, however varietal resistance also influenced this figure. Some crops of the 4-rated Q208 exhibited up to 30% infested stools but the disease did not continue to escalate; the following ratoon crop showed near zero smut. Q208$^{\phi}$ appears to be resilient in the face of the smut epidemic and has suffered very little yield losses in all Queensland districts. High disease pressure may give rise to significant infestation but almost always low disease severity. In fact there has not been a single crop of Q208$^{\phi}$ observed under commercial cropping conditions where significant yield losses from smut have occurred. The escalation rates we suggest are therefore only for highly susceptible varieties under favourable Queensland growing conditions. More resistant canes show much lower escalation rates (if the disease escalates at all)

Another component of the management plan provided guidance on expected smut yield losses. Yield loss estimates from overseas suggested a 0.5% yield loss for each 1% stools infested (Hoy, 1986). Our data for Q157 in a badly-infested crop in the Herbert appeared to confirm this, illustrating the potential for severe commercial losses. However, project observations showed that the relationship existed only in highly susceptible varieties where a concurrent increase in disease severity accompanied increasing % stools infested. By definition, it is only where stools are in severity categories 2, 3 and 4 that significant losses occur. We found some crops of 7-8 rated varieties where stool infestation was high (up to 60%) but smut severity remained low (around 1), and consequently yield losses also remained negligible. This information is important when calculating yield losses in varieties of differing resistance. Even in highly susceptible varieties, severity categories may change during the growing season. Moisture stressed crops of Q174$^{\phi}$ in the Herbert were observed late in the 2009 dry season where average smut severity was high (3 or 4 rating). However, better growing conditions during and after the 2010 wet season led to significant crop recovery; the survival, growth and maturing of previously healthy tillers led to sugarcane yields of up to 70 tonnes / ha. There may also be differences in the ability of varieties to recover from smut infestation. *Ad hoc* observations in the Herbert suggest that Q174[Φ] is more resilient than Q157, when severely infested by smut. This emphasises that general rules are useful but don't always predict what will happen under commercial cropping conditions. Further analyses of the epidemiology data are needed. Modelling of the losses from smut should also occur and be linked to predicted losses; we have data from Mackay that related smut severity category in individual stools of HS varieties with stool harvest parameters. These data could be used to model predicted losses from smut with stools infested at severity category 1, 2, 3 or 4. This will provide further data on smut vs yield losses. So relating yield losses to percent infested stools data should be treated carefully when severity data is lacking.

The most significant smut infestations have probably been in the Herbert, compared to all the other Queensland cane-growing districts. This is due in part to:

i. climatic effects, with higher temperatures compared to Mackay and Bundaberg-Isis,
ii. the Herbert starting with the highest proportion of highly susceptible varieties, and
iii. there were delays in the supply of alternative resistant planting material because of the failure of a strategic propagation plot.

It appears that the wet tropics and New South Wales production areas may suffer least from the disease – again because of climatic effects. However, the full extent of this will not be evident for a couple more years. The wet tropics provides a very interesting study area since the local industry has opted not to remove highly susceptible varieties from the approved planting lists. A couple of farmers in the area have planted the HS Q166[Φ] in 2010; these crops should be monitored for smut to observe disease progression, particularly primary smut infection (via infested planting material) and then disease escalation as the crop develops. These data will show how HS varieties tolerate smut in the wet tropics.

Although the Burdekin appears to have dodged a bad smut epidemic, it should not be forgotten that this area will be highly favourable to smut. Once the other regions have eliminated HS varieties, it is possible that the underlying, base smut infection pressure will be higher in the Burdekin, depending on the resistance dynamics of the commercial crops grown. Thresholds for resistance in the Burdekin may need to be as high, or higher than the other regions.

Extension of research results was a very significant aspect of this project; over 90 Powerpoint presentations were made to industry over the 3.5 year period. These included AGMs of Productivity Service Companies, the Australian Cane Farmers Association, local shed meetings around the state, BSES Field Days, ACFA committee meetings, BSES breakfast meetings, a BSES Activate Breakfast meeting and conferences of the ACFA and ASSCT. Results were also extended at discipline (Australasian Plant Pathology Society) and international (IAPSIT) meetings. On many occasions there was an intense desire within the sugarcane industry for epidemiology information, especially when smut was spreading across districts and increasing in severity.

The effectiveness of the smut management plan in limiting industry financial losses from the current epidemic was compared to a 'no variety' solution. This clearly shows the success of the adopted industry program and that it delivered a successful outcome. It emphasises the importance of industry regulation and the ability of different sectors to work together for the common good. To have a major disease sweep through the industry with such small losses is a very significant achievement. The major foundation of this strategy lay in the rapid elimination of highly susceptible varieties from commercial crops. Without a strong, uncompromising approach to this strategy, smut-associated yield losses in the Australian sugarcane industry would have been far higher. Industry leaders (BSES, CPSL companies, and canegrowers) should be congratulated for the approach taken.

Even though SRDC-funding for this project has now ceased, there remains a need for further smut research, particularly to refine what will happen in current smut-infested crops of 7 and 8-rated varieties. Observations in the 2011 crop particularly will be valuable. Our project suggests that beyond 2012, smut will have largely run its course and the epidemic will have passed. The opportunity to gain valuable commercial crop epidemiology data will then be gone too. In the meantime any further data that can be obtained will provide a better understanding of how varieties respond to smut. Yield data obtained from the Mackay variety trial will enable a better definition of the relationship between resistance and yield loss so that the level of resistance needed in commercial Queensland crops in the long term can be optimised.

10.0 PUBLICATIONS ARISING FROM THE PROJECT

- Magarey, R.C., Denney, D., Croft, B.J., Lonie, K.J. and Willcox, T.G. 2008. Smut epidemiology studies in the Bundaberg-Isis area in 2006-2007. Proceedings of the Australian Society of. Sugar Cane Technologists, 30: 63-71.
- Magarey, R.C., Denney, D., Sheahan, T., Fowell, L., Croft, B.J., Lonie, K.J., Bull, J.I., Bhuiyan, S. and Willcox, T.G. 2009. Results from smut epidemiology studies in the Herbert, Mackay and Bundaberg-Isis areas in 2007-2008. Proceedings of the Australian Society of. Sugar Cane Technologists, 31: 145-157.
- Magarey, R.C., Denney, D., Sheahan, Bull, J.I., 2010. The Australian sugarcane smut epidemic: epidemiological considerations and predictions for the final stages. Proceedings of the Australian Society of. Sugar Cane Technologists, 32: 375-387.
- Magarey, R.C., Denney, D., Sheahan, Bull, J.I., 2010. Yield losses caused by sugarcane smut in several crops in Queensland. Proceedings of the Australian Society of. Sugar Cane Technologists, 32: 347-354.
- Magarey, R.C., Sheahan, T., Sefton, M, Kerkwyk, R, Bull, J.I 2011. Yield losses from sugarcane smut: indications from Herbert mill data and from individual crop assessments. Proceedings of the Australian Society of. Sugar Cane Technologists, 33: (In Draft)

11.0 LITERATURE CITED

- Bock, K.R. (1964). Studies on sugarcane smut (*Ustilago scitaminea*) in Kenya. Transactions of the British Mycological Society 47: 403-417.
- Ferriera, S.A. and Comstock, J.C. (1989). Smut, In ‘Diseases of sugarcane’.(Eds. Ricaud, C., Egan, B.T., Gillaspie, A.G. Jr, Hughes, C.G.) pp. 211-229. Elsevier, Amsterdam.
- Hoy, J.W. (1986). Incidence of sugarcane smut in Louisiana and its effect on yield. Plant Disease 70: 59-60.
- Hoy, J.W., Grisham, M.P.and Chao, C.P. (1991). Production of sori and dispersal of teliospores of *Ustilago scitaminea* in Louisiana. Phytopathology 81: 574-579.
- Lee-Lovick, G. (1978). Smut of sugarcane – *Ustilago scitaminea*. Review of Phytopathology 57: 181-188.

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