# BSES Limited

**ESTIMATING DISEASE-ASSOCIATED YIELD LOSSES IN BREEDING SELECTION TRIALS**

**Endemic diseases: Pachymetra root rot, orange rust and yellow spot**

**By**

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**PR07004**

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**SUMMARY**

Previous work has shown that plant improvement stage 3 selection trials can be used to assess the relationship between yield and disease resistance with particular Queensland endemic diseases - principally Pachymetra root rot, yellow spot and orange rust. Results provide a means for fine-tuning the plant improvement program - ensuring that commercial varieties have just the right level of resistance to maximise high yielding ability while minimising disease-associated yield losses.

In this study, data from 2003-series stage 3 (FATs) trials in northern and central districts were studied to determine the relationship between resistance and yield for Pachymetra root rot and orange rust. As yellow spot only occurs in the high rainfall areas of northern Queensland, analyses for this disease were restricted to this region only. Brown rust was to be included in the study but the difficulty is assessing disease resistance in FATs, and the lack of disease, made obtaining data to brown rust impossible. Additional data were available for Pachymetra root rot for northern series trials (1995-2004) providing more detailed information for this disease.

The data analysis showed that losses to Pachymetra root rot can be very significant in both northern and central districts (>40% for tonnes cane and tonnes sugar in individual trials) and that losses consistently are above 10%. CCS was largely unaffected while tonnes cane and tonnes sugar/ha were the main yield components affected.

Yellow spot caused inconsistent losses in northern trials, but on average still reduced yield (tonnes cane and tonnes sugar) by over 10%. In some years and in some locations losses were reduced considerably.

Orange rust caused huge yield losses in the year it was first detected (2000); at some locations losses in the 2000 plant crop were nearly 60% (tonnes cane and tonnes sugar). In later years, losses were greatly reduced and similar to those caused by yellow spot.

Environmental variables are very likely to have influenced yield losses caused by these diseases. Past analyses have shown that the central district favours spore germination conditions for *Puccinia kuehnii* (orange rust pathogen) and yield losses caused by orange rust seemed to be greater in that region. The high orange rust infection pressure in 2000, associated with very extensive plantings of the susceptible Q124, are very likely to have contributed to the large orange rust-associated yield losses seen in plant crops in that year. Lower losses later were probably a result of lower infection pressures associated with reduced cropping of the susceptible Q124 and an increase in bio-control of the disease. Further investigations are necessary to quantify the effects of the bio-controls. There was some linkage between Pachymetra root rot and annual rainfall though this needs to be investigated further.

A consideration of crop resistance profiles for northern and central crops in 2004, and assessment of the Resistance Index (RI) of clones in the plant improvement program, provided a gauge of the need to select for higher levels of disease resistance. RI values suggest there is a high level of orange rust resistance in FAT clones, intermediate level of Pachymetra root rot resistance, and less resistance to yellow spot.

It is recommended that FAT substation procedures be examined in the light of the interaction between residual Pachymetra spore populations and yield effects in crops subsequent trial plantings.

## 1.0 BACKGROUND

Sugarcane diseases exert a significant influence on the yield of commercial crops in Queensland. There are a number of endemic diseases that are widely dispersed through the industry that reduce commercial crop yields. A long-term, concerted disease control program in Queensland has reduced the influence of these diseases, but has not been able to entirely eliminate yield effects. The most important endemic diseases are listed in Table 1 and are caused by bacterial, fungal, viral and unknown causal agents.

**Table 1 The most important endemic diseases in the Queensland sugarcane industry**

| Disease | Causal agent | Species |
|---|---|---|
| Brown rust | Fungus | *Puccinia melanocephala* |
| Orange rust | Fungus | *Puccinia kuehnii* |
| Yellow spot | Fungus | *Mycovellosiella koepkei* |
| Chlorotic streak | Unknown | Unknown |
| Mosaic | Virus | Potyvirus |
| Leaf scald | Bacterium | *Xanthomonas albilineans* |
| Fiji leaf gall | Virus | Fiji disease virus |
| Ratoon stunting disease | Bacterium | *Leifsonia xyli s.sp. xyli* |
| Pachymetra root rot | Fungus | *Pachymetra chaunorhiza* |
| Nematodes | Nematodes | Various species |

Until recently, a limited amount of research had been undertaken examining the yield effects of these diseases, particularly the influence of disease resistance on yield losses. Yield loss research has been summarised by Magarey and Croft (1998). It is accepted that endemic diseases can cause significant yield losses in susceptible varieties, but losses in varieties of intermediate resistance, and the influence of the environment on these losses is largely unknown.

### 1.1 Factors affecting disease occurrence

A number of factors interact to affect the occurrence and severity and sugarcane diseases. These are important in governing yield losses and are described briefly below.

There are several key environmental factors that influence disease incidence (particularly leaf diseases); these are relative humidity, temperature and rainfall. The plant host also provides a key influence on disease incidence (varietal resistance), and pathogens may be unstable leading to variation in their ability to infest their host. Plant pathologists use the following diagram (Figure 1) to illustrate the relationship between these variables.

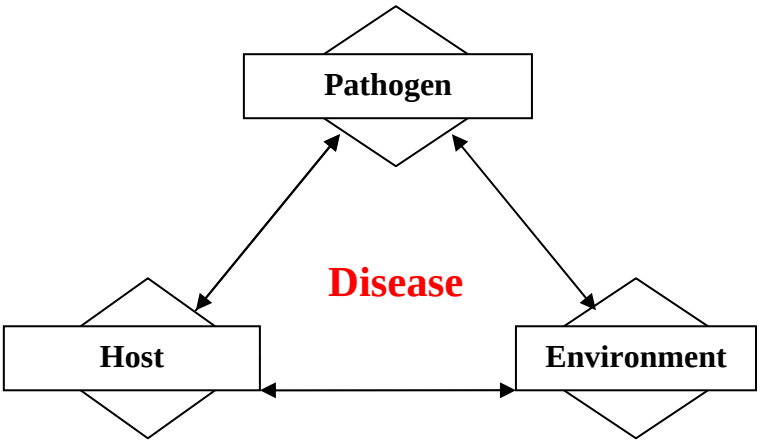



**Figure 1 The relationship between the host, pathogen, environment and disease**

### 1.1.1 Environmental variation

As the environment varies, the ability of the pathogen to invade the host also varies. This is very important with a number of diseases, especially leaf diseases. Relative humidity and temperature vary constantly and leaf pathogens have specific environmental requirements for different aspects of the disease cycle. This is particularly evident during the infection process, where conditions required for spore germination and hyphal spread into the host tissue are very specific and greatly influenced by the pervading environmental conditions. In years when rainfall is below average, low relative humidity may make conditions unsuitable for spore germination. As a consequence, leaf disease severity, and hence associated yield losses, will also be very low. In other years above average rainfall may favour the disease and lead to large yield losses. For this reason, assessing the effect of a leaf disease on yield in any one year (alone) will be insufficient for quantifying the long term yield effects of that disease. Losses would be better estimated by collating 10 years of data where below average, normal and above average rainfall and temperature conditions are experienced.

#### 1.1.1.1 Climatic requirements for leaf pathogens

The conditions needed for disease to occur also vary between pathogens. Previous work has shown that environmental requirements for spore germination in *Puccinia melanocephala* (brown rust) and *P. kuehnii* (orange rust) vary significantly; *P. melanocephala* requires free water (as in a dew) as does *Mycovellosiella koepkei* (yellow spot pathogen) while *P. kuehnii* requires relative humidity over 97% (Staier et al, 2004). These requirements are illustrated in Figure 2. Temperature also exerts a major influence on disease incidence; the requirements for *Puccinia melanocephala, Puccinia kuehnii* and *Mycovellosiella koepkei* are illustrated in Table 2. These two interacting factors exert major effects on leaf disease occurrence. Brown rust occurs during spring months after cool nights (with dew) and with warm sunny days. Orange rust is favoured by wet season conditions where relative humidity and temperatures are high; these conditions also favour yellow spot.

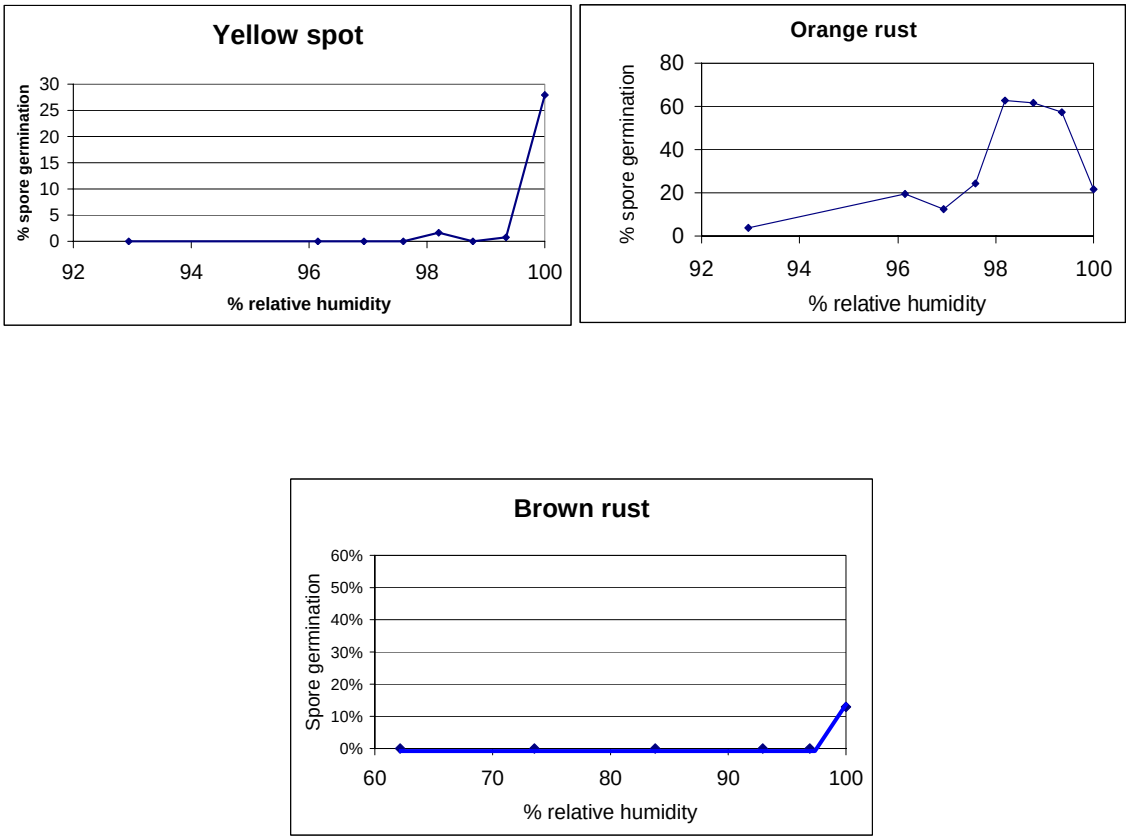



**Figure 2** **Graphs illustrating the relative humidity requirements of the three major leaf disease pathogens in Queensland - *Mycovellosiella koepkei* (yellow spot), *Puccinia kuehnii* (orange rust) and *P. melanocephala* (brown rust). Germination of spores of *P. melanocephala* in free water (not shown) was optimal with 52% of spores germinating**

**Table 2** **Optimum temperatures for spore germination in each pathogen**

| Disease | Pathogen | Optimum temperatures |
|---|---|---|
| Brown rust | *Puccinia melanocephala* | 11-27$^{o}$C |
| Orange rust | *Puccinia kuehnii* | 17-23$^{o}$ C |
| Yellow spot | *Mycovellosiella koepkei* | 20-30$^{o}$C |

Some analysis has been undertaken comparing the favourability of different locations for orange rust occurrence (Figures 3 and 4), based on optimum spore germination conditions. These data provide some indication as to where the disease may exert its greatest influence. Ideally, monitoring of weather conditions in each cane-growing area would provide the best information as to when (or if) optimum conditions for disease occurrence occur.

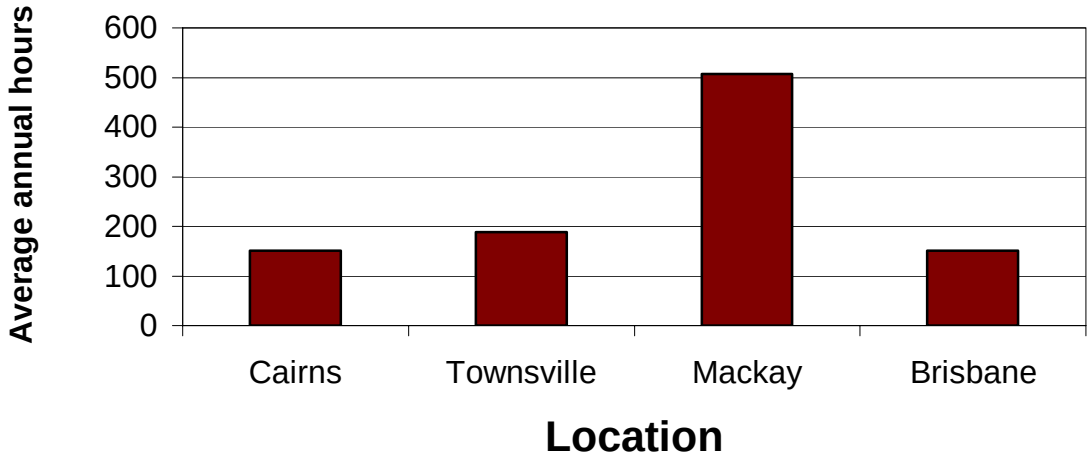



**Figure 3** **Average annual number of hours suited to the germination of spores of *Puccinia kuehnii* in major Queensland centres**

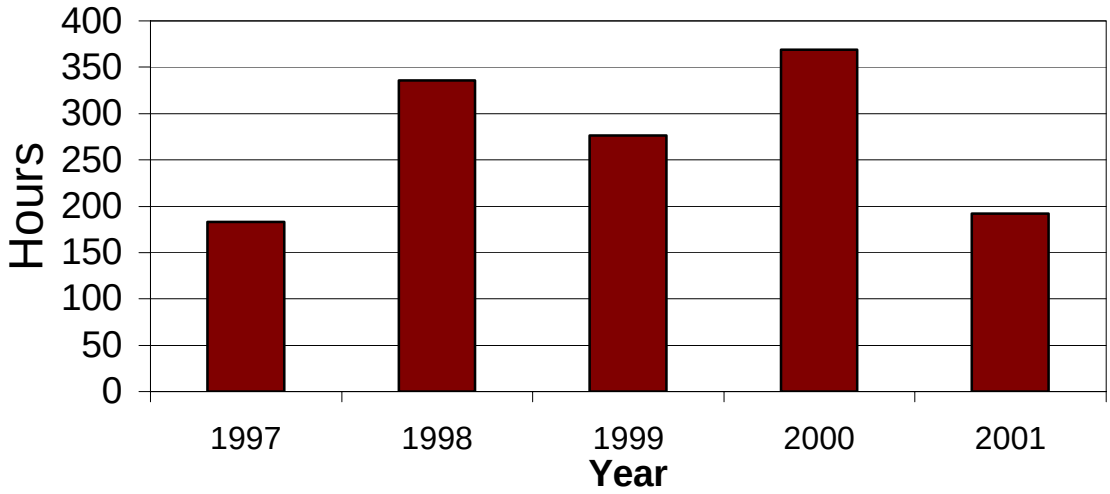



**Figure 4** **A comparison of accumulated hours of suitable conditions in the Mackay area for *Puccinia kuehnii* (orange rust) spore germination in the 1997-2001 period**

#### 1.1.1.2 Climatic requirements for soil borne pathogens

For soil-borne diseases, such as Pachymetra root rot, environmental variation is an important issue too. Research conducted in the early 1990s, on the wet tropical coast, suggested that rainfall had a very important role in governing disease incidence (Magarey and Soper, 1992). The authors found a relationship between spore population and rainfall beneath two varieties (Q117 and Q124) in the Gordonvale-Fishery Falls area. Higher rainfall was associated with increased spore populations, suggesting higher disease levels were present in higher rainfall districts.

The soil environment is more stable than atmospheric conditions, the latter may vary drastically within even a few minutes or hours. Soil conditions tend to buffered by much slower changes in soil moisture conditions. However soil environmental factors can again exert a significant influence on soil-borne disease incidence.

### 1.1.2 Pathogen variation

Pathogen variation can have an important influence on disease levels. The propensity of pathogens to change varies with species; some pathogens are stable while others are prone to mutation.

For many years, orange rust was a very rare and minor pathogen - so rare that few people had ever seen the disease. However, with the wide-spread planting of the variety Q124 in the 1990s, opportunity arose for the orange rust pathogen, *Puccinia kuehnii,* to mutate. Pathogen mutation is thought to have led to the previously resistant variety Q124 suddenly becoming susceptible to the disease; variation in the pathogen led to a strain that 'overcame' the disease resistance of Q124. Such variation in a pathogen has been seen regularly in stem rust of wheat caused by *Puccinia graminis*. Changes in *P. kuehnii* immediately had a huge influence on disease levels, which rose from minor to where the disease affected over 140,000 ha of crops in the year 2000 (Magarey, 2005). Orange rust caused one of the most significant disease epidemics in the history of the Australian sugar industry simply because pathogen variation made a previously resistant variety susceptible.

### 1.1.3 Host variation

Host variation is of great significance for the Australian sugar industry too, providing a key disease control strategy. The industry relies on this variation for selecting varieties with sufficient resistance to the major diseases, releasing only these to the industry. A major activity of sugar industry plant pathologists is to assess hosts (varieties) for resistance to the major endemic diseases in the Australian industry; the aim is to reduce disease-associated yield losses to negligible levels. The variation in disease resistance and how this affects yield losses with several major endemic diseases is the focus of the research described in this report.

Host selection is normally based on specific disease resistance screening trials. The BSES Experiment Station at Woodford undertakes resistance screening for major Australian sugarcane diseases; similar work is undertaken at the BSES Tully Experiment Station. There is also some natural selection for host resistance in breeding selection trials. The presence of major endemic diseases will lead to yield losses in susceptible clones; the selection of clones on yield will naturally select for disease resistance - if the endemic disease is significantly affecting sugarcane yield. The research detailed below aimed to quantify this very issue - how much are the major endemic diseases affecting the yield of clones in routine plant improvement selection trials.

#### 1.1.3.1 Routine resistance screening trials

BSES pathologists have routinely screened for resistance with many of the endemic sugarcane diseases present in the Australian sugar industry. These include those listed in Table 3. In each case, pathogen inoculum is applied to each test clone, either mechanically or through the application of infested vectors.

**Table 3 Detailed below are the routine resistance screening trials conducted by BSES, the timing of these in the plant improvement program and the nature of the test**

| Disease | When | Test |
|---|---|---|
| Fiji leaf gall | Early and late in selection program | Glasshouse and field |
| Mosaic | Late in selection program | Field |
| Red rot | Late in selection program | Field |
| Leaf scald | Early and late in selection program | Field |
| Pachymetra root rot | Mid-selection program (some areas) | Glasshouse |
| RSD | Not routine - late | Field |

There is no specific resistance screening for ratoon stunting disease (RSD) as varietal resistance is not the major disease control strategy for this disease. Sanitation (sterilisation of contaminated equipment) and the planting of disease-free planting material are the two cornerstone control strategies for RSD.
For many years, there remained no resistance screening for yellow spot, except indirect screening associated with selection based on yield variation in clones in the breeding program. Specific brown rust selection occurred when the disease first appeared in the Australian sugar industry in 1978, but subsequently yield selection in the plant improvement program was considered sufficient to lead to the discard of highly susceptible clones. Up until 2000, selection for orange rust was also indirect - but the very rare occurrence of the disease meant that in reality selection was unnecessary.

#### 1.1.3.1.1 Rating system for disease resistance

In all the routine resistance screening trials undertaken by BSES, standard varieties of known field reaction are included in each new trial. The incorporation of a range of varieties that vary from resistant to highly susceptible provides a basis for assessing the resistance of each test clone incorporated into the resistance screening trial. Such standards also assist in dealing with variation in environmental conditions that may be affecting disease incidence. If in some years low disease levels result from sub-optimal weather conditions, lower disease levels will also occur in the susceptible standard canes. By relating disease incidence in the standard varieties (through regression analyses), such variation is accounted for. It has been found that the relationship between **relative** disease incidence and clone susceptibility remains relatively constant no matter what levels of disease occur in the screening trial. Determining the relationship between disease incidence in the standard varieties and their resistance rating in the current trial therefore enables a resistance rating to be applied to each of the test clones. The rating provides an estimate as to how that clone will react to the presence of the disease under commercial crop conditions.

The standard international rating system for varieties is based on a sliding 1 to 9 scale where 1 implies a high level of resistance to the disease, and 9 implies a high level of susceptibility. This is outlined in Table 4.

**Table 4 The resistance-susceptibility categories and how they relate to the standard international 1 to 9-based rating system**

| Resistance category | Resistant | Intermediate | Susceptible |
|---|---|---|---|
| Resistance rating (1 to 9 scale) | 1, 2 or 3 | 4, 5 or 6 | 7, 8 or 9 |

Negligible commercial losses could be expected in commercial varieties rated 1, while very high yield losses could be expected in varieties with a 9 rating. BSES has ensured that for the most important diseases, all susceptible clones in the plant improvement program are discarded (not released to industry), so as to avoid significant commercial yield losses. This varies a little between diseases and also depends in some cases on inoculum levels present in commercial fields. A sub-optimal disease environment in a district may allow more susceptible varieties to be grown compared to districts where conditions are highly favourable.

The objectives of the study reported here were to relate disease-associated yield losses with varietal resistance with several of the more important, but lesser researched endemic diseases. For some of the major diseases, other factors besides current commercial yield losses decide the basis for clone selection; these include epidemiological considerations and disease control measures. Examples include leaf scald, Fiji leaf gall, mosaic, chlorotic streak and red rot. These diseases were not included in this study.

## 1.2 Other factors affecting yield losses associated with endemic diseases

Other factors besides the immediate environmental conditions, pathogen variation and host resistance may influence disease-associated yield losses.

### 1.2.1 Timing of disease occurrence

The onset of suitable environmental conditions for disease may vary considerably by year. For instance, wet season conditions may begin in December, rather than February on the wet tropical coast. This leads to high relative humidity, warm temperatures and good spore germination conditions when the growing crop is still small. For orange rust, this leads to high disease levels during the major crop growing period. In this case there is much opportunity for the disease to significantly affect biomass production - and reduced tonnages (tonnes cane per ha) are likely. If these conditions prevail for many months (a long wet season) the crop canopy may be diseased well into the normal maturity period, when CCS levels normally rise. If the canopy is badly affected, CCS will also be reduced. A number of combinations (scenarios) may arise, each influencing the yield effects caused by leaf diseases. Possible outcomes are described in Table 5.

**Table 5 The potential effect of a leaf disease on crop production, depending on when environmental conditions favour disease occurrence**

| Disease occurrence | Crop biomass effects | Sugar content effects |
|---|---|---|
| Early through to late | Yes | Yes |
| Early only | Yes | No |
| Late only | No | Yes |
| Negligible occurrence | No | No |

Timing of disease incidence, and disease severity through the growing period, therefore have a huge influence on yield losses. The effect of a disease on yield is therefore best provided not by one single disease assessment during the season, but by the continuous

monitoring of disease severity during the growth of the crop. Of course this requires a very large resource input which is rarely available in the current research environment.

In the analyses reported below for orange rust and yellow spot, it is not surprising therefore that in some years biomass yield (tonnes cane per ha) is reduced by these diseases, while in other years sugar content only is affected, and in still others - there is no associated yield effect.

### 1.2.2 Spore production and dispersal

For a pathogen to influence crop yields the pathogen must first reach the susceptible crop. This is related to spore production in already diseased crops and dispersal of these spores to previously disease-free crops.

#### 1.2.2.1 Leaf diseases

The presence of pathogen spores is an important factor influencing disease incidence. A long period of favourable conditions for a leaf disease will lead to a large number of disease cycles - where initial pathogen infection is followed by disease development and spore production from infested tissue. The population of spores in the atmosphere increases considerably as the length of the period favouring the disease increases. With the rust pathogens, spore production can be extensive, and ‘clouds’ of spores may hover or blow across cane growing districts applying intense disease pressure to susceptible crops.

This was the case with orange rust in the Mackay district in the year 2000. Farmers reported that after moving through diseased crops, their shirts were dis-coloured orange by rust spores. Enormous atmospheric spore populations were associated with over 100,000ha of badly diseased crops of the susceptible Q124 being cultivated in the Mackay area. In the Herbert district, even house veranda floors became orange due to large populations of *P. kuehnii* spores. Back then we had no means to quantify the atmospheric populations. As the proportion of Q124 decreased so too did the spore populations; the intensity of disease infection pressure decreased as a result.

#### 1.2.2.2 Pachymetra root rot

As for leaf diseases, spore populations are a key factor in controlling Pachymetra root rot incidence and severity. Previous work by BSES has shown that varietal resistance significantly influences spore populations under commercial crops; there is a very strong relationship between varietal resistance and spore counts (Magarey, 1991; Figure 5).

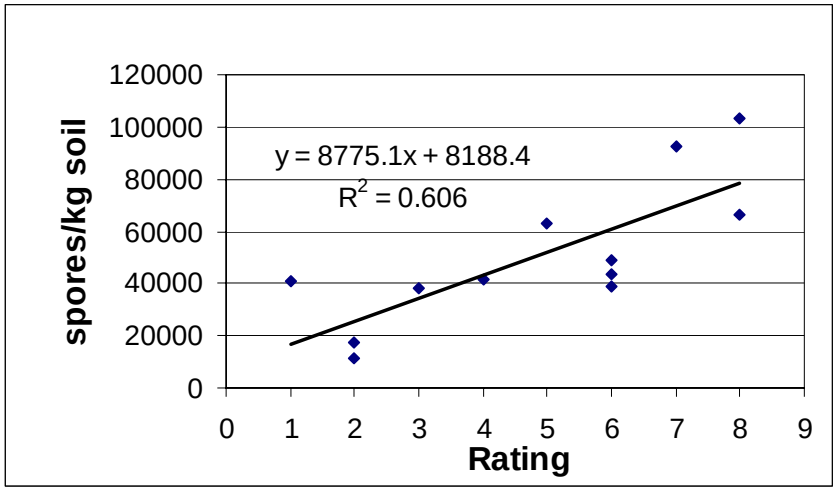



**Figure 5 Pachymetra root rot spore populations developing over a plant and first ratoon crop under varieties of differing resistance (1-9 scale) in the Mackay district**

Research has also shown that yield losses in susceptible varieties are also related to spore populations (Magarey, 1994; Figure 6).

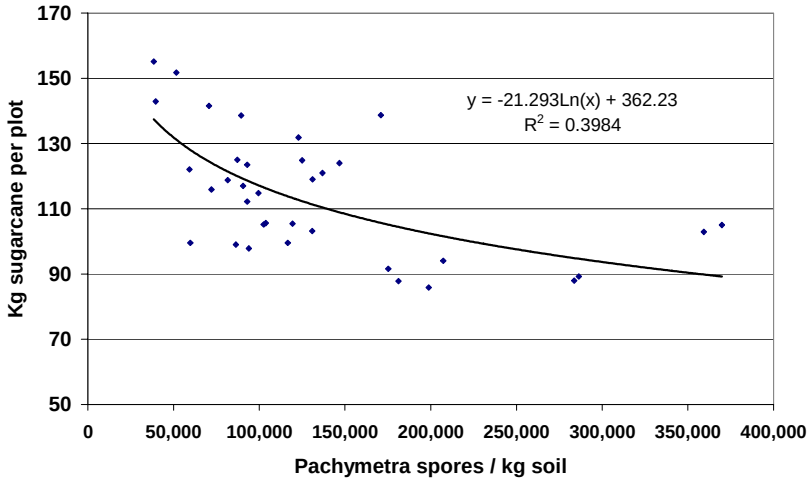



**Figure 6 The effect of increasing Pachymetra soil spore inoculum populations on the yield of a susceptible variety (Q90) in northern Queensland**

BSES Tully provides a soil testing service for farmers that quantifies the spore population under commercial crops in Queensland (Magarey, 1989). Likely yield effects are predicted from spore count information so that farmers can select varieties with sufficient resistance to the disease to minimise yield losses.
In plant improvement selection trials, the influence of clones on spore populations has been investigated. Large variation in spore populations across previous selection trial plots has been found (from 38,000 spores / kg to 350,000 spores / kg).

The replanting of this site with a susceptible variety, and monitoring of spore populations in the plant, first and second ratoon crops illustrates how spore populations may increase

dramatically in successive crops. Average populations for plant, first ratoon and second ratoon crops are illustrated in Figure 7.

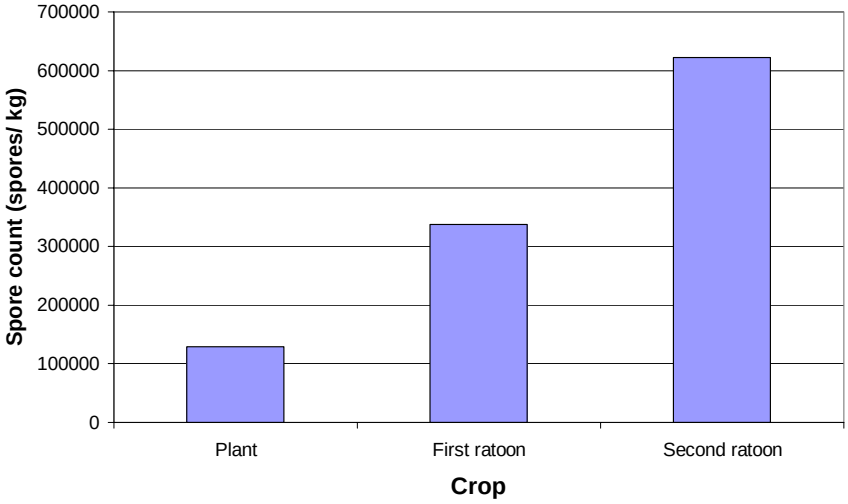



**Figure 7 Average Pachymetra spore population increases in plant, first and second ratoon crops under a susceptible variety (Q90) at Miriwinni, northern Queensland**

Planting selection experiments sites without a very long fallow period (five years or longer) will therefore lead to very significant interaction between initial spore populations, clone susceptibility and final yield. Some clones will be planted on plots with low initial Pachymetra populations while others will be planted on plots with high initial counts - depending on the resistance of the clones planted previously in those plots. Selection for yield will therefore be compromised by the spore populations present at the initiation of the selection trial

### 1.3 Rainfall during the study period

In considering the effect of the endemic diseases, a factor to be considered is the rainfall received during the study period. Rainfall affects relative humidity and the length of time water is present on leaf surfaces - as well as affecting soil moisture conditions. Both affect the severity of diseases, either leaf diseases or Pachymetra root rot. Rainfall during the 1995-2004 period for Tully is presented in Figure 8.

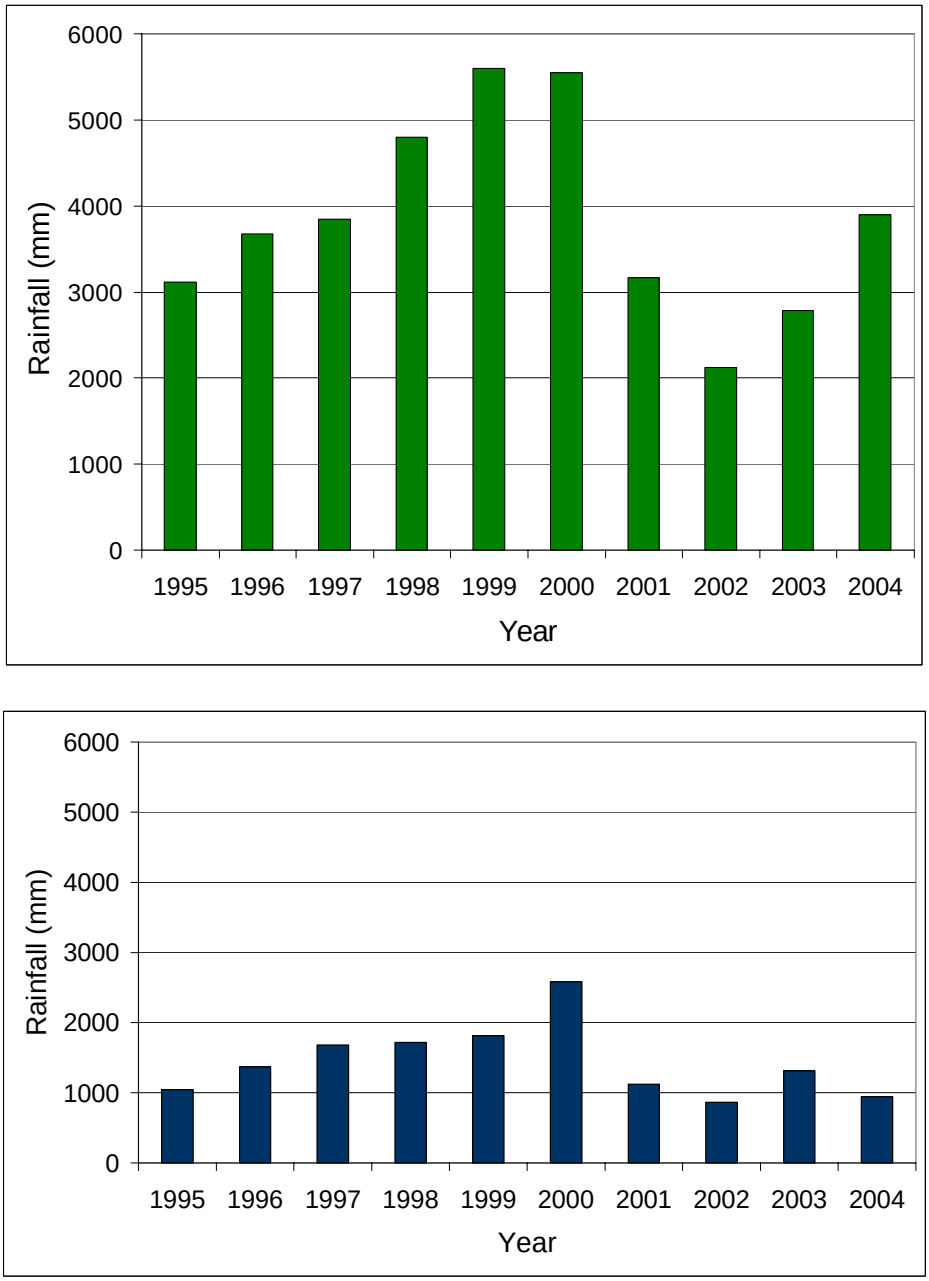



**Figure 8 Rainfall during the 1995-2004 study period for Tully (top) and Mackay (bottom)**

## 1.4 Assessing yield losses in plant improvement selection trials

### 1.4.1 Basis of the method

The basis of using plant improvement trials to investigate the relationship between varietal resistance and endemic disease-associated yield losses was explored only in recent times by Magarey and Bull (2001, 2003) and Magarey et al (2002, 2004). Briefly the method relied on the fact that where experiments incorporating a large number of clones are planted, the average yield of susceptible clones will be lower than the average yield of resistant clones - if the disease is exerting significant yield effects at that site. The following diagram illustrates this point (Figure 9)

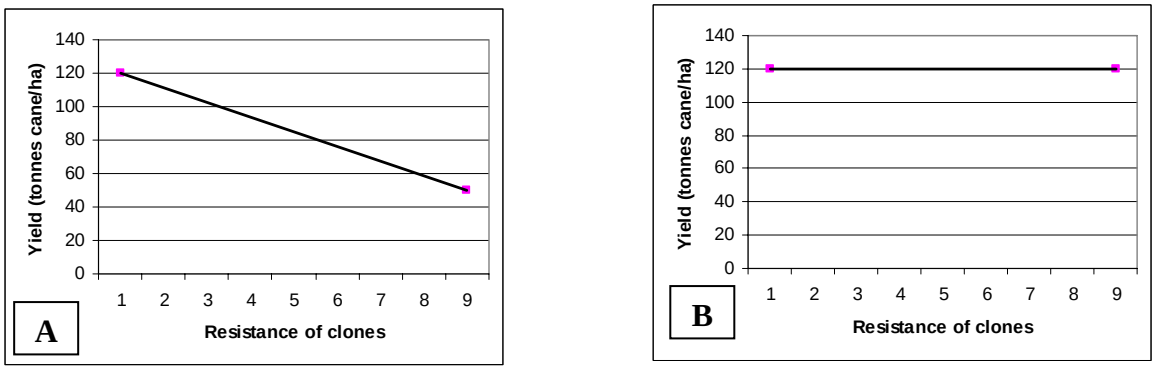



**Figure 9 Theoretical relationships between resistance of clones and the yield (tonnes cane per ha) of clones in plant breeding selection trials. Graph A illustrates the situation where the endemic disease is influencing the yield of clones, while B illustrates no yield effect**

### 1.4.2 Statistical considerations

Although individual clones may vary considerably in their genetic yielding ability, the use of the average yield for all clones of the same resistance category enables this variation to be 'removed' from the regression analysis and the effect of the disease on yield parameters to be visualised. If a regression between the yield of all clones (not the average yield of clones of the same resistance rating) was adopted, some statistical inconsistencies would arise. Yield variation incorporated into the regression would vary with resistance rating; resistant clones (1 rating) would not be influenced by the disease and variation in yield would be controlled by genetic factors for yield plus the influence of susceptibilities to other diseases and environmental influences. On the other hand, susceptible clones would include the same variation plus variation arising from yield effects from the endemic disease.

In considering the disease resistance-yield relationship, no yield effect of a disease will result in no significant regression between yield and resistance (a scatter of points); a significant regression would be expected with a disease-associated effect on yield. There may be either positive or negative relationships between resistance and yield parameter. Examples include the following; it is known that crop biomass reduction associated with some diseases causes a rise in sugar content (CCS) in affected crops. This may be evidenced by a positive relationship between susceptibility and CCS. In this instance a negative relationship between tonnes cane / ha and susceptibility would also be expected.

### 1.4.3 Disease assessed

The ability to use this method to assess yield losses obviously depends on the uniform and broad distribution of pathogen inoculum in plant improvement selection trials. This in turn depends on the nature of the disease. In considering these parameters, regression analyses were undertaken for orange rust, yellow spot, brown rust and Pachymetra root rot in selected districts. These diseases are not evenly distributed through the industry because the environment in some districts favours the disease while in others it does not. Table 6 provides details on where these diseases are found in the Queensland sugar industry.

**Table 6 The general incidence of yellow spot, orange rust, brown rust and Pachymetra root rot in Queensland sugarcane districts. Some local variation occurs - for instance in some parts of southern Queensland, Pachymetra root rot is not present**

| **Sugarcane regions** / ***Disease*** | **Northern** *(Coast)* | **Northern** *(Tableland)* | **Burdekin** | **Central** | **Southern** |
|---|---|---|---|---|---|
| Orange rust | + | + | + | + | + |
| Brown rust | [1]+ | + | + | + | + |
| Yellow spot | [2]+ | + | - | - | - |
| Pachymetra root rot | + | - | - | + | + |

**Notes:**

1.Brown rust incidence is highly variable - in some years environmental conditions favour disease incidence in August, other times in November, other times in-between these months while in other years there is little disease occurring.

2. Yellow spot is favoured by high rainfall and the highest disease levels occur in the Babinda-Tully districts. In wet years, the disease may also be significant in the Herbert, and be found in the Burdekin and Central districts.

It should be borne in mind that the incursion of sugarcane smut in June 2006 caused a rapid re-deployment of pathology staff and the inability to undertake some project activities. This particularly applied to measuring environmental data and relating these to disease-associated yield losses.

## 2.0 OBJECTIVES

- Assess the resistance of clones to Pachymetra root rot, orange rust, yellow spot and brown rust in plant improvement stage 3 trials
- Relate disease resistance to the yield of clones (using regression analyses)
- Summarise losses from each disease in the 2003 series trials.
- Provide information to the plant breeders to ensure appropriate breeding strategies.

## 3.0 RELATING YIELD AND DISEASE RESISTANCE

Research was conducted in several sugarcane regions over several years to investigate the relationships between the different endemic diseases and the resistance of clones. With orange rust and yellow spot, this required the assessment of clone resistance within the plant improvement selection trials (relying on natural disease incidence) while with Pachymetra root rot, results from routine glasshouse screening trials were used for northern district analyses.

In the plant improvement program, four or five trials are planted each year (the series is labelled by the year in which the clones are planted) in each district in widely dispersed commercial fields; the same clones are usually planted in each trial. Identification of consistently high yielding clones in most trials in a district provides the basis for selecting clones for possible commercial release. In the leaf disease-related work undertaken, identification of the resistance of clones in one trial in a series was sufficient to obtain disease resistance ratings for use in analyses in each of the other trials of the same series.

Accordingly, appropriate trials in each series were selected for assessing clonal resistance. Some trials were unsuitable for assessment because most plots were lodged (making access to clones impossible) or there was insufficient disease present due to poor environmental conditions operating at that site (this would be expected to result in no relationship between disease resistance and yield at that site).

### 3.1 Analyses

The same procedure was applied to analyses with each disease; analyses included the following: -

- Regression analyses between yield parameters (CCS / tonnes cane per ha / tonnes sugar per ha) and clone resistance for individual trials.
- Identification of regressions where the $r^2$ was 0.20 and above (i.e. the disease susceptibility could explain at least 20% of the yield variation)
- Calculation of maximum yield losses in each selection trial based on the regression equation.
- Determination of the average yield loss for each yield parameter using data from all selection trials in the same series. In undertaking this, yield data for each resistance rating were first expressed as a percentage of the mean yield for the 1-rated clones; this enabled easy calculation of the percent yield losses for clones of any resistance rating. A regression was undertaken for each set of mean data to provide an overall assessment of the yield losses associated with that disease in that particular selection series.

The research conducted with each disease, and the results, are outlined in individual disease sections below. Over 270 regressions were undertaken using data from over 90 individual selection trials.

## 4.0 PACHYMETRA ROOT ROT

### 4.1 Introduction

Pachymetra root rot (caused by *Pachymetra chaunorhiza*) is of major concern in the northern, Herbert, central and Bundaberg (part of the southern) districts (Magarey et al, 2004). The disease has been found on only one farm on the Atherton Tableland (why this is mentioned will become clear later) and only in some parts of southern Queensland. Pachymetra root rot is of limited occurrence in New South Wales.

### 4.2 Method

#### 4.2.1 Resistance screening

##### 4.2.1.1 Northern program

The main resistance screening program for Pachymetra root rot is undertaken at BSES Tully and incorporates a glasshouse-based screen that includes artificial soil infestation, maintenance of constant soil environmental conditions and growth of test plants in small pots for 12 weeks (Croft, 1989). As a result, resistance ratings have a high level of repeatability and the method provides a reliable means for assessing the field resistance of commercial varieties. Magarey (1991) investigated the relationship between glasshouse-

based resistance ratings and the production of spores beneath field plots of the same varieties. The relationship was generally very good, though there were a few exceptions - where the glasshouse rating was different for a commercial variety compared to what was expected from spore population studies.

Tully-based resistance screening of clones in stage 3 trials is only possible for clones from the northern program. Quarantine issues associated with Fiji leaf gall (and now sugarcane smut) prevent all clones from stage 3 trials in the central and southern programs from being assessed in routine glasshouse trials. In analyses of the northern trials reported here, regression analyses utilised existing stored resistance data on clones planted in northern stage 3 trials, and yield data for the same trials collected and stored by plant breeders. These data are available from 1995 to 2004.

#### 4.2.1.2 Central Program

In general, clones from the central and southern programs were not able to be assessed for Pachymetra resistance at BSES Tully, though a few of the more important ones are sent through quarantine and are eventually screened in Tully. To undertake yield loss research for stage 3 trials in central and southern districts, an alternative method was trialled. This was time, labour and resource intensive and required the collection of soil samples from beneath individual plots of all clones in a selection trial and assay for Pachymetra spores. The following method was employed.

##### 4.2.1.2.1 Soil sampling and resistance ratings

Soil samples were collected from beneath all plots (two replicates) of each clone in one trial from the series being analysed. Details of the trials sampled are included in Table 7. Soil sampling was to 25cm depth and samples were collected using 4.5 cm ‘Dutch-head’ augers. Soils from each plot were dispatched to Tully where they were sieved, mixed thoroughly, sampled and processed for Pachymetra root rot assay as described by Magarey (1989). Mean data were calculated for each clone and the lowest and highest populations identified; the clone with the lowest spore count was identified as a 1-rated clone (‘standard’) while the clone with the highest spore population was identified as a ‘9-rated’ standard. The equation of the straight line linking these two points (resistance rating and spore population) was used to describe the relationship between resistance rating and spore population in all clones. Resistance ratings for each clone were then applied using this equation.

Where glasshouse-based resistance ratings were available for the most important clones and varieties, correlation of the two ratings (glasshouse and field spore-based ratings) was undertaken.

### 4.3 Plant improvement series investigated

Table 7 provides information of the selection trial series assessed for the relationship between Pachymetra resistance and yield.

**Table 7 Plant improvement series trials analysed for the relationship between Pachymetra root rot resistance and yield**

| District | Northern *(Coast)* | Northern *(Tableland)* | Central |
|---|---|---|---|
| **Series / Year** | | | |
| 1995 | [1]+ | | |
| 1996 | + | | |
| 1997 | + | | |
| 1998 | + | | |
| 1999 | + | +? | + |
| 2000 | + | | |
| 2001 | + | | + |
| 2002 | + | | |
| 2003 | + | + | + |
| 2004 | + | | |

[1]+ denotes that all trials (usually 4-5) in that series were analysed for the relationship between resistance and yield parameters.

## 4.4 Results

### 4.4.1 Northern trials

There was a fairly consistent relationship between Pachymetra root rot resistance and yield parameters in the northern series trials investigated. Pachymetra root rot was not associated with yield losses in all trials, but there were a number where disease resistance explained a sizable proportion of the variation in clone yield (using average clonal yields). The r-squared values (>0.20) for each trial regression between yield parameter and Pachymetra resistance, details of the regression equations and maximum yield losses occurring in 9-rated clones in each trial where the r-squared was >0.20, are contained in the Appendix.

For each trial at a certain location within a district and series (year), the mean yield data for clones of the same resistance rating were expressed as a percentage of those for the 1-rated clones. In the northern district, this led to either 4 or 5 separate sets of information where the % yield loss for yield parameters could be related to each yield component (CCS, tonnes cane per ha, and tonnes sugar per ha). The mean percentage yield data was then calculated over all trials for the one series (year) in each district. Mean data combining plant and first ratoon data were calculated. This provides an overall assessment of the relationship between Pachymetra resistance and % yield loss. For Pachymetra root rot, average loss figures were calculated for the 1999 series trials in northern Queensland, and for the 2003 series trials in the same district; graphs of these data are presented in Figure 10.

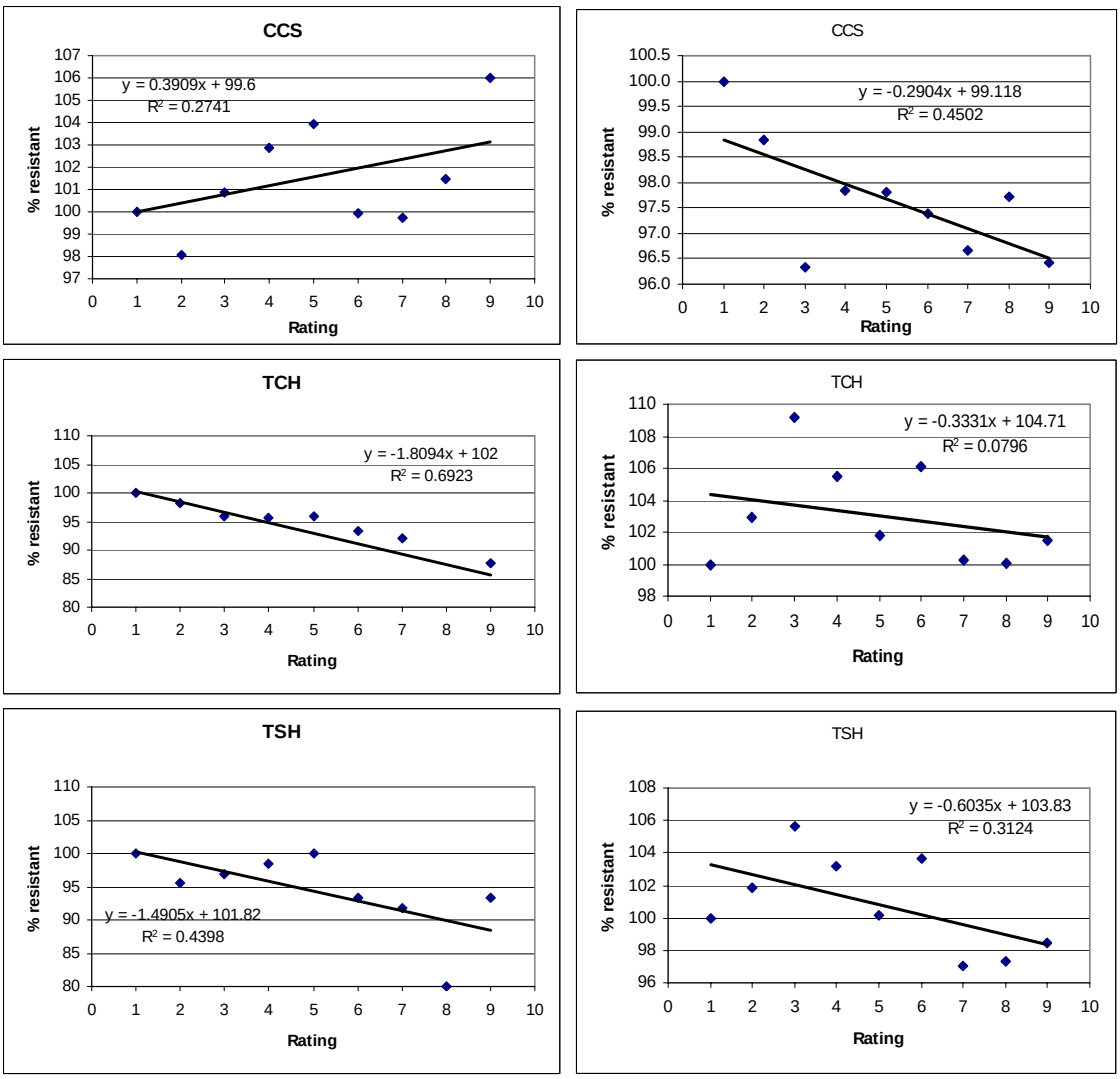



**Figure 10 Average yield data (CCS, tonnes cane and tonnes sugar) for all northern trials in the 1999 (left) and 2003 (right) trials; regressions indicate the relationship between Pachymetra root rot resistance and yield**

**Table 8 Calculated percent Pachymetra root rot-associated yield losses for susceptible clones (compared to resistant clones) in plant improvement selection trials: 1999 and 2003 series. Data are mean figures for plant and first ratoon crops**

| Yield parameter<br>Trial series | Tonnes cane/ha | Tonnes sugar/ha |
|---|---|---|
| 1999 | 14.5 | 11.9 |
| 2003 | 2.7 | 4.8 |

Average data were also calculated for all trials in the period 1995-1999, and for the following five years, 2000-2004. These are included in Figure 11. Mean data for all years (1995-2004) were also calculated.

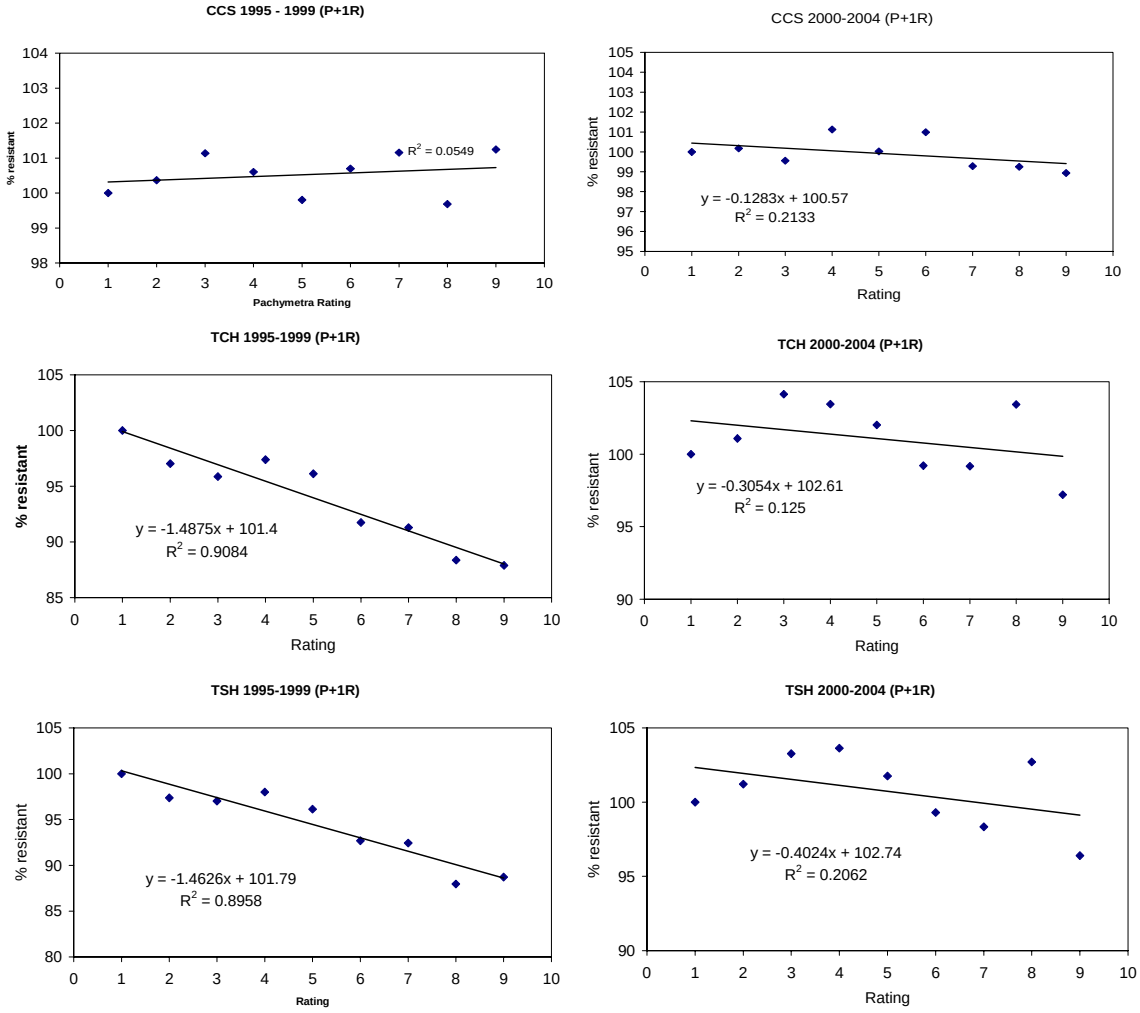



**Figure 11 Five year average data for the relationship between Pachymetra root rot and yield parameters in northern selection trials (average of all sites, and plant and first ratoon crops). The 1995-1999 series averages are illustrated at left, and 2000-2004 series averages at right**

These data suggest a strong relationship between Pachymetra root rot and tonnes cane per ha (biomass), and tonnes sugar per ha - especially for the mean data for the period 1995-1999, and for the 1999 series analyses. CCS was generally not related to Pachymetra

resistance though there were cases where CCS increased with susceptibility, while in other cases reduced CCS was associated with susceptibility.

The maximum yield losses associated with Pachymetra root rot resistance at each FAT trial location in the northern district are illustrated in Table 9. These data show very large losses maybe associated with susceptibility to Pachymetra root rot in individual trials.

**Table 9 Maximum yield losses associated with Pachymetra root rot in each of the northern FAT series trials (1995-2004 data). Details of the series and crop class are provided for the maximum yield loss at each location (Tch = tonnes cane/ha; Tsh = tonnes sugar/ha)**

| Location | **Babinda** | | **Mulgrave 1** | | **Mulgrave 2** | | **Mourilyan 1** | | **Mourilyan 2** | | **Tully** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Yield parameter | Tch | Tsh | Tch | Tsh | Tch | Tsh | Tch | Tsh | Tch | Tsh | Tch | Tsh |
| % loss | 41.2 | 40.6 | 49.8 | 48.4 | 47.2 | 43.1 | 36.8 | 41.4 | 24.3 | 24.4 | 49.4 | 46.3 |
| Series | 1998 | | 2000 | | 1997 | | 1997 | | 1996 | | 1997 | |
| Crop class | 2R | | 2R | | 1R | | 1R | | 2R | | 2R | |

The percent yield loss associated with Pachymetra root rot in northern trials between 1995-2004 (average of plant and first ratoon data) is illustrated in Figure 12 (tonnes cane/ha) and Figure 13 (tonnes sugar/ha). Yield losses for each trial series (labelled according to year of planting) in this period are compared to Tully rainfall recordings in Figure 14, and the data are regressed to assess the association between rainfall and % yield (tonnes cane) losses in Figure 15. The resistance index (RI) of clones in each trial series is presented in Figure 16.

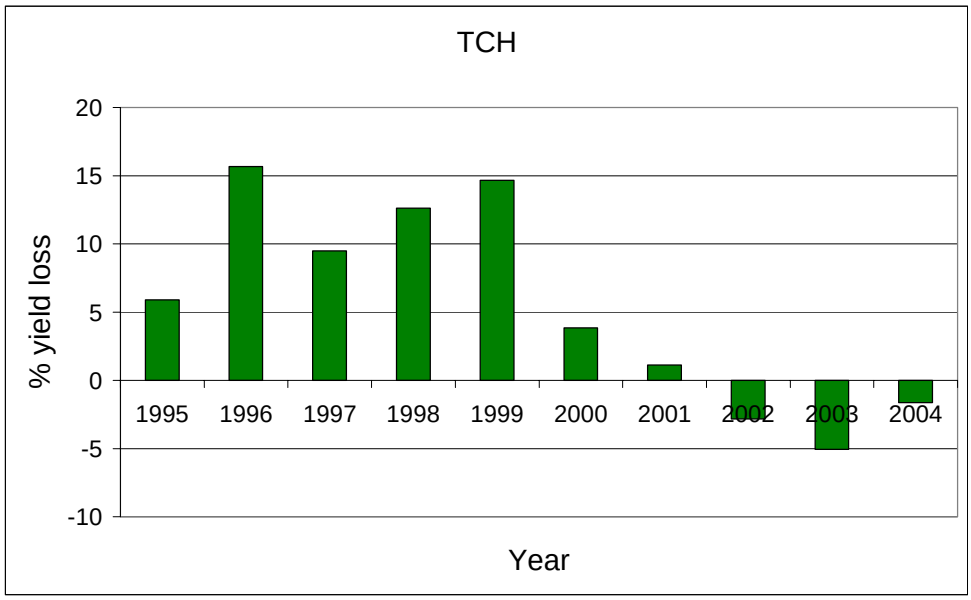



**Figure 12 Percent yield loss associated with Pachymetra root rot for tonnes cane/ha in each series (average of plant and first ratoon data) from 1995-2004**

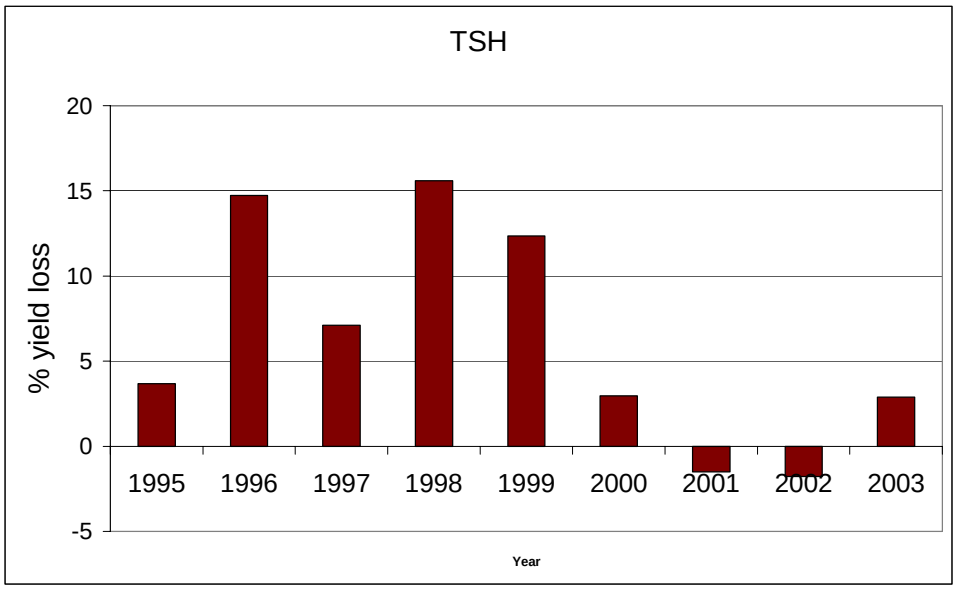



**Figure 13 Percent yield loss associated with Pachymetra root rot for tonnes sugar/ha in each series (average of plant and first ratoon data) from 1995-2003**

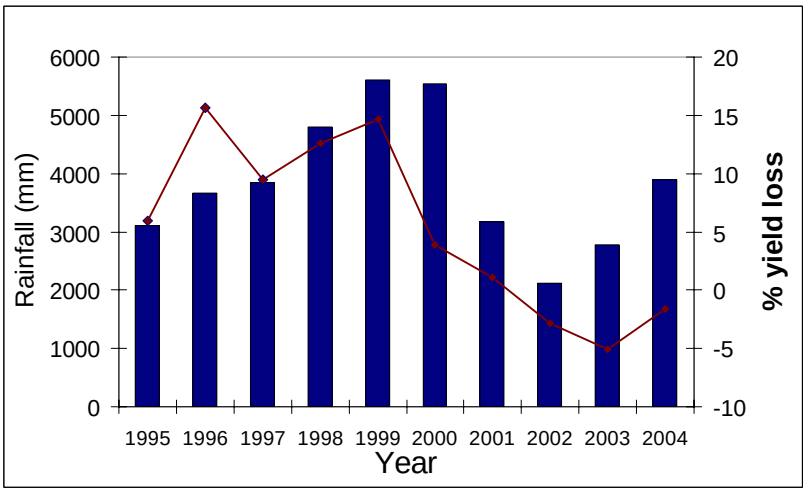



**Figure 14 The relationship between % yield losses associated with Pachymetra root rot (line) and rainfall (bars) at one site in northern Queensland (Tully)**

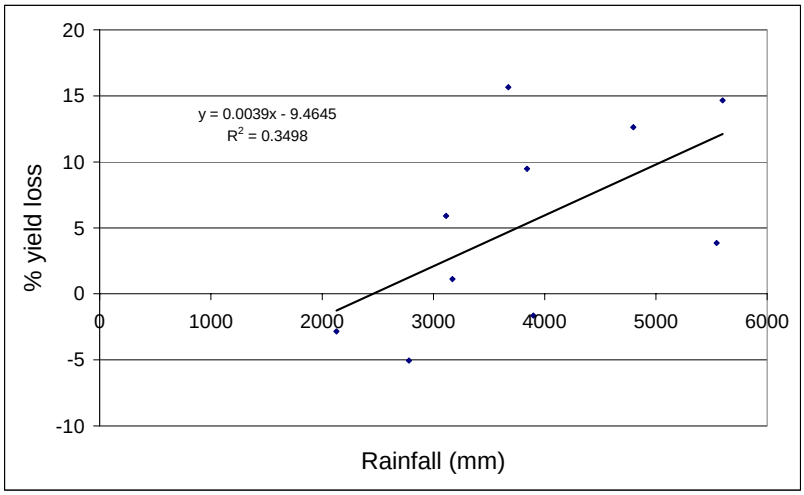



**Figure 15 The regression relationship between rainfall in Tully and the average yield losses associated with Pachymetra root rot in northern Queensland selection trials in the 1995-2004 period**

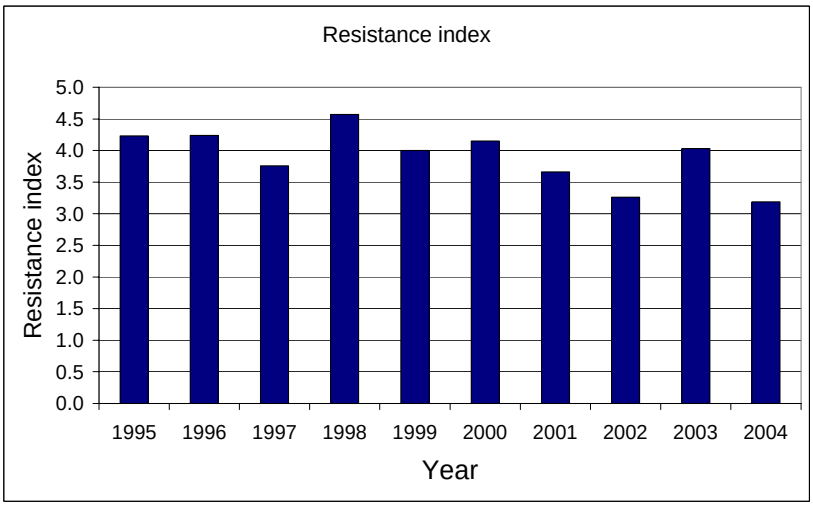



**Figure 16 The Pachymetra resistance index (RI) of the clones included in each FAT series in northern Queensland (1995-2004). RI refers to the average resistance of clones within that population (clones in an individual series)**

Of interest are the analyses conducted using Tableland selection trial data. These show no, or a poor, relationship between the Pachymetra resistance of clones and yield parameters. Very little Pachymetra root rot has been observed in Tableland cane fields. The analyses for the 1999 (2003?) series trials are outlined in Figure 17.

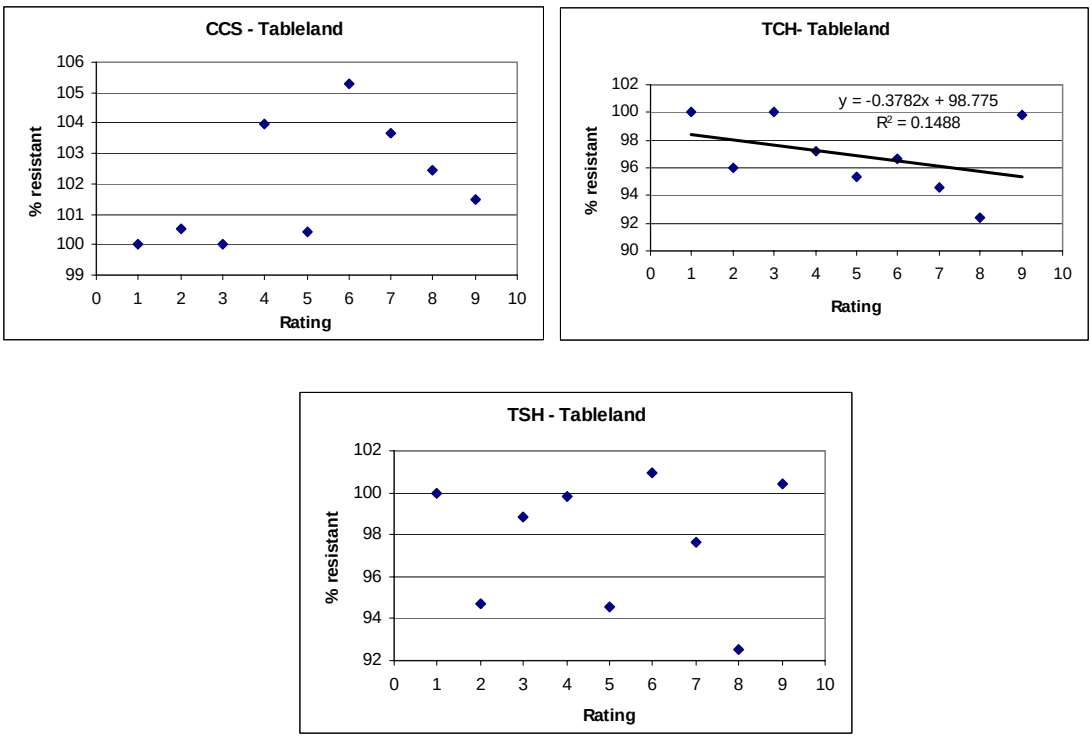


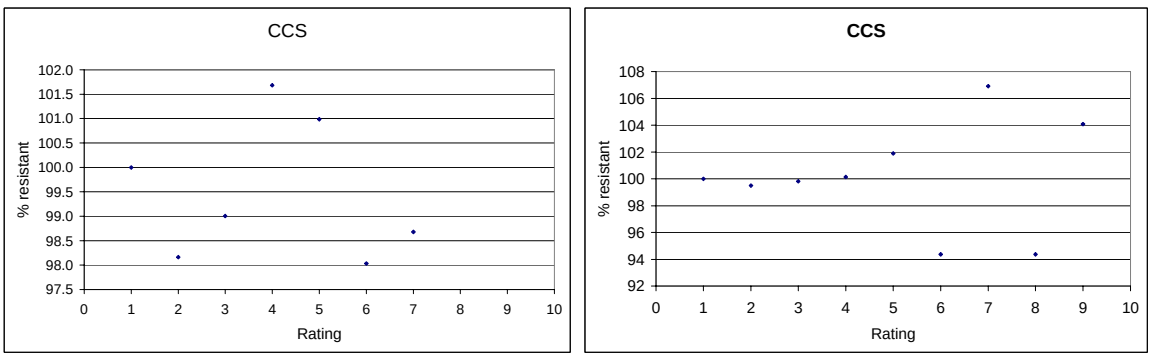

**Figure 17 The relationship between Pachymetra root rot resistance and yield parameters in Tableland trials in the 1999-planted series. Pachymetra root rot has only been detected on the Atherton Tablelands at one site; at that site inoculum densities were very low**

### 4.4.2 Central district trials

#### 4.4.2.1 Resistance ratings

In central district analyses, there was an inconsistent relationship between spore-based resistance ratings and those arising from glasshouse resistance screening. In some years, the correlation was good while in 2000 series trials, the relationship was poor (data not shown).

*Yield analyses:*
In the 2003 series trial analysed, there were strong relationships between tonnes cane/ha and tonnes sugar/ha and resistance ratings obtained either from spore counts or glasshouse resistance screening. These are illustrated in Figure 18 and Table 10.



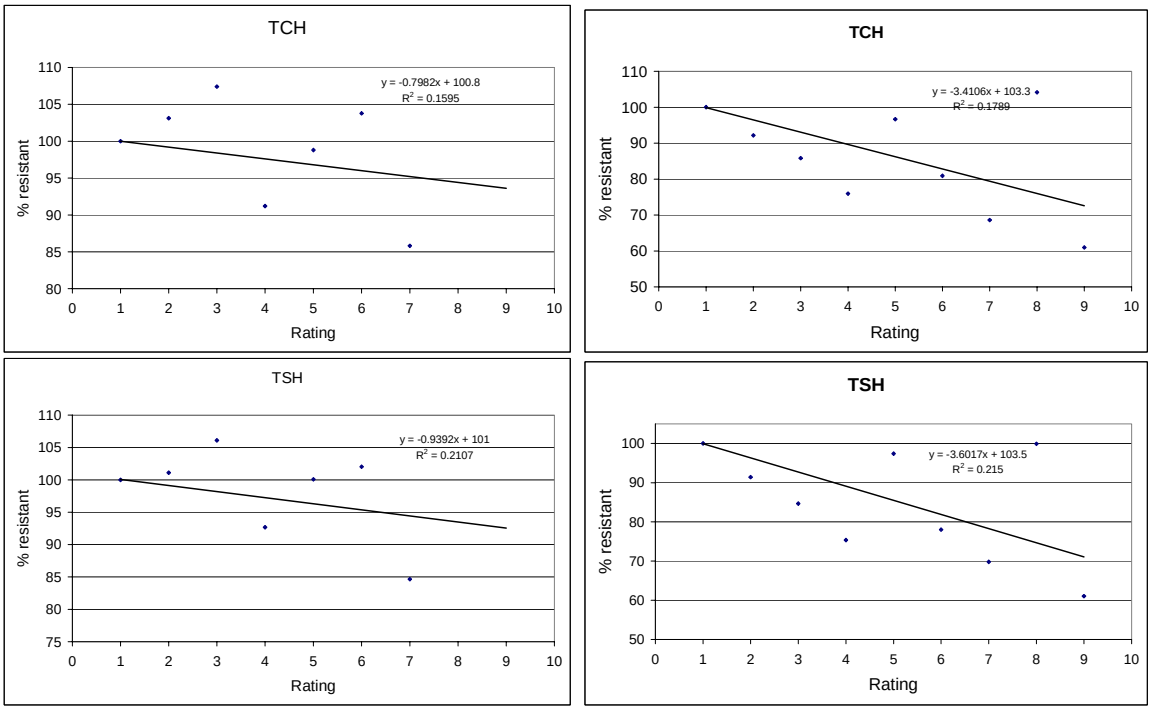



**Figure 18 Average yield data (CCS, tonnes cane and tonnes sugar) for a 2003 series central district trial (Racecourse). Yield data using glasshouse resistance ratings (left) were compared with yield loss data based on resistance ratings originating from spore counts (right); limited glasshouse ratings meant less data are included in the analyses presented at left**

**Table 10 Calculated percent Pachymetra root rot-associated yield losses for susceptible clones (compared to resistant clones) in a plant improvement selection trial in Central Queensland, 2003 series. Data refer to plant crop results and have been analysed using spore count-derived vs. glasshouse resistance ratings**

| Yield parameter<br>Rating method | CCS | Tonnes cane/ha<br>(% loss) | Tonnes sugar/ha<br>(% loss) |
|---|---|---|---|
| Spore ratings | ns | 21.0 | 22.2 |
| Glasshouse ratings | ns | 19.2 | 13.4 |

### 4.5 Discussion

There seemed to be a clear association between Pachymetra resistance and yield parameters in breeding selection trials in the northern district, especially in some years and locations. It is generally accepted that Pachymetra root rot spore populations in the northern area are high (Magarey et al, 2004) and that some natural selection for disease resistance has been occurring in plant improvement selection trials over the last 20 years. The data confirm that the disease is of importance in selecting high yielding varieties and that varietal resistance is important for minimising disease-associated yield losses.

The absence of a relationship between Pachymetra root rot resistance and yield parameters in a Tableland trial confirms that the there is no inherent relationship between clonal resistance to Pachymetra and yielding ability.

Of concern was the variation in the data between the 1995-1999 and those post-2000. When further investigations were made, it was found that selection trial procedures changed for northern trials in the year 2000. In that year, sub-stations were adopted for the staging of selection trials. Instead of using 'new' commercial fields each time for selection trials, the same farmer's field was used for all trials after 2000 (four sub-stations per region). Trials were planted in rotation each year into the same field; new trials were planted onto 'old trial sites' after a short fallow of 6-8 months. Previous research has shown that substantial differences in Pachymetra inoculum densities will exist in plots in these fields when new trials are planted; this variation no doubt exerts a significant yield effect on clones in each new trial. Such yield effects will disrupt the relationship between clone resistance and yield and could lead to the poor relationships seen in this study.

Not only will this practice affect disease yield loss relationships, but will also add to the 'noise' associated with selecting clones based on yield data. Some clones of intermediate resistance may not be selected due to excessive yield loss associated with high initial Pachymetra inoculum densities in plots; other intermediate clones may be selected based on superior yield characteristics because they were planted in plots with unusually low Pachymetra inoculum densities - these being associated with resistant clones in the previous trial. These effects should be taken into consideration when revising plant breeding trial procedures.

It should also be borne in mind that climatic variation may also have influenced the strength of the resistance-yield relationship. Rainfall in particular showed some relationship with yield losses - though further study will be needed to distinguish causation. Distinguishing the influence of each factor was not possible here - though it is likely the previous clone effect will have been very significant.

Of interest were the resistance index (RI) values for Pachymetra root rot for clones in northern FAT trials. The data suggest that although RI values decreased slightly from 1995 to 2004, the differences were not great and that these would not account for the reduced yield losses subsequent to 2000.

The lack of relationship between Pachymetra root rot spore counts and glasshouse ratings in some trials hindered obtaining details of the effect of Pachymetra root rot in central district trials. However, data from the 2003 series trials suggests losses of around 20% in both tonnes cane/ha and tonnes sugar/ha. These are significant losses. It should be noted that FAT trials in the central district are not planted on sub-stations but in previously 'un-used' commercial fields. Other research has addressed the relationship between

Pachymetra root rot and yield in the Mackay district (Magarey et al, 2003). In this research, varieties of differing resistance to Pachymetra were planted in a field where there was a distinct difference in Pachymetra inoculum density (created through the previous cropping of a resistant and susceptible variety in each half of the field). A range of varieties varying in resistance were then planted over the inoculum boundary. Harvest of the plant crop provided Pachymetra associated yield loss data and information on the effect of resistance of these losses. These data are presented below in Figure 19.

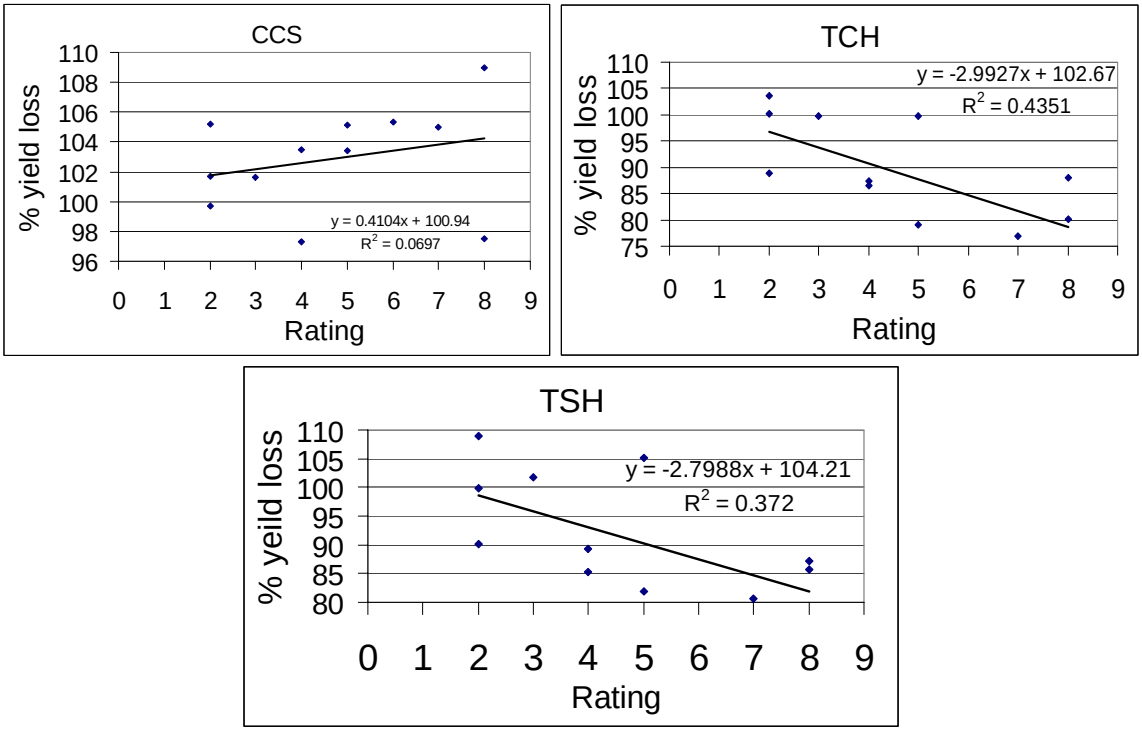



**Figure 19 The relationship between Pachymetra root rot resistance and yield losses in an experiment conducted in Mackay where yield of varieties varying in resistance were recorded at a single site influenced by high and low inoculum densities**

Interestingly, losses attributed to the disease in this experiment were similar to the average yield loss data from the 2003 series central district trials. The major effect was exerted through biomass reduction, while CCS was largely unaffected by Pachymetra root rot. Other yield loss research (Magarey, 1994) provided a similar result - high biomass losses but little effect of Pachymetra on sugar content.

These data collected using different methods are consistent and confirm the importance of Pachymetra roo rot on sugarcane yield in both northern and central Queensland.

## 5.0 YELLOW SPOT

### 5.1 Introduction

Yellow spot is of major concern principally in the northern (wet tropical coast) region. Some wetter parts of the Herbert district are also regularly affected, but not the drier areas

in that region. The disease is of principal concern in the higher rainfall areas and is definitely worse in the years with highest rainfalls. In previous years (late 1960s-early 1970s) some varieties were not released for commercial production because of their susceptibility to yellow spot. Data analyses were limited to the northern district because of the limited distribution of the disease.

## 5.2 Method

### 5.2.1 Resistance screening

In the series examined, resistance screening was based on the assessment of leaf area affected by the disease in clones within one plant improvement trial (for each series / year). A trial was selected where the plots of individual clones could be accessed. In some trials, high disease levels were present but lodged plots prevented entry to gain data on disease incidence, and hence resistance data. The method for assessing resistance relied on the identification of a leaf at the same relative position (for instance, the seventh down from the spindle leaf) in the canopy in each clone. Four leaves in the same relative position in each of four separate stalks were selected in each plot. The method has been described in detail elsewhere (Magarey et al, 2002); this ensured a good comparative assessment between all clones. Two assessors each visually assessed the percent leaf area affected by yellow spot; all assessments by each assessor for each of the four leaves was recorded and used for application of resistance ratings. These data were collected when yellow spot was approaching the peak of disease occurrence; this was usually toward the end of the wet season in the April-May period.

Mean values for percent leaf area affected were then calculated for each clone and clones with the lowest and highest disease levels identified. After appropriate arcsin transformation of the data, a 1 rating was applied to the clone with the lowest disease level and a 9 rating to the clone with the highest disease level. Resistance ratings for all other clones were applied on the basis of the equation of the line relating these two ratings / disease levels.

## 5.3 Plant improvement series investigated

Table 11 provides information on the series (based on year) analysed for the relationship between yellow spot and yield.

**Table 11 Plant improvement series trials analysed for the relationship between yellow spot resistance and yield**

| District<br>Series / Year | Northern |
|---|---|
| 1999 | + |
| 2000 | - |
| 2001 | - |
| 2002 | - |
| 2003 | + |

## 5.4 Results

The relationship between yellow spot resistance and yield parameters was not as consistent as the effect of Pachymetra root rot in the northern series trials investigated.

Yellow spot was associated with yield losses in some trials, but the effect was inconsistent. The r-squared values (>0.20) for each trial regression between yield parameter and yellow spot resistance, plus details of the regression equations are presented for the same trials in the Appendix.

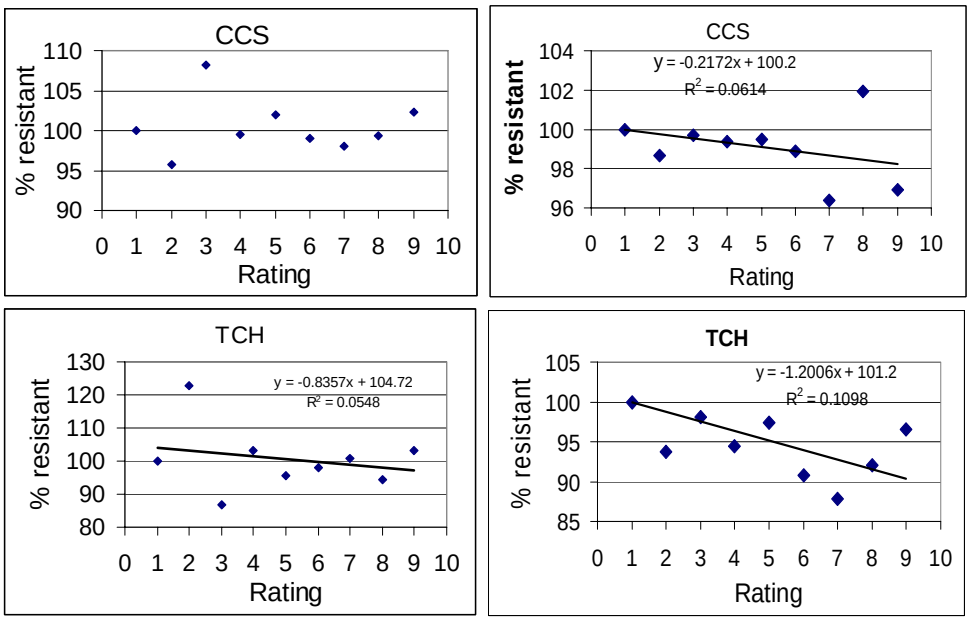
As for Pachymetra root rot, for each trial at a certain location within a district and series (year), the mean yield data for clones of the same resistance rating were expressed as a percentage of those for the 1-rated clones. This led to either 4 or 5 separate sets of information where the % yield loss for yield parameters could be related to each yield component (CCS, tonnes cane per ha, and tonnes sugar per ha). The mean percentage yield data were then calculated over all trials for the one series (year) in each district. Mean figures combining plant and first ratoon data were calculated. This provided an overall assessment of the relationship between yellow spot resistance and % yield loss. Maximum yield losses occurring in 9-rated clones in each trial where the r-squared was >0.20 are contained in the Appendix.

The average yield losses for each yield parameter (CCS, tonnes cane/ha and tonnes sugar/ha) over all trials in the 1999 and 2003 series are contained in Table 12.

**Table 12 Calculated percent yellow spot-associated yield losses for susceptible clones (compared to resistant clones) in plant improvement selection trials: 1999 and 2003 series. Data are mean figures for plant and first ratoon crops**

| Yield parameter<br>Trial series | Tonnes cane/ha | Tonnes sugar/ha |
|---|---|---|
| 1999 | 13.9 | 9.8 |
| 2003 | 5.3 | 7.8 |

The regressions relating average loss figures for both the 1999 and 2003 series trials in northern Queensland are presented in Figures 20 and 21.



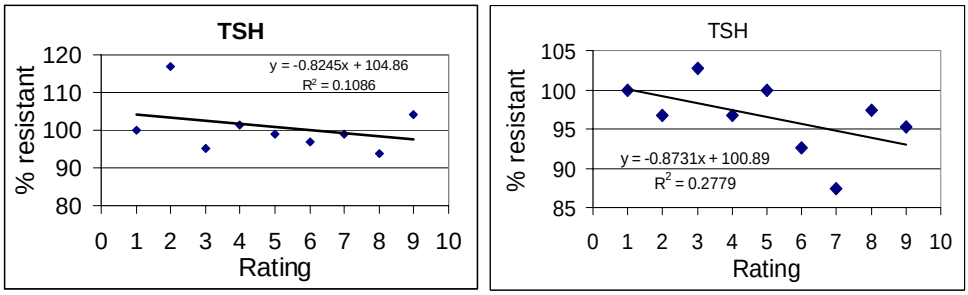



**Figure 20 Summary yield data relating yellow spot resistance to yield parameters in 1999 (left) and 2003 (right) series trials in northern Queensland**

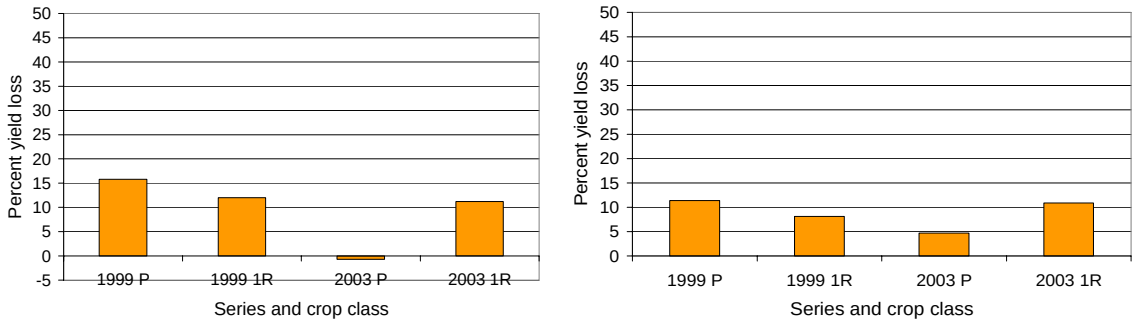



**Figure 21 Magnitude of yellow spot-associated yield losses in northern trials by year and crop class (left TCH; right TSH)**

These data suggest some relationship between yellow spot and CCS, tonnes cane per ha (biomass) and tonnes sugar per ha.

The maximum yield losses associated with yellow spot resistance at each FAT trial location in the northern district are illustrated in Table 13. These data show that large losses maybe associated with susceptibility to yellow spot in some locations - but the losses are not of the same magnitude in individual trials as for Pachymetra.

| Location | **Babinda** | | **Mulgrave 1** | | **Mulgrave 2** | | **Mourilyan 1** | | **Mourilyan 2** | | **Tully** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Yield parameter | Tch | Tsh | Tch | Tsh | Tch | Tsh | Tch | Tsh | Tch | Tsh | Tch | Tsh |
| % loss | 22.72 | 28.3 | 18.5 | 14.3 | ns | ns | ns | ns | 24.2 | ns | 27.0 | 22.8 |
| Series | 1999 | | 1999 | | | | | | 1999 | | 1999 | |
| Crop class | 2R | | P | | | | | | P | | 1R | |

Ns = not significant

**Table 13 Maximum yield losses associated with yellow spot in each of the northern FAT series trials (1999 and 2003 data). Details of the series and crop class are provided for the maximum yield loss at each location (Tch = tonnes cane/ha; Tsh = tonnes sugar/ha)**

## 5.5 Discussion

There seemed to be only some association between yellow spot resistance and yield parameters in breeding selection trials in the northern district. There were far fewer trials (compared to Pachymetra root rot) where yellow spot resistance explained more than 20% of the variation in the yield of clones. Even so when mean figures over all trials and series were calculated, the losses associated with yellow spot susceptibility were still quite large, and on a comparable scale as for Pachymetra root rot. Why the r squared values were much lower with yellow spot is unknown.

The relatively high level of susceptibility in stage 3 clones in breeding selection trials tends to suggest the lack of a strong selection pressure for yellow spot resistance in stage 1 and stage 2 trials. This could either be because the disease does not greatly affect sugarcane yield or that the disease occurs sporadically and inconsistent selection based on varying environmental conditions leads to a lack of elimination of susceptible clones. There are no doubt occasions when the disease does reduce yields and when commercial crop yields suffer. This can be seen in individual trial data in the 2003 series (for instance the Tully trial). This has been shown in other studies (Magarey et al, 2004; Egan, 1972). Further research with fungicides may shed more light on the importance of the disease and how this varies with weather /climate variation.

The highest yield losses associated with yellow spot were in the 1999 series trials, and this coincides with higher rainfall; the lowest Tully rainfall (1925-2006) on record for Tully was in 2002, while rainfalls in 1999 and 2000 were higher than average. Higher levels of disease were noticeable in this period in susceptible commercial crops.

The use of breeding selection trials for assessing the effects of yellow spot should be continued for a number of years. In this study only several years (series) of data were able to be analysed; by recording yield loss information over 5-10 years, the long-term effect of the disease would become much clearer.

# 6.0 ORANGE RUST

## 6.1 Introduction

Orange rust is of major concern right throughout the Queensland industry. Data presented earlier in this report suggest that some districts are more favourable to the disease than others. Observations in 2000 suggest that the disease may severely affect crops in each major cane growing region. Data analyses were mainly limited to the northern and central districts; application of resistance ratings for clones in Burdekin trials was attempted - but access to these crops when the disease was at moderate-severe levels was impossible due to the large crops and extensive lodging. The relationship between resistance and yield is likely to be similar to the outcomes from the analyses conducted with northern and central district data.

## 6.2 Method

### 6.2.1 Resistance screening

Resistance screening for orange rust was undertaken in exactly the same way as for yellow spot. As the two diseases occur at similar times of the year, some assessments (for instance in northern trials) occurred at the same time.

## 6.3 Plant improvement series investigated

Table 14 provides information of the series (based on year) assessed for the relationship between orange rust and yield.

**Table 14 Plant improvement series trials analysed for the relationship between orange rust and yield**

| District<br>Series / Year | Northern | Central |
|---|---|---|
| 1999 | + | + |
| 2003 | + | + |

## 6.4 Results

### 6.4.1 Northern trials

The relationship between orange rust and yield parameters varied according to the series (year) and location. On some occasions the relationship was very strong while in other years the relationship was relatively weak. The r-squared values (>0.20) for each regression between yield parameter and clone, plus details of the regression equations for the same trials are presented in the Appendix.

As for Pachymetra root rot, for each trial at a certain location within a district and series (year), the mean yield data for clones of the same resistance rating were expressed as a percentage of those for the 1-rated clones. This led to either 4 or 5 separate sets of information where the % yield loss for yield parameters could be related to each yield

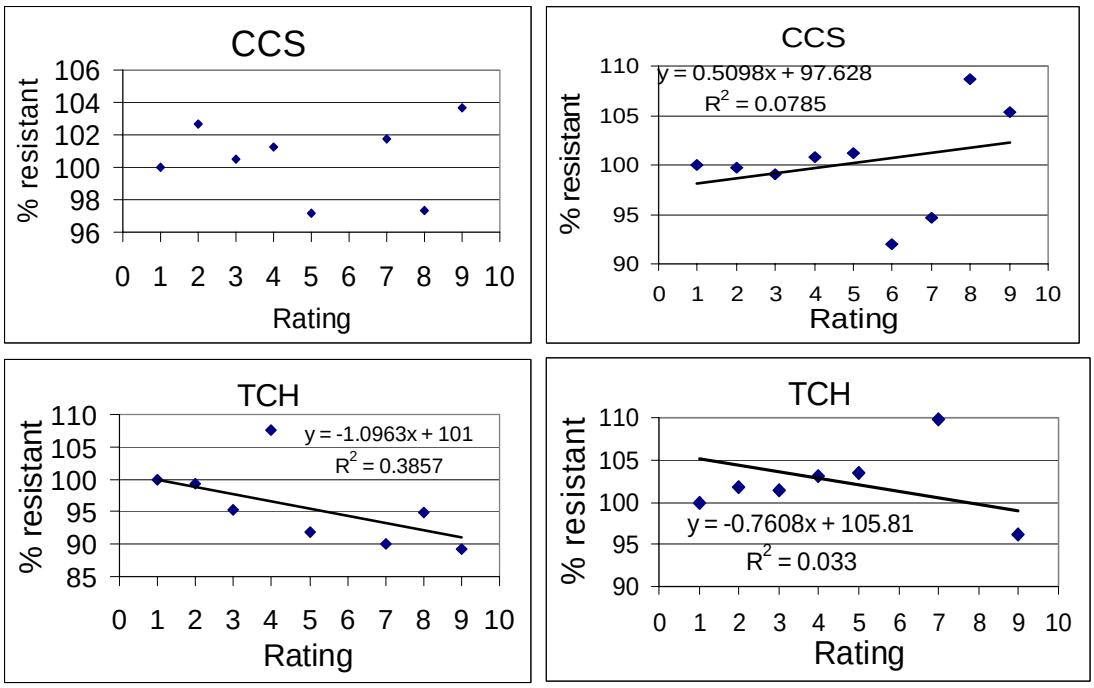
component (CCS, tonnes cane per ha, and tonnes sugar per ha). The mean percentage yield data were then calculated over all trials for the one series (year) in each district. Mean data combining plant and first ratoon data were calculated. This provided an overall assessment of the relationship between orange rust resistance and % yield loss.
The average yield losses for each yield parameter (CCS, tonnes cane/ha and tonnes sugar/ha) over all trials in the 1999 and 2003 series are contained in Table 15.

**Table 15 Calculated percent orange rust-associated yield losses for susceptible clones (compared to resistant clones) in northern plant improvement selection trials: 1999 and 2003 series. Data are mean figures for plant and first ratoon crops**

| Yield parameter<br>Trial series | Tonnes cane/ha | Tonnes sugar/ha |
|---|---|---|
| 1999 | 11.4 | 12.3 |
| 2003 | 3.8 | 3.2 |

Maximum yield losses occurring in 9-rated clones in each trial where the r-squared was >0.20 are contained in the Appendix.

For orange rust, average loss figures were calculated for the 1999 and 2003 series trials in northern Queensland; graphs based on these data are presented in Figure 22. The magnitude of yield losses in each analysed series by plant and first ratoon crop are presented in Figure 23.



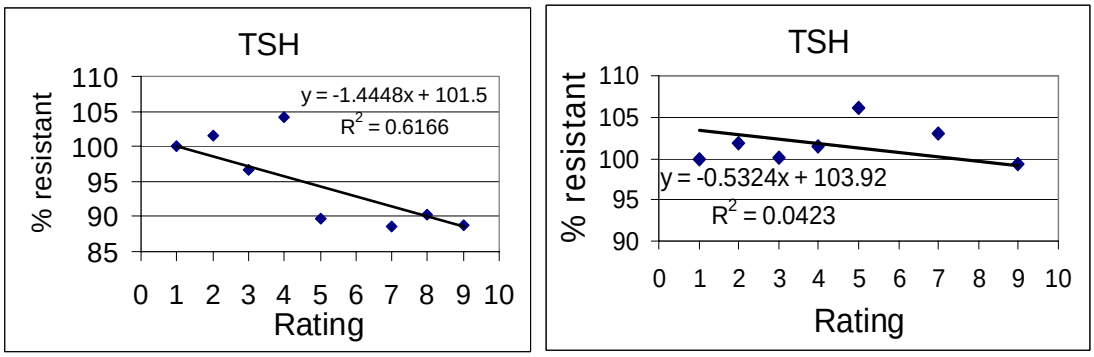



**Figure 22 Summary yield data relating orange rust resistance to yield parameters in 1999 (left) and 2003 (right) series trials in northern Queensland**

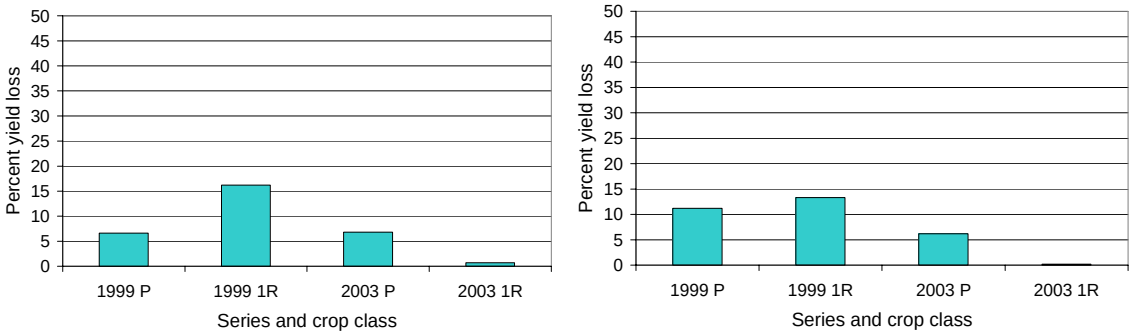



**Figure 23 Magnitude of yield losses in northern trials by year and crop class (left TCH; right TSH)**

The maximum yield losses associated with orange rust resistance at each FAT trial location in the northern district are illustrated in Table 16. These data show that significant losses may be associated with susceptibility to orange rust.

**Table 16 Maximum yield losses associated with orange rust in each of the northern FAT series trials (1999 and 2003 data). Details of the series and crop class are provided for the maximum yield loss at each location (Tch = tonnes cane/ha; Tsh = tonnes sugar/ha)**

| Location | **Babinda** | | **Mulgrave 1** | | **Mulgrave 2** | | **Mourilyan 1** | | **Mourilyan 2** | | **Tully** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Yield parameter | Tch | Tsh | Tch | Tsh | Tch | Tsh | Tch | Tsh | Tch | Tsh | Tch | Tsh |
| % loss | 25.4 | 22.4 | 34.2 | 33.3 | ns | 14.6 | ns | ns | 19.8 | 16.2 | ns | ns |
| Series | 1999 | | 1999 | | 1999 | | | | 2003 | | | |
| Crop class | 1R | | 1R | | P | | | | 1R | | | |

### 6.4.2 Central trials

In the central district analyses, there was a very strong relationship between orange rust resistance and yield loss, particularly in plant crops of the 1999-planted series. The r-squared values (>0.20) for each regression between yield parameter and clone, plus details of the regression equations, are presented in the Appendix.

Maximum yield losses occurring in 9-rated clones in each trial where the r-squared was >0.20 are also contained in the Appendix. The relationship between yield loss and resistance for the 1999 and 2003 series are presented in Figures 24 and 25. Mean yield loss figures are included in Table 16.

**Table 16 Calculated percent orange rust-associated yield losses for susceptible clones (compared to resistant clones) in plant improvement selection trials: 1999 and 2003 central district series. Data are mean figures for plant and first ratoon crops**

| Yield parameter<br>Trial series | Tonnes cane/ha | Tonnes sugar/ha |
|---|---|---|
| 1999 | 28.5 | 27.6 |
| 2003 | -3.4 | -7.6 |

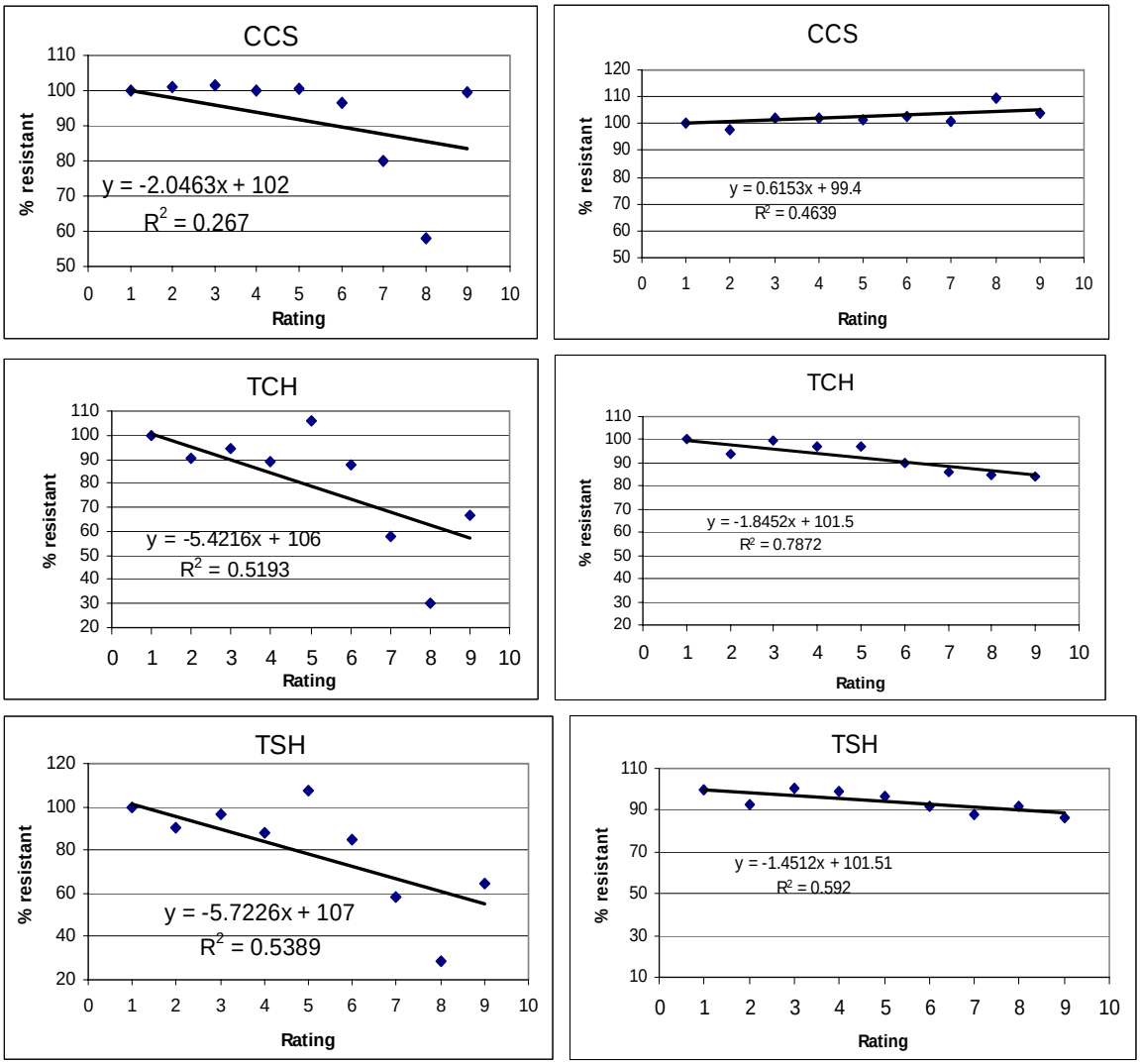



**Figure 24 Summary yield data relating orange rust resistance to yield parameters in 1999 series plant crops (left) and first ratoon (right) in central Queensland**

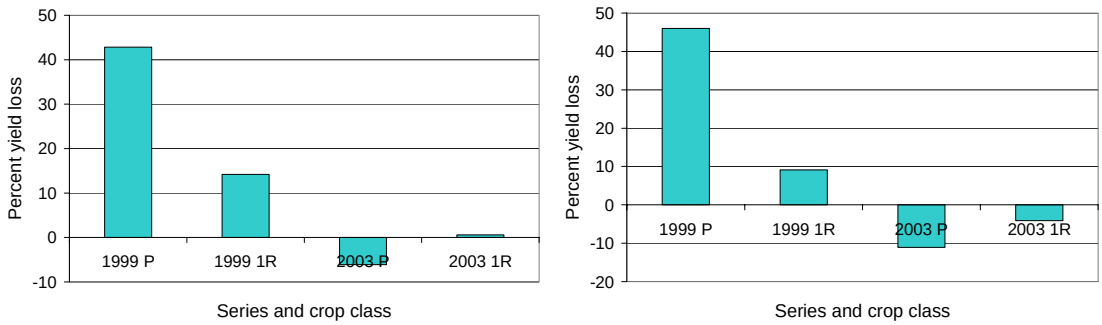



**Figure 25 Magnitude of yield losses in central trials by year and crop class (left TCH; right TSH)**

The maximum yield losses associated with orange rust resistance at each FAT trial location in the central district is illustrated in Table 17. These data show that very large losses maybe associated with susceptibility to orange rust under favourable conditions.

**Table 17 Maximum yield losses associated with orange rust in each of the central FAT series trials (1999 and 2003 data). Details of the series and crop class are provided for the maximum yield loss at each location (tch = tonnes cane/ha; tsh = tonnes sugar/ha)**

| Location | **Proserpine** | | **Farleigh** | | **Marian** | | **Pleystowe** | | **Racecourse** | | **Plane Creek** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Yield parameter | tch | tsh | tch | tsh | tch | tsh | tch | tsh | tch | tsh | tch | tsh |
| % loss | 33.8 | 32.1 | 58.8 | 59.6 | 29.9 | 31.0 | 58.9 | 58.8 | 11.6 | 31.1 | 25.7 | 29.9 |
| Series | 1999 | | 1999 | | 1999 | | 1999 | | 2003 | 1999 | 2003 | |
| Crop class | P | | P | | P | | P | | 1R | P | 1R | |

These data suggest a variable relationship between orange rust and yield parameters - with variation between years and districts.

## 6.5 Discussion

The data reported for both northern and central districts capture a precise moment in history, when orange rust first appeared in the industry. At this point in time, two factors were operating: i. there was a huge area planted to a very susceptible variety (Q124). This meant that the amount of disease present within districts was at a very high level. Magarey (2005) reported on industry assessments and an estimated 140,000ha of sugarcane was severely affected by orange rust during 2000. This is likely to be the highest single-year disease occurrence in the history of the Australian industry; ii. The recent introduction of this strain of orange rust meant that biological controls affecting the disease were not operating at a high level; disease incidence was therefore relatively unconstrained by bio-control agents. Recent observations in the Tully area suggest that some hyper-parasitic fungi are commonly found associated with crops affected by orange rust. In the central district, some insect larvae have also been found feeding on orange rust spores in recent years.

Together, both these factors suggest that in the first year of the disease epidemic, very high inoculum pressure was affecting susceptible varieties leading to high disease levels.

In the analyses undertaken here, yield effects match these observations. The greatest yield losses were in the 1999-planted trial series (both central and northern districts). In the central district, yield losses were as high as 40% in some trials in plant crops. This is far higher than what was observed for Pachymetra root rot and yellow spot and is likely to be related to the high levels of disease inoculum. Later analyses suggest the effect of orange rust was less, and this could have been associated with the lower inoculum production (associated with reduced areas of commercial crops of Q124) coupled with a build up in biological control mechanisms. It is possible that slightly reduced clonal resistance may be needed in the future (compared to the year 2000) because of this. Higher rainfalls in the 1999-2000 period could also have contributed to the higher yield losses associated with orange rust in the 1999 series trials. The accumulated hours of conducive conditions (see Figure 4) also suggest this period was very suitable for orange rust escalation.

The highest yield losses from orange rust were in the central district. As mentioned climatic variables strongly favoured the disease in that region and there was a very high infection pressure associated with the large area planted to the susceptible Q124. Losses in northern Queensland were less as there was a much smaller proportion of the susceptible Q124 planted in the north compared to the central district. The combination of less Q124 coupled with less conducive environmental conditions led to lower yield losses in 2003 series trials. The obvious potential for orange rust to cause significant yield losses is highlighted by the data presented. Ongoing losses however are likely to be small.

In future analyses of the kind adopted here, generally high levels of resistance in the Australian germplasm (especially after the year 2000) will pose problems for this type of analysis - there were too few clones of high disease susceptibility to accurately gauge the yield of susceptible clones.

## 7.0 BROWN RUST

### 7.1 Introduction

It was not possible to undertake brown rust analyses using the breeding selection trials. Attempts at assessing the resistance of clones in plant breeding selection trials failed due to the lack of disease in field plots when trials were inspected. It was especially difficult to undertake these inspections in trials remote from Tully, as the timing of travel to locations such as Mackay when brown rust was affecting crops was difficult to arrange. There were occasions when the disease was affecting commercial crops, but inspection of breeding selection trials failed to locate sufficient disease to assess clones for resistance.

Some research with brown rust yield losses and the effect of varietal resistance has been undertaken in the past (Taylor et al, 1985). This research was undertaken when the disease was first identified in Australia and centred on the use of fungicides to create high and low disease comparative plots. Two trials were undertaken, one in northern Queensland and one in southern Queensland. The southern Queensland data were reanalysed to relate varietal resistance with yield losses.

### 7.2 Method

The experimental method will not be outlined in detail here but briefly it involved a split plot experiment where fungicide (oxycarboxin) was applied to some plots and not to paired plots of the same variety. Brown rust was assessed at different intervals during the

course of the growing crop in each of five varieties that differed in resistance to the diseases. Yield (CCS, tonnes cane/ha and tonnes sugar/ha) was assessed in the mature crop.

In these analyses, the percent leaf area affected in the 7th leaf from the top of the stalk was used to assess the resistance of each of the varieties (Q110, Q87, Q108, Q90 and QS70-77) present in the experiment. The resistance of the clones was regressed against the percent yield loss (tonnes cane/ha; tonnes sugar/ha) to determine the relationship between resistance and yield losses. Because only a limited number of varieties were used in the regression, there is limited interpretation that should be applied to the relationship between resistance and yield.

### 7.3 Results

Figure 26 below illustrates the relationship between brown rust resistance and losses in tonnes cane/ha and tones sugar/ha. In both cases, losses were significant in the most susceptible variety (QS70-77).

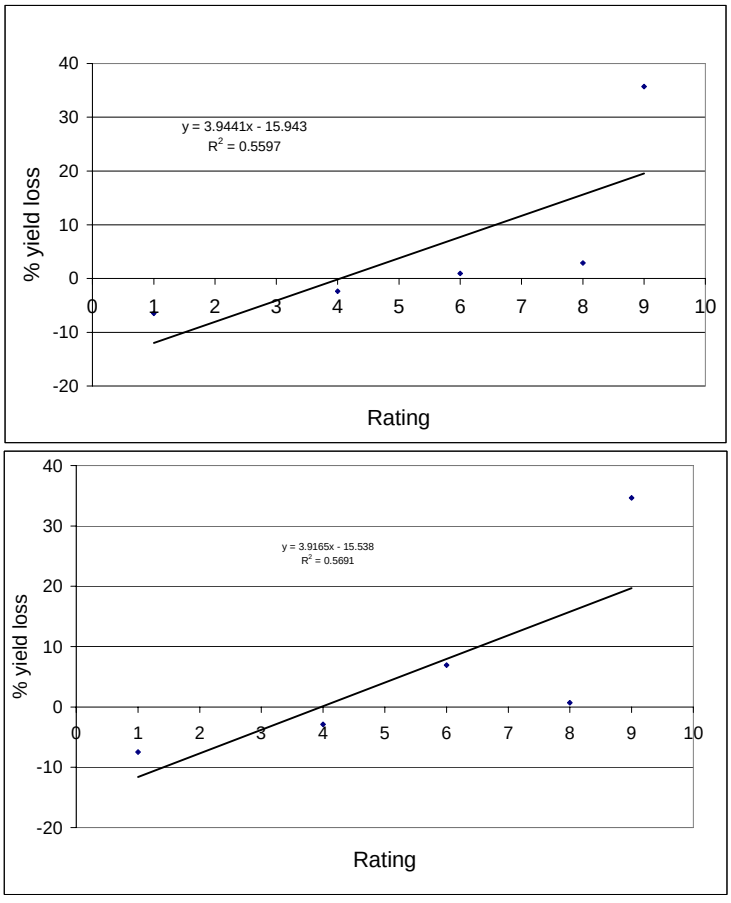



**Figure 26 Brown rust associated yield losses in the Isis Mill area (1982-83) - tonnes cane/ha (top) and tonnes sugar/ha (bottom)**

### 7.4 Discussion

Only limited interpretation should be placed on the analyses reported for brown rust as a very limited data set was used to investigate the yield loss x resistance relationship. These data do suggest a similar relationship to orange rust - roughly linear relationship with maximum losses around 30% (tonnes cane and tonnes sugar). It is obvious that further data capture is needed and further investigation of the relationship between resistance and yield.

Other evidence suggests that brown rust can exert a significant effect on sugarcane yield and that breeding for resistance is necessary in order to maximise commercial yields of sugarcane crops. Experience around the world has shown that the disease has made the commercial cropping of susceptible varieties uneconomic, and has necessitated the use of resistant or intermediate resistance varieties (Raid and Comstock, 2000).

## 8.0 AVERAGE CROP RESISTANCE AND DISEASE RESISTANCE PROFILES

Of interest in any discussion on yield effects of diseases is a consideration of the general resistance of commercial crops to those diseases and how the resistance of seedlings produced in the breeding program compares to expected disease-associated yield losses.

Magarey (2006) calculated the average resistance of crops in each region of Queensland. This was undertaken by obtaining data on the proportion of the crop produced in each area by each variety, using disease resistance ratings for each variety, and calculating a weighted mean resistance rating for all crops produced in the region based on the resistance data. Further details relating to these calculations are described by Magarey (2006). Profiles for the northern and central districts for all diseases for the 2004 crop are illustrated in Figure 27.

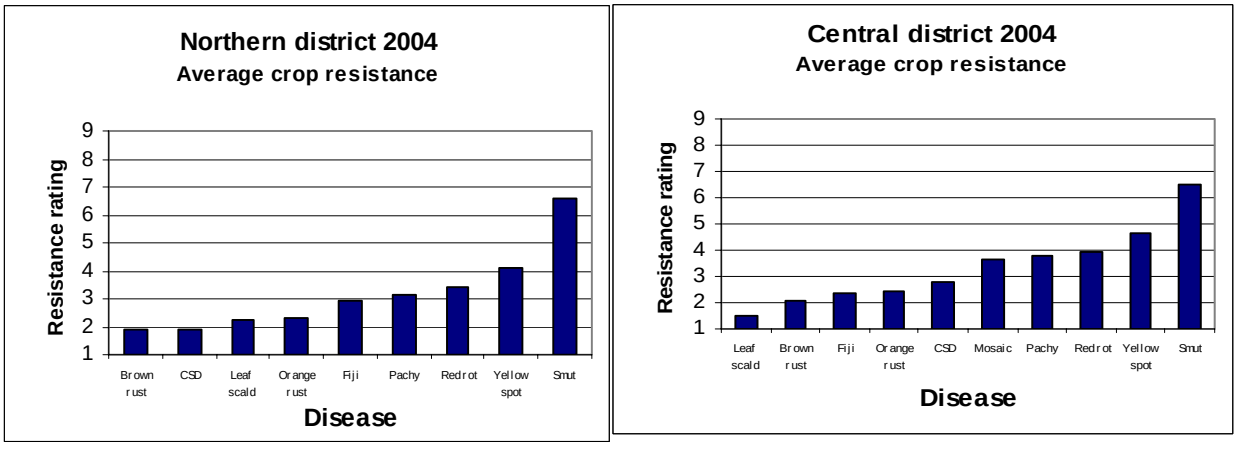
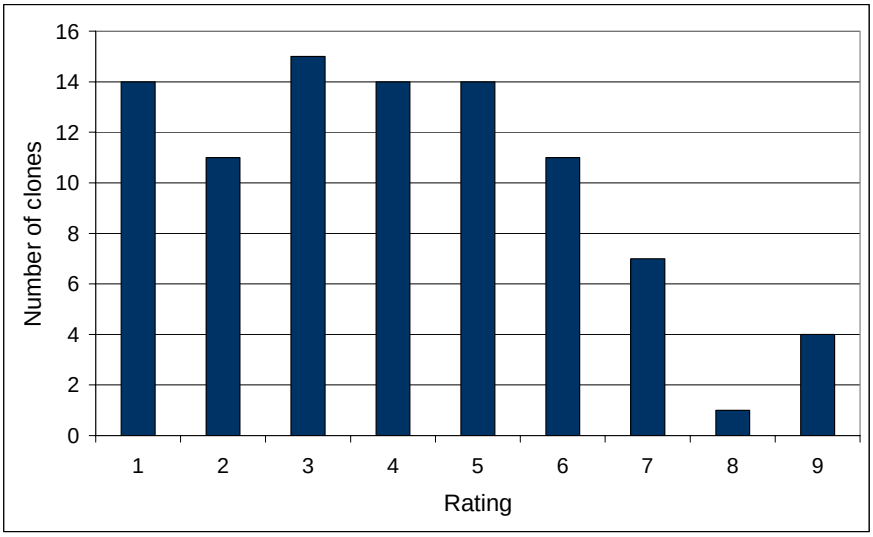


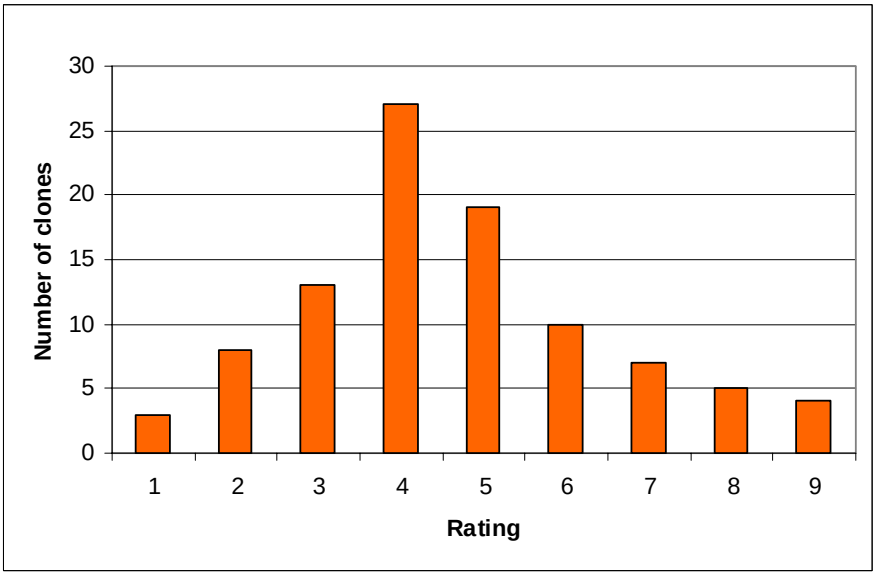

**Figure 27 The average 2004 crop disease resistance to various endemic diseases in northern and central Queensland**

These data illustrate the relatively high level of resistance present for orange rust, and the lower level of resistance to Pachymetra root rot and yellow spot (for the latter this is relevant for northern Queensland only).

Yield loss data obtained form plant improvement selection trials could be used to estimate the percentage yield losses occurring regularly in crops in each region, assuming losses in breeding trials were indicative of those suffered on average in commercials fields. For example if maximum losses for Pachymetra root rot with a 9 rated variety were 15%, then average crop resistance of 4 would suggest district losses are 4/9 x 15% = 6.7% annually. If the general resistance of the crop within a region rose, then losses would be reduced proportionally.

Also of interest are the resistance profiles of clones in plant improvement selection trials, as this provides a background understanding of what breeders have to select for future commercial varieties. If high levels of susceptible varieties are coming through the system, then there is little room to select for a high level of resistance. Data for Pachymetra root rot, yellow spot and orange rust for the 2003 series northern trials are included in Figure 28.



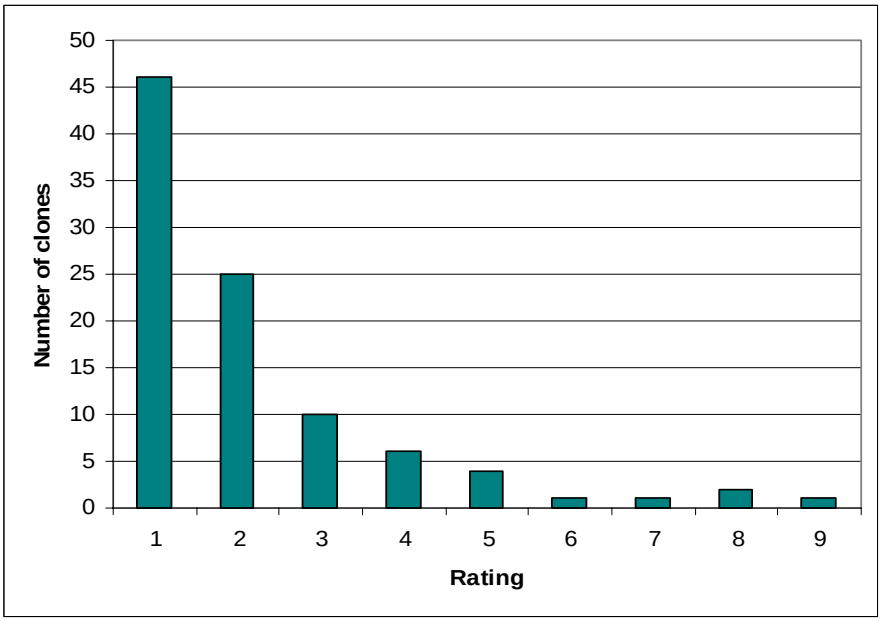



**Figure 28 The resistance profiles of the same 2003 northern series clones to Pachymetra root rot (top), yellow spot (middle) and orange rust (bottom) illustrating the diversity in inherent resistance to the three diseases**

The Resistance Index (RI) for each disease in the 2003 northern series is illustrated in Table 18. This again illustrates the higher level of resistance present in the germplasm to orange rust, and the lower level of resistance to yellow spot.

**Table 18 The resistance index for each disease in the 1999 and 2003 series clones in northern (Pachymetra root rot / yellow spot / orange rust) and central (orange rust) FATs**

| Disease / Series | Pachymetra root rot | Yellow spot | Orange rust | |
|---|---|---|---|---|
| | | | ***Northern*** | ***Central*** |
| 1999 | 4.0 | 5.5 | 2.1 | 3.1 |
| 2003 | 4.0 | 4.6 | 2.2 | 2.8 |

In plant improvement selection strategies, not only is the potential yield losses caused by each disease in a region an important consideration, but also the urgency to produce new commercial varieties with higher levels of resistance (if a disease is causing excessive yield losses in commercial crops) and the level of resistance present in seedling clones passing through the selection program. All the information could be gathered from the type of data presented in this report.

## 9.0 COMPARISON OF YIELD LOSSES CAUSED BY EACH DISEASE

The analysis of the same series of trials allows some comparison of the relative influence of each disease on yield. It is clear from overall mean yield loss figures that each disease reduced yield (tonnes cane/ha or tonnes sugar/ha) on average by between 10-15%. In individual trials, much greater losses were recorded for each disease - particularly orange

rust in plant crops in 1999 in the central district and Pachymetra root rot in northern trials in the 1995-1999 period. The strength of the relationship between Pachymetra root rot and yield loss was stronger than for the other diseases. Ad hoc observations suggest that natural selection for Pachymetra root rot resistance has been occurring in northern FAT selection trials over the last 20 years, and this supports the proposition that the disease is reducing yield consistently in these trials.

The lack of selection for yellow spot resistance tends to suggest the opposite - that the disease affects yield in a sporadic way - perhaps being more dependant on weather conditions, and therefore less consistently affecting yield. This would reduce natural selection in breeding trials. Higher RI values for yellow spot illustrate the lower level of resistance for yellow spot in the seedling population.

Of the two leaf diseases, orange rust - especially in the central district - caused the most severe average yield losses with yield reduced by up to 40%. However, in later trials the effect of orange rust and yellow spot was comparable and more minor in effect. Lower rainfall in the northern district may have contributed to reduced yield effects in this region, but there is also no doubt that lower levels of inoculum contributed. Increased bio-control is also likely to be a factor. Table 18 details the average yield losses (tonnes cane/ha and tonnes sugar/ha) for the 1999 and 2003 series trials for northern Queensland.

**Table 18 Average yield losses associated with each disease in northern series trials in 1999 and 2003**

| Series (year) | **1999** | | | **2003** | | |
|---|---|---|---|---|---|---|
| Crop class | Disease | Tonnes cane / ha | Tonnes sugar / ha | Disease | Tonnes cane / ha | Tonnes sugar / ha |
| Plant | Yellow spot | 15.8 | 11.4 | Yellow spot | -0.7 | 4.7 |
| | Orange rust | 6.6 | 11.2 | Orange rust | 6.8 | 6.2 |
| First ratoon | Yellow spot | 12.0 | 8.1 | Yellow spot | 11.2 | 10.9 |
| | Orange rust | 16.2 | 13.3 | Orange rust | 0.7 | 0.2 |
| Mean (P+1R) | Yellow spot | 13.9 | 9.8 | Yellow spot | 5.3 | 7.8 |
| | Orange rust | 11.4 | 12.3 | Orange rust | 3.8 | 3.2 |
| | Pachymetra | 14.5 | 11.9 | Pachymetra | 2.7 | 4.8 |

These are illustrated graphically in Figure 29 for the 1999 series trials.

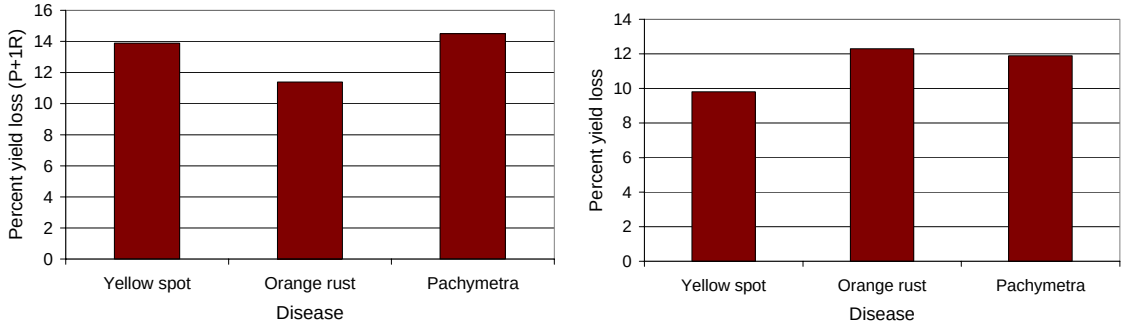



**Figure 29 Magnitude of yield losses caused by the different diseases in northern trials (left TCH; right TSH). The results are mean figures for plant plus first ratoon crops in the 1999 series trials**

## 10.0 GENERAL DISCUSSION

It is clear from these analyses that endemic diseases are significantly affecting the yield of clones in plant breeding selection trials. This suggests that incorporating sufficient resistance to these diseases in commercial varieties is important for maximising commercial yields. Of the three diseases, Pachymetra root rot has consistently reduced yields in FATs and is the most important on-going disease influence. However, the effect of orange rust in the central district in 2000-harvested plant crops was also very large - but losses were much lower in first ratoon crops of the same series.

The relationship between resistance and yield in all three diseases appeared similar; there was a linear relationship between losses and yield. In other research conducted with Pachymetra root rot in the central district (Magarey et al, 2003), losses in highly resistant varieties were negligible and it is likely negligible losses would have been associated with highly resistant clones with each disease in these analyses.

Climate also is likely to have had a significant influence on yield losses in these studies. Higher yield losses were seen with the leaf diseases in the 1999 series trials compared to the 2003 series - rainfall is likely to have influenced the favourability of the environment for these diseases. The higher inoculum levels associated with large areas of the susceptible Q124 would have contributed to higher orange rust losses in that year also.

The Pachymetra data suggest that plant breeders should consider revising, or at least giving further contemplation to the operation of breeding sub-stations. The interaction of residual Pachymetra inoculum with yield, is at best contributing ‘noise’ to the data and at worst leading to the selection of clones that will perform sub-optimally in the presence of the disease. Practical issues need to be combined with disease considerations in the design of sub-station sites.

Possible problems with this type of analysis include having a suitable range of resistance in clones in FAT trials. With orange rust, the high level of resistance present in clones meant that there tended to be few clones in the susceptible category. This decreased the reliability of yield values at this end of the scale in the regression analyses. For Pachymetra root rot and yellow spot this was generally of lesser significance. The lack of relationship between resistance and yield with Pachymetra root rot in Tableland trials illustrates that there was no inherent relationship between resistance to Pachymetra root rot and yield parameters.

## 11.0 CONCLUSION

- There were significant yield losses associated with endemic diseases in many FATs planted in northern and central Queensland
- Losses to Pachymetra root rot were the most consistent and were up to 40% in some locations in northern Queensland.
- Losses associated with orange rust were around 40% in central Queensland in the year 2000, but lower in subsequent years.
- Yellow spot caused significant losses in some years but was less consistent in its effects

- When mean data for all trials and all series were analysed it was found that each disease caused losses of between 10-15% (tonnes cane/ha and tonnes sugar/ha).
- Rainfall, inoculum pressure and bio-control effects are likely to have contributed to variation in disease-associated yield losses.
- It is recommended that further yield loss studies are undertaken over a longer period to establish the long term effect of these diseases, especially for the leaf diseases.
- Further monitoring of climatic conditions coupled with more extensive monitoring of leaf disease levels during the growing season will enable stronger conclusions to be drawn of the relationship between weather and yield losses.
- This work coupled with knowledge of the resistance of parents and clones will enable optimum levels of disease resistance to be incorporated into commercial varieties.
- FAT sub-station site procedures should be reviewed to take into account residual Pachymetra inoculum influences on clone yield.

## 12.0 FUTURE WORK

- There are further analyses that could be undertaken with these data, including the following: -
  - Determining the mean yield losses occurring for the endemic diseases at each FAT location within a district
  - Comparing average losses at each site with weather conditions (such as rainfall) to further determine the relationship between rainfall and yield losses.
- Additional work could include assessing soil moisture conditions (as opposed to simple rainfall measurements) to investigate the linkage between soil moisture and severity of Pachymetra root rot.
- Recording of temperature, relative humidity, leaf wetness and rainfall at each FAT site and to relate these conditions to the severity of leaf diseases at each site. This will provide much further information on the requirements for leaf diseases.
- The above information, relating yield losses to disease resistance, if recorded over an extended period will allow predictions on what percentage of years in each area will be prone to significant yield losses from that disease. This in turn will provide further guidance to plant breeders on what level of resistance to incorporate into commercial varieties.
- Further analyse central district Pachymetra FAT data for individual trial losses and the influence of regional conditions on these losses.

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## 15.0 APPENDICES

### Appendix 1 – Yield loss calculations for Pachymetra root rot using average northern trial data for 1995-1999 and 2000-2004

| 5 Year Series | Trial | TCH | | | | | TSH | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| All Northern | | Intercept | M | 0 Rating | 1 rating | 9 rating | % loss | Intercept | M | 0 rating | 1 rating | 9 rating | % loss |
| 1995-1999 | P | 100.65 | -1.144 | 100.65 | 99.506 | 89.21 | **10.3** | 101.57 | -1.0979 | 101.57 | 100.4721 | 90.591 | **9.8** |
| | 1R | 102.15 | -1.8309 | 102.15 | 100.3191 | 83.841 | **16.4** | 102.01 | -1.8274 | 102.01 | 100.1826 | 83.736 | **16.4** |
| | P+1R | 101.4 | -1.4875 | 101.4 | 99.9125 | 86.525 | **13.4** | 101.79 | -1.4626 | 101.79 | 100.3274 | 87.164 | **13.1** |
| 2000-2004 | P | 101.85 | -0.3552 | 101.85 | 101.4948 | 98.298 | **3.1** | 102 | -0.4927 | 102 | 101.5073 | 97.073 | **4.4** |
| | 1R | 103.36 | -0.2557 | 103.36 | 103.1043 | 100.803 | **2.2** | 103.49 | -0.3122 | 103.49 | 103.1778 | 100.368 | **2.7** |
| | P+1R | 102.61 | -0.3054 | 102.61 | 102.3046 | 99.556 | **2.7** | 102.74 | -0.4024 | 102.74 | 102.3376 | 98.716 | **3.5** |

**Appendix 2 - R-squared values for the regressions between Pachymetra resistance and yield component for each FAT in northern Queensland (1995-2004 series)**

| Year | Trial | Babinda | | | Mulgrave 1 | | | Mulgrave 2 | | | Mourilyan 1 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CCS | TCH | TSH | CCS | TCH | TSH | CCS | TCH | TSH | CCS | TCH | TSH |
| 1995 | P | 0.26 | | | | | | | | | 0.45 | | |
| | 1R | | | | | | | | -0.37 | -0.39 | | -0.51 | -0.47 |
| | 2R | | | | | | | | | | | | |
| 1996 | P | | | | | -0.84 | -0.80 | | -0.27 | -0.19 | | -0.42 | -0.27 |
| | 1R | | -0.24 | -0.39 | -0.22 | -0.55 | -0.66 | | -0.39 | -0.35 | 0.24 | -0.53 | -0.39 |
| | 2R | | | | | -0.52 | -0.45 | 0.41 | -0.71 | -0.62 | | -0.66 | -0.71 |
| 1997 | P | | -0.48 | -0.47 | | | | | -0.51 | -0.41 | -0.62 | | |
| | 1R | 0.44 | -0.49 | -0.38 | | -0.52 | -0.42 | 0.44 | -0.52 | -0.46 | | -0.92 | -0.90 |
| | 2R | | | | -0.62 | -0.21 | -0.33 | 0.25 | -0.20 | | -0.30 | -0.40 | -0.50 |
| 1998 | P | -0.46 | | | -0.28 | -0.26 | -0.42 | | -0.55 | -0.60 | | -0.73 | -0.74 |
| | 1R | -0.32 | -0.78 | -0.80 | -0.40 | -0.58 | -0.81 | | -0.35 | -0.28 | | -0.38 | -0.49 |
| | 2R | | -0.49 | -0.45 | | -0.31 | -0.42 | 0.23 | | | 0.35 | -0.38 | -0.29 |
| 1999 | P | | -0.59 | -0.54 | 0.32 | -0.47 | -0.29 | 0.53 | -0.62 | | | -0.65 | -0.71 |
| | 1R | | -0.47 | -0.49 | 0.22 | -0.20 | | 0.24 | -0.44 | -0.35 | | -0.65 | -0.71 |
| | 2R | | -0.72 | -0.70 | | | | 0.3 | -0.45 | -0.37 | | -0.37 | -0.29 |
| 2000 | P | | -0.29 | -0.25 | | | | | | | | | |
| | 1R | | | | | -0.49 | -0.46 | | | | | -0.41 | -0.46 |
| | 2R | | -0.49 | -0.38 | | -0.81 | -0.76 | | | | | | -0.25 |
| 2001 | P | | -0.23 | | | | | | | | | -0.24 | |
| | 1R | 0.23 | -0.28 | | | | | | | | | -0.20 | |
| | 2R | | | | | -0.73 | -0.65 | | | | 0.30 | | 0.27 |
| 2002 | P | | | | | | | | | | 0.21 | | |
| | 1R | | | | | | | | | | -0.20 | | |
| | 2R | | | | | -0.27 | -0.20 | | | | | -0.49 | -0.65 |
| 2003 | P | -0.34 | 0.21 | | | -0.31 | -0.50 | | | | -0.47 | | |
| | 1R | -0.64 | | | | | -0.22 | | | | | -0.29 | -0.53 |
| | 2R | | | | | | | | | | | 0.31 | 0.48 |
| 2004 | P | | | -0.21 | | | | | | | -0.41 | | |
| | 1R | -0.37 | | -0.23 | | | | | | | | -0.25 | -0.21 |

| Year | Trial | Mourilyan 2 | | | Tully | | |
|---|---|---|---|---|---|---|---|
| | | CCS | TCH | TSH | CCS | TCH | TSH |
| 1995 | P | | | | -0.33 | | |
| | 1R | | | | | | |
| | 2R | | | | | | |
| 1996 | P | | -0.45 | -0.50 | | | |
| | 1R | | -0.30 | -0.33 | | -0.31 | -0.43 |
| | 2R | -0.20 | -0.50 | -0.51 | | -0.24 | |
| 1997 | P | | | | | 0.24 | 0.22 |
| | 1R | | | | | | |
| | 2R | | | | | -0.62 | -0.58 |
| 1998 | P | | | | | | |
| | 1R | | | | | | |
| | 2R | | | | | -0.61 | -0.52 |
| 1999 | P | | -0.41 | -0.33 | 0.51 | -0.28 | |
| | 1R | | -0.46 | -0.40 | 0.21 | -0.61 | -0.55 |
| | 2R | | -0.48 | -0.48 | | -0.20 | |
| 2000 | P | | | | 0.43 | | |
| | 1R | | | | | | |
| | 2R | | | | | | |
| 2001 | P | | | | | | |
| | 1R | | | | 0.34 | | |
| | 2R | | | | 0.75 | 0.21 | 0.57 |
| 2002 | P | | | | -0.23 | | |
| | 1R | | | | | | |
| | 2R | | | | 0.29 | -0.25 | |
| 2003 | P | | | | | | |
| | 1R | | | | -0.33 | | |
| | 2R | | | | | | |
| 2004 | P | | | | -0.30 | | |

**Appendix 3 - Yield loss calculations for Pachymetra root rot using data from each location in northern trial data for 1995-2004 (blank spaces occur where the r-squared <0.20)**

| Year | Trial | Babinda TCH | | | | | | TSH | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Intercept | M | 0 Rating | 1 rating | 9 rating | % loss | Intercept | M | 0 rating | 1 rating | 9 rating | % loss |
| 1995 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |
| | 2R | | | | | | | | | | | | |
| 1996 | P | | | | | | | | | | | | |
| | 1R | 72.4 | -1.32 | 72.4 | 71.08 | 59.2 | **16.7** | 9.4 | -0.185 | 9.4 | 9.215 | 7.55 | **18.1** |
| | 2R | | | | | | | | | | | | |
| 1997 | P | 119.8 | -2.94 | 119.8 | 116.86 | 90.4 | **22.6** | 15.2 | -0.312 | 15.2 | 14.888 | 12.08 | **18.9** |
| | 1R | 101.8 | -3.04 | 101.8 | 98.76 | 71.4 | **27.7** | 14.8 | -0.349 | 14.8 | 14.451 | 11.31 | **21.7** |
| | 2R | | | | | | | | | | | | |
| 1998 | P | | | | | | | | | | | | |
| | 1R | 60.5 | -2.22 | 60.5 | 58.28 | 38.3 | **34.3** | 8.9 | -0.35 | 8.9 | 8.55 | 5.4 | **36.8** |
| | 2R | 69 | -3.02 | 69 | 65.98 | 38.8 | **41.2** | 11.7 | -0.505 | 11.7 | 11.195 | 6.65 | **40.6** |
| 1999 | P | 64.8 | -1.21 | 64.8 | 63.59 | 52.7 | **17.1** | 9.3 | -0.164 | 9.3 | 9.136 | 7.66 | **16.2** |
| | 1R | 67.7 | -1.1 | 67.7 | 66.6 | 56.7 | **14.9** | 10.9 | -0.185 | 10.9 | 10.715 | 9.05 | **15.5** |
| | 2R | 101.3 | -2.49 | 101.3 | 98.81 | 76.4 | **22.7** | 17.9 | -0.545 | 17.9 | 17.355 | 12.45 | **28.3** |
| 2000 | P | 60.5 | -0.783 | 60.5 | 59.717 | 52.67 | **11.8** | 9.9 | -0.139 | 9.9 | 9.761 | 8.51 | **12.8** |
| | 1R | | | | | | | | | | | | |
| | 2R | 105.6 | -3.15 | 105.6 | 102.45 | 74.1 | **27.7** | 17.3 | -0.525 | 17.3 | 16.775 | 12.05 | **28.2** |
| 2001 | P | 109.3 | -0.801 | 109.3 | 108.499 | 101.29 | **6.6** | 17.3 | -0.118 | 17.3 | 17.182 | 16.12 | **6.2** |
| | 1R | 103.4 | -0.732 | 103.4 | 102.668 | 96.08 | **6.4** | | | | | | |
| | 2R | | | | | | | | | | | | |
| 2002 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |
| | 2R | | | | | | | | | | | | |
| 2003 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |
| | 2R | | | | | | | | | | | | |
| 2004 | P | | | | | | | 13.6 | -0.133 | 13.6 | 13.467 | 12.27 | **8.9** |
| | 1R | | | | | | | 9.6 | -0.089 | 9.6 | 9.511 | 8.71 | **8.4** |

| Year | Trial | Mulgrave 1 TCH | | | | | | TSH | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Intercept | M | 0 Rating | 1 rating | 9 rating | % loss | Intercept | M | 0 rating | 1 rating | 9 rating | % loss |
| 1995 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |
| | 2R | | | | | | | | | | | | |
| 1996 | P | 116.7 | -2.7 | 116.7 | 114 | 89.7 | **21.3** | 19.5 | -0.459 | 19.5 | 19.041 | 14.91 | **21.7** |
| | 1R | 116.7 | -1.7 | 116.7 | 115 | 99.7 | **13.3** | 17.9 | -0.313 | 17.9 | 17.587 | 14.77 | **16.0** |
| | 2R | 102.5 | -2.3 | 102.5 | 100.2 | 79.5 | **20.7** | 16.1 | -0.341 | 16.1 | 15.759 | 12.69 | **19.5** |
| 1997 | P | 106.5 | -0.988 | 106.5 | 105.512 | 96.62 | **8.4** | 16.3 | -0.153 | 16.3 | 16.147 | 14.77 | **8.5** |
| | 1R | 109 | -1.68 | 109 | 107.32 | 92.2 | **14.1** | 17.2 | -0.298 | 17.2 | 16.902 | 14.22 | **15.9** |
| | 2R | 82 | -1.38 | 82 | 80.62 | 68.2 | **15.4** | 12.7 | -0.265 | 12.7 | 12.435 | 10.05 | **19.2** |
| 1998 | P | 124.6 | -1.39 | 124.6 | 123.21 | 110.7 | **10.2** | 18.2 | -0.237 | 18.2 | 17.963 | 15.83 | **11.9** |
| | 1R | 92.8 | -1.1 | 92.8 | 91.7 | 81.8 | **10.8** | 13.9 | -0.215 | 13.9 | 13.685 | 11.75 | **14.1** |
| | 2R | 101.3 | -1.96 | 101.3 | 99.34 | 81.7 | **17.8** | 18 | -0.386 | 18 | 17.614 | 14.14 | **19.7** |
| 1999 | P | 80.1 | -1.76 | 80.1 | 78.34 | 62.5 | **20.2** | 11.7 | -0.192 | 11.7 | 11.508 | 9.78 | **15.0** |
| | 1R | 93.5 | -1.78 | 93.5 | 91.72 | 75.7 | **17.5** | 15.7 | -0.228 | 15.7 | 15.472 | 13.42 | **13.3** |
| | 2R | | | | | | | | | | | | |
| 2000 | P | | | | | | | | | | | | |
| | 1R | 80.6 | -1.13 | 80.6 | 79.47 | 69.3 | **12.8** | 13.6 | -0.181 | 13.6 | 13.419 | 11.79 | **12.1** |
| | 2R | 104.1 | -5.46 | 104.1 | 98.64 | 49.5 | **49.8** | 16.7 | -0.852 | 16.7 | 15.848 | 8.18 | **48.4** |
| 2001 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |
| | 2R | 129.7 | -5.39 | 129.7 | 124.31 | 75.8 | **39.0** | 23.6 | -0.942 | 23.6 | 22.658 | 14.18 | **37.4** |
| 2002 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |
| | 2R | 139.7 | -3.84 | 139.7 | 135.86 | 101.3 | **25.4** | 21.9 | -0.532 | 21.9 | 21.368 | 16.58 | **22.4** |
| 2003 | P | 101.3 | -1.53 | 101.3 | 99.77 | 86 | **13.8** | 13.1 | -0.261 | 13.1 | 12.839 | 10.49 | **18.3** |
| | 1R | | | | | | | 22.3 | -0.148 | 22.3 | 22.152 | 20.82 | **6.0** |
| | 2R | | | | | | | | | | | | |
| 2004 | P | | | | | | | | | | | | |

| Year | Trial | Mulgrave 2 TCH | | | | | | TSH | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Intercept | M | 0 Rating | 1 rating | 9 rating | % loss | Intercept | M | 0 rating | 1 rating | 9 rating | % loss |
| 1995 | P | | | | | | | | | | | | |
| | 1R | 113.7 | -2.62 | 113.7 | 111.08 | 87.5 | **21.2** | 18.6 | -0.147 | 18.6 | 18.453 | 17.13 | **7.2** |
| | 2R | | | | | | | | | | | | |
| 1996 | P | 132.2 | -1.13 | 132.2 | 131.07 | 120.9 | **7.8** | 20.1 | -0.149 | 20.1 | 19.951 | 18.61 | **6.7** |
| | 1R | 129.6 | -1.72 | 129.6 | 127.88 | 112.4 | **12.1** | 20.8 | -0.239 | 20.8 | 20.561 | 18.41 | **10.5** |
| | 2R | 107.1 | -3.82 | 107.1 | 103.28 | 68.9 | **33.3** | 17.6 | -0.571 | 17.6 | 17.029 | 11.89 | **30.2** |
| 1997 | P | 112.8 | -2.08 | 112.8 | 110.72 | 92 | **16.9** | 16.1 | -0.239 | 16.1 | 15.861 | 13.71 | **13.6** |
| | 1R | 107.2 | -5.34 | 107.2 | 101.86 | 53.8 | **47.2** | 16.7 | -0.764 | 16.7 | 15.936 | 9.06 | **43.1** |
| | 2R | 71.5 | -1.88 | 71.5 | 69.62 | 52.7 | **24.3** | | | | | | |
| 1998 | P | 122.5 | -1.57 | 122.5 | 120.93 | 106.8 | **11.7** | | | | | | |
| | 1R | 89.5 | -1.18 | 89.5 | 88.32 | 77.7 | **12.0** | 12.6 | -0.161 | 12.6 | 12.439 | 10.99 | **11.6** |
| | 2R | | | | | | | | | | | | |
| 1999 | P | 108.1 | -2.61 | 108.1 | 105.49 | 82 | **22.3** | 13.9 | -0.118 | 13.9 | 13.782 | 12.72 | **7.7** |
| | 1R | 108.8 | -2.41 | 108.8 | 106.39 | 84.7 | **20.4** | 18.4 | -0.355 | 18.4 | 18.045 | 14.85 | **17.7** |
| | 2R | 93.5 | -3.29 | 93.5 | 90.21 | 60.6 | **32.8** | 16.1 | -0.482 | 16.1 | 15.618 | 11.28 | **27.8** |
| 2000 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |
| | 2R | | | | | | | | | | | | |
| 2001 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |
| | 2R | | | | | | | | | | | | |
| 2002 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |
| | 2R | | | | | | | | | | | | |
| 2003 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |
| | 2R | | | | | | | | | | | | |
| 2004 | P | | | | | | | | | | | | |

| Year | Trial | Mourilyan 1 TCH | | | | | | TSH | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Intercept | M | 0 Rating | 1 rating | 9 rating | % loss | Intercept | M | 0 rating | 1 rating | 9 rating | % loss |
| 1995 | P | | | | | | | | | | | | |
| | 1R | 92.6 | -1.11 | 92.6 | 91.49 | 81.5 | **10.9** | | | | | | |
| | 2R | | | | | | | | | | | | |
| 1996 | P | 76.5 | -0.92 | 76.5 | 75.58 | 67.3 | **11.0** | 11.5 | -0.147 | 11.5 | 11.353 | 10.03 | **11.7** |
| | 1R | 75.9 | -1.34 | 75.9 | 74.56 | 62.5 | **16.2** | 11 | -0.15 | 11 | 10.85 | 9.5 | **12.4** |
| | 2R | 69.4 | -2.1 | 69.4 | 67.3 | 48.4 | **28.1** | 10.7 | -0.327 | 10.7 | 10.373 | 7.43 | **28.4** |
| 1997 | P | | | | | | | | | | | | |
| | 1R | 68.2 | -2.68 | 68.2 | 65.52 | 41.4 | **36.8** | 10 | -0.44 | 10 | 9.56 | 5.6 | **41.4** |
| | 2R | 39.5 | -1.34 | 39.5 | 38.16 | 26.1 | **31.6** | 6.1 | -0.228 | 6.1 | 5.872 | 3.82 | **34.9** |
| 1998 | P | 107.4 | -3.13 | 107.4 | 104.27 | 76.1 | **27.0** | 16.5 | -0.496 | 16.5 | 16.004 | 11.54 | **27.9** |
| | 1R | 107.8 | -1.41 | 107.8 | 106.39 | 93.7 | **11.9** | 16.2 | -0.273 | 16.2 | 15.927 | 13.47 | **15.4** |
| | 2R | 99.1 | -2.65 | 99.1 | 96.45 | 72.6 | **24.7** | 17.1 | -0.392 | 17.1 | 16.708 | 13.18 | **21.1** |
| 1999 | P | 86.1 | -3.77 | 86.1 | 82.33 | 48.4 | **41.2** | 15.6 | -0.656 | 15.6 | 14.944 | 9.04 | **39.5** |
| | 1R | | | | | | | | | | | | |
| | 2R | 100.6 | -0.757 | 100.6 | 99.843 | 93.03 | **6.8** | 18.4 | -0.131 | 18.4 | 18.269 | 17.09 | **6.5** |
| 2000 | P | | | | | | | | | | | | |
| | 1R | 108.1 | -1.51 | 108.1 | 106.59 | 93 | **12.7** | 18.5 | -0.251 | 18.5 | 18.249 | 15.99 | **12.4** |
| | 2R | | | | | | | 16.2 | -0.241 | 16.2 | 15.959 | 13.79 | **13.6** |
| 2001 | P | 121.1 | -1.51 | 121.1 | 119.59 | 106 | **11.4** | | | | | | |
| | 1R | 101.5 | -0.976 | 101.5 | 100.524 | 91.74 | **8.7** | 15.3 | -0.134 | 15.3 | 15.166 | 13.96 | **8.0** |
| | 2R | | | | | | | | | | | | |
| 2002 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |
| | 2R | 117.9 | -3.12 | 117.9 | 114.78 | 86.7 | **24.5** | 19.5 | -0.559 | 19.5 | 18.941 | 13.91 | **26.6** |
| 2003 | P | | | | | | | | | | | | |
| | 1R | 93.3 | -0.85 | 93.3 | 92.45 | 84.8 | **8.3** | 14.7 | -0.148 | 14.7 | 14.552 | 13.22 | **9.2** |
| | 2R | | | | | | | | | | | | |
| 2004 | P | | | | | | | 17.9 | -0.131 | 17.9 | 17.769 | 16.59 | **6.6** |
| | 1R | 73.8 | -0.842 | 73.8 | 72.958 | 65.38 | **10.4** | 10.3 | -0.111 | 10.3 | 10.189 | 9.19 | **9.8** |

| Year | Trial | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mourilyan 2 | | | | | | | | | | | | |
| | TCH | | | | | | | TSH | | | | | |
| | | Intercept | M | 0 Rating | 1 rating | 9 rating | % loss | Intercept | M | 0 rating | 1 rating | 9 rating | % loss |
| 1995 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |
| | 2R | | | | | | | | | | | | |
| 1996 | P | 119.8 | -1.47 | 119.8 | 118.33 | 105.1 | **11.2** | 19.4 | -0.29 | 19.4 | 19.11 | 16.5 | **13.7** |
| | 1R | 90.8 | -1.86 | 90.8 | 88.94 | 72.2 | **18.8** | 13.2 | -0.297 | 13.2 | 12.903 | 10.23 | **20.7** |
| | 2R | 52.5 | -1.38 | 52.5 | 51.12 | 38.7 | **24.3** | 8 | -0.211 | 8 | 7.789 | 5.89 | **24.4** |
| 1997 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |
| | 2R | | | | | | | | | | | | |
| 1998 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |
| | 2R | | | | | | | | | | | | |
| 1999 | P | 88.7 | -1.41 | 88.7 | 87.29 | 74.6 | **14.5** | 12.6 | -0.141 | 12.6 | 12.459 | 11.19 | **10.2** |
| | 1R | 92.6 | -1.87 | 92.6 | 90.73 | 73.9 | **18.5** | 15.1 | -0.254 | 15.1 | 14.846 | 12.56 | **15.4** |
| | 2R | 116.8 | -1.1 | 116.8 | 115.7 | 105.8 | **8.6** | 21.3 | -0.254 | 21.3 | 21.046 | 18.76 | **10.9** |
| 2000 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |
| | 2R | | | | | | | | | | | | |
| 2001 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |
| | 2R | | | | | | | | | | | | |
| 2002 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |
| | 2R | | | | | | | | | | | | |
| 2003 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |
| | 2R | | | | | | | | | | | | |
| 2004 | P | | | | | | | | | | | | |

| Year | Trial | Tully | | | | | | TSH | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Intercept | M | 0 Rating | 1 rating | 9 rating | % loss | Intercept | M | 0 rating | 1 rating | 9 rating | % loss |
| 1995 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |
| | 2R | | | | | | | | | | | | |
| 1996 | P | | | | | | | | | | | | |
| | 1R | 91.2 | -0.314 | 91.2 | 90.886 | 88.06 | **3.1** | 12.6 | -0.429 | 12.6 | 12.171 | 8.31 | **31.7** |
| | 2R | 100.2 | -1.23 | 100.2 | 98.97 | 87.9 | **11.2** | | | | | | |
| 1997 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |
| | 2R | 72.1 | -3.75 | 72.1 | 68.35 | 34.6 | **49.4** | 10.1 | -0.494 | 10.1 | 9.606 | 5.16 | **46.3** |
| 1998 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |
| | 2R | 115.2 | -3.09 | 115.2 | 112.11 | 84.3 | **24.8** | 18.4 | -0.39 | 18.4 | 18.01 | 14.5 | **19.5** |
| 1999 | P | 71.4 | -1.63 | 71.4 | 69.77 | 55.1 | **21.0** | 10.4 | -0.2 | 10.4 | 10.2 | 8.4 | **17.6** |
| | 1R | 102.2 | -1.99 | 102.2 | 100.21 | 82.3 | **17.9** | 16.5 | -0.278 | 16.5 | 16.222 | 13.72 | **15.4** |
| | 2R | 114.4 | -0.381 | 114.4 | 114.019 | 110.59 | **3.0** | | | | | | |
| 2000 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |
| | 2R | | | | | | | | | | | | |
| 2001 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |
| | 2R | | | | | | | | | | | | |
| 2002 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |
| | 2R | 101.7 | -1.98 | 101.7 | 99.72 | 81.9 | **17.9** | | | | | | |
| 2003 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |
| | 2R | | | | | | | | | | | | |
| 2004 | P | | | | | | | | | | | | |

## Appendix 4 - Yield loss calculations for Pachymetra root rot using average northern trial data for 1999 and 2003 data

| Year | Trial | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Northern Average | | | | | | | | | | | |
| | TCH | | | | | | | TSH | | | | |
| | | Intercept | M | 0 Rating | 1 rating | 9 rating | % loss | Intercept | M | 0 rating | 1 rating | 9 rating | % loss |
| **1999** | **P** | 78.36 | -0.5707 | 78.36 | 77.7893 | 72.653 | **6.6** | 11.404 | -0.1402 | 11.404 | 11.2638 | 10.002 | **11.2** |
| | **1R** | 91.363 | -1.6183 | 91.363 | 89.7447 | 75.18 | **16.2** | 15.082 | -0.2191 | 15.082 | 14.8629 | 12.891 | **13.3** |
| | **2R** | | | | | | | | | | | | |
| **2003** | **P** | 91.128 | -0.6816 | 91.128 | 90.4464 | 84.312 | **6.8** | 13.523 | -0.0923 | 13.523 | 13.4307 | 12.6 | **6.2** |
| | **1R** | 112.97 | -0.0923 | 112.97 | 112.8777 | 112.047 | **0.7** | 18.461 | -0.0042 | 18.461 | 18.4568 | 18.419 | **0.2** |
| | **2R** | | | | | | | | | | | | |

**Appendix 5 - R-squared values for the regressions between yellow spot resistance and yield component for each FAT in northern Queensland (1999 and 2003 series; blank spaces occur where the r-squared <0.20)**

| Year | Trial | Babinda | | | Mulgrave 1 | | | Mulgrave 2 | | | Mourilyan 1 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CCS | TCH | TSH | CCS | TCH | TSH | CCS | TCH | TSH | CCS | TCH | TSH |
| 1999 | P | | | | | -0.44 | -0.49 | | | | | | |
| | 1R | 0.48 | | | | -0.38 | -0.22 | | | | | | |
| | 2R | | | | | | | | | | | | |
| 2003 | P | | | | | | | | | | | -0.26 | -0.40 |
| | 1R | | | | | | | | | | 0.21 | | |
| | 2R | | | | | | | | | | | | |

| Year | Trial | Mourilyan 2 | | | Tully | | |
|---|---|---|---|---|---|---|---|
| | | CCS | TCH | TSH | CCS | TCH | TSH |
| 1999 | P | 0.63 | -0.25 | | | -0.36 | -0.54 |
| | 1R | | -0.18 | | 0.21 | -0.57 | -0.69 |
| | 2R | | | | | | |
| 2003 | P | | | | | | |
| | 1R | | | | | | |
| | 2R | | | | -0.4 | | |

**Appendix 6 - Yield loss calculations for yellow spot in northern trials for 1999 and 2003 series trials (blank spaces occur where the r-square for the regression was <0.20)**

| Year | Trial | Babinda | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TCH | | | | | | TSH | | | | | |
| | | Intercept | M | 0 Rating | 1 rating | 9 rating | % loss | Intercept | M | 0 rating | 1 rating | 9 rating | % loss |
| 1999 | P | | | | | | 0.0 | | | | | | 0.0 |
| | 1R | | | | | | 0.0 | | | | | | 0.0 |
| | 2R | 101.3 | -2.49 | 101.3 | 98.81 | 76.4 | 22.7 | 17.9 | -0.545 | 17.9 | 17.355 | 12.45 | 28.3 |
| 2003 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |
| | 2R | | | | | | | | | | | | |

| Year | Trial | Mulgrave 1 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TCH | | | | | | TSH | | | | | |
| | | Intercept | M | 0 Rating | 1 rating | 9 rating | % loss | Intercept | M | 0 rating | 1 rating | 9 rating | % loss |
| 1999 | P | 84.7 | -1.71 | 84.7 | 82.99 | 67.6 | 18.5 | 12.2 | -0.191 | 12.2 | 12.009 | 10.29 | 14.3 |
| | 1R | 96.7 | -1.53 | 96.7 | 95.17 | 81.4 | 14.5 | 15.5 | -0.141 | 15.5 | 15.359 | 14.09 | 8.3 |
| | 2R | | | | | | | | | | | | |
| 2003 | P | | | | | | 0.0 | | | | | | 0.0 |
| | 1R | | | | | | | | | | | | 0.0 |
| | 2R | | | | | | | | | | | | |

| Year | Trial | Mulgrave 2 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TCH | | | | | | TSH | | | | | |
| | | Intercept | M | 0 Rating | 1 rating | 9 rating | % loss | Intercept | M | 0 rating | 1 rating | 9 rating | % loss |
| 1999 | P | | | | | | 0.0 | | | | | | 0.0 |
| | 1R | | | | | | 0.0 | | | | | | 0.0 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2R | | | | | 0.0 | | | | | | | 0.0 |
| 2003 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |
| | 2R | | | | | | | | | | | | |

| Year | Trial | Mourilyan 1 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TCH | | | | | | TSH | | | | | |
| | | Intercept | M | 0 Rating | 1 rating | 9 rating | % loss | Intercept | M | 0 rating | 1 rating | 9 rating | % loss |
| 1999 | P | | | | | | 0.0 | | | | | | 0.0 |
| | 1R | | | | | | 0.0 | | | | | | 0.0 |
| | 2R | | | | | | 0.0 | | | | | | 0.0 |
| 2003 | P | | | | | | | | | | | | |
| | 1R | | | | | | 0.0 | | | | | | 0.0 |
| | 2R | | | | | | | | | | | | |

| Year | Trial | Mourilyan 2 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TCH | | | | | | TSH | | | | | |
| | | Intercept | M | 0 Rating | 1 rating | 9 rating | % loss | Intercept | M | 0 rating | 1 rating | 9 rating | % loss |
| 1999 | P | 99.2 | -2.6 | 99.2 | 96.6 | 73.2 | 24.2 | | | | | | 0.0 |
| | 1R | 88.1 | -0.476 | 88.1 | 87.624 | 83.34 | 4.9 | | | | | | 0.0 |
| | 2R | | | | | | 0.0 | | | | | | 0.0 |
| 2003 | P | | | | | | 0.0 | | | | | | |
| | 1R | | | | | | 0.0 | | | | | | |
| | 2R | | | | | | | | | | | | |

| Year | Trial | Tully | | | | | | TCH | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Intercept | M | 0 Rating | 1 rating | 9 rating | % loss | Intercept | M | 0 rating | 1 rating | 9 rating | % loss |
| 1999 | P | 76.9 | -1.94 | 76.9 | 74.96 | 57.5 | 23.3 | 11.2 | -0.252 | 11.2 | 10.948 | 8.68 | 20.7 |
| | 1R | 118.3 | -3.44 | 118.3 | 114.86 | 83.9 | 27.0 | 18.5 | -0.457 | 18.5 | 18.043 | 13.93 | 22.8 |
| | 2R | | | | | | | | | | | | |
| 2003 | P | | | | | | | | | | | | |
| | 1R | 126.5 | -1.89 | 126.5 | 124.61 | 107.6 | 13.7 | 22.1 | -0.414 | 22.1 | 21.686 | 17.96 | 17.2 |
| | 2R | | | | | | 0.0 | | | | | | |

## Appendix 7 - Yield loss calculations for yellow spot using average northern trial data for 1999 and 2003

| Year | Trial | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Northern | | | | | | | | | | | |
| | TCH | | | | | | | TSH | | | | |
| | | Intercept | M | 0 Rating | 1 rating | 9 rating | % loss | Intercept | M | 0 rating | 1 rating | 9 rating | % loss |
| **1999** | **P** | 86.004 | -1.4852 | 86.004 | 84.5188 | 71.152 | **15.8** | 11.87 | -0.1491 | 11.87 | 11.7209 | 10.379 | **11.4** |
| | **1R** | 93.738 | -1.2306 | 93.738 | 92.5074 | 81.432 | **12.0** | 15.087 | -0.1344 | 15.087 | 14.9526 | 13.743 | **8.1** |
| **2003** | **P** | 83.74 | 0.0606 | 83.74 | 83.8006 | 84.346 | **-0.7** | 13.596 | -0.0702 | 13.596 | 13.5258 | 12.894 | **4.7** |
| | **1R** | 111.12 | -1.3707 | 111.12 | 109.7493 | 97.413 | **11.2** | 18.27 | -0.2191 | 18.27 | 18.0509 | 16.079 | **10.9** |

**Appendix 8 - R-squared values for the regressions between orange rust resistance and yield component for each FAT in northern Queensland (1999 and 2003 series; blank spaces occur where the r-square for the regression <0.20)**

| Year | Trial | Babinda | | | Mulgrave 1 | | | Mulgrave 2 | | | Mourilyan 1 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CCS | TCH | TSH | CCS | TCH | TSH | CCS | TCH | TSH | CCS | TCH | TSH |
| 1999 | P | -0.38 | | -0.22 | | -0.73 | -0.61 | -0.2 | | -0.33 | | | |
| | 1R | | -0.47 | -0.49 | 0.22 | -0.20 | | 0.24 | -0.44 | -0.35 | | | |
| | 2R | | -0.72 | -0.70 | | | | 0.3 | -0.45 | -0.37 | | | |
| 2003 | P | | | | | | | | | | | -0.26 | -0.40 |
| | 1R | | | | | | | | | | 0.22 | | |
| | 2R | 0.76 | -0.89 | -0.83 | | | | | | | | | |

| Year | Trial | Mourilyan 2 | | | Tully | | |
|---|---|---|---|---|---|---|---|
| | | CCS | TCH | TSH | CCS | TCH | TSH |
| 1999 | P | | | | -0.23 | | |
| | 1R | | -0.37 | | | | |
| | 2R | | | | | | |
| 2003 | P | | | | | | |
| | 1R | | | | | | |
| | 2R | | | | | 0.32 | 0.43 |

**Appendix 9 - Yield loss calculations for orange rust for northern trials for the 1999 and 2003 series (blank spaces occur where the r-square for the regression <0.20)**

| Year | Trial | Babinda | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TCH | | | | | | TSH | | | | | |
| | | Intercept | M | 0 Rating | 1 rating | 9 rating | % loss | Intercept | M | 0 rating | 1 rating | 9 rating | % loss |
| 1999 | P | | | | | | **0.0** | 9.1 | -0.131 | 9.1 | 8.969 | 7.79 | **13.1** |
| | 1R | 70.7 | -1.94 | 70.7 | 68.76 | 51.3 | **25.4** | 11.2 | -0.272 | 11.2 | 10.928 | 8.48 | **22.4** |
| | | | | | | | **0.0** | | | | | | |
| 2003 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |
| | | 74.3 | -2.82 | 74.3 | 71.48 | 46.1 | **35.5** | 10.9 | -0.358 | 10.9 | 10.542 | 7.32 | **30.6** |

| Year | Trial | Mulgrave 1 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TCH | | | | | | TSH | | | | | |
| | | Intercept | M | 0 Rating | 1 rating | 9 rating | % loss | Intercept | M | 0 rating | 1 rating | 9 rating | % loss |
| 1999 | P | 78.8 | -1.78 | 78.8 | 77.02 | 61 | **20.8** | 11.8 | -0.276 | 11.8 | 11.524 | 9.04 | **21.6** |
| | 1R | 99.5 | -3.64 | 99.5 | 95.86 | 63.1 | **34.2** | 17 | -0.606 | 17 | 16.394 | 10.94 | **33.3** |
| | | | | | | | | | | | | | |
| 2003 | P | | | | | | **0.0** | | | | | | **0.0** |
| | 1R | | | | | | | | | | | | **0.0** |

| Year | Trial | Mulgrave 2 TCH | | | | | | TSH | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Intercept | M | 0 Rating | 1 rating | 9 rating | % loss | Intercept | M | 0 rating | 1 rating | 9 rating | % loss |
| 1999 | P | | | | | | 0.0 | 14 | -0.224 | 14 | 13.776 | 11.76 | 14.6 |
| | 1R | | | | | | 0.0 | | | | | | 0.0 |
| | | | | | | | 0.0 | | | | | | 0.0 |
| 2003 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |

| Year | Trial | Mourilyan 1 TCH | | | | | | TSH | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Intercept | M | 0 Rating | 1 rating | 9 rating | % loss | Intercept | M | 0 rating | 1 rating | 9 rating | % loss |
| 1999 | P | | | | | | 0.0 | | | | | | 0.0 |
| | 1R | | | | | | | | | | | | 0.0 |
| | | | | | | | 0.0 | | | | | | 0.0 |
| 2003 | P | | | | | | | | | | | | 0.0 |
| | 1R | | | | | | 0.0 | | | | | | 0.0 |

| Year | Trial | Mourilyan 2 TCH | | | | | | TSH | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Intercept | M | 0 Rating | 1 rating | 9 rating | % loss | Intercept | M | 0 rating | 1 rating | 9 rating | % loss |
| 1999 | P | | | | | | 0.0 | | | | | | 0.0 |
| | 1R | 87.7 | -1.1 | 87.7 | 86.6 | 76.7 | 11.4 | | | | | | 0.0 |
| | | | | | | | 0.0 | | | | | | 0.0 |
| 2003 | P | | | | | | | | | | | | |
| | 1R | 86.5 | -1.86 | 86.5 | 84.64 | 67.9 | 19.8 | 13.5 | -0.239 | 13.5 | 13.261 | 11.11 | 16.2 |

| Year | Trial | Tully | | | | | TCH | | | | | | TSH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Intercept | M | 0 Rating | 1 rating | 9 rating | % loss | Intercept | M | 0 rating | 1 rating | 9 rating | % loss |
| **1999** | **P** | | | | | | **0.0** | | | | | | **0.0** |
| | **1R** | | | | | | **0.0** | | | | | | **0.0** |
| **2003** | **P** | | | | | | | | | | | | |
| | **1R** | 65.9 | 2.44 | 65.9 | 68.34 | 90.3 | **-32.1** | 9.6 | 0.411 | 9.6 | 10.011 | 13.71 | **-36.9** |

## Appendix 10 - Yield loss calculations for orange rust using average central trial data for 1999 and 2003 series

| Year | Trial | Central Average TCH | | | | | | TSH | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Intercept | M | 0 Rating | 1 rating | 9 rating | % loss | Intercept | M | 0 rating | 1 rating | 9 rating | % loss |
| **1999** | **P** | 98.662 | -4.4804 | 98.662 | 94.1816 | 53.858 | **42.8** | 16.235 | -0.7902 | 16.235 | 15.4448 | 8.333 | **46.0** |
| | **1R** | 99.401 | -1.5483 | 99.401 | 97.8527 | 83.918 | **14.2** | 15.127 | -0.1517 | 15.127 | 14.9753 | 13.61 | **9.1** |
| **2003** | **P** | 66.875 | 0.4546 | 66.875 | 67.3296 | 71.421 | **-6.1** | 10.59 | 0.1324 | 10.59 | 10.7224 | 11.914 | **-11.1** |
| | **1R** | 65.745 | -0.0404 | 65.745 | 65.7046 | 65.341 | **0.6** | 11.249 | 0.0514 | 11.249 | 11.3004 | 11.763 | **-4.1** |

**Appendix 11 - R-squared values for the regressions between orange rust resistance and yield component for each FAT in central Queensland (1999 and 2003 series; blank spaces occur where the r-square for the regression <0.20)**

| Year | Trial | Farleigh | | | Marian | | | Pleystowe | | | Racecourse | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CCS | TCH | TSH | CCS | TCH | TSH | CCS | TCH | TSH | CCS | TCH | TSH |
| 1999 | P | | -0.66 | -0.62 | | -0.45 | -0.46 | | -0.72 | -0.71 | -0.56 | | -0.53 |
| | 1R | -0.39 | -0.46 | -0.36 | -0.26 | | | -0.65 | -0.61 | -0.51 | -0.41 | | |
| 2003 | P | | | | | | | | | | | | |
| | 1R | 0.24 | | | 0.68 | 0.77 | 0.74 | | | | 0.23 | 0.25 | |
| | | Plane Creek | | | Proserpine | | | | | | | | |
| | | CCS | TCH | TSH | CCS | TCH | TSH | | | | | | |
| 1999 | P | | -0.28 | | | -0.39 | -0.45 | | | | | | |
| | 1R | | -0.69 | -0.53 | | | | | | | | | |
| 2003 | P | | | | -0.66 | | | | | | | | |
| | 1R | | | | | 0.72 | 0.85 | | | | | | |

**Appendix 12 - Yield loss calculations for orange rust using data from each trials in the central district for 1999 and 2003 series trials (blank spaces occur where the r-square for the regression <0.20)**

| Year | Trial | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Farleigh | | | | | | | | | | | |
| | TCH | | | | | | TSH | | | | | |
| | | Intercept | M | 0 Rating | 1 rating | 9 rating | % loss | Intercept | M | 0 rating | 1 rating | 9 rating | % loss |
| 1999 | P | 122.88 | -7.541 | 122.88 | 115.339 | 47.47 | **58.8** | 19.479 | -1.209 | 19.479 | 18.27 | 7.389 | **59.6** |
| | 1R | 141.71 | -4.231 | 144.71 | 140.479 | 102.4 | **27.1** | 22.69 | -0.5959 | 22.69 | 22.0941 | 16.731 | **24.3** |
| 2003 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |

| Year | Trial | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Marian | | | | | | | | | | | |
| | TCH | | | | | | TSH | | | | | |
| | | Intercept | M | 0 Rating | 1 rating | 9 rating | % loss | Intercept | M | 0 rating | 1 rating | 9 rating | % loss |
| 1999 | P | 96.421 | -3.1009 | 96.421 | 93.3201 | 65.412 | 29.9 | 15.459 | -0.514 | 15.459 | 14.945 | 10.319 | 31.0 |
| | 1R | | | | | | | | | | | | |
| 2003 | P | | | | | | | | | | | | |
| | 1R | 44.636 | 2.265 | 44.636 | 46.901 | 67.286 | -43.5 | 7.0076 | 0.4481 | 7.0076 | 7.4557 | 11.4886 | -54.1 |

| Year | Trial | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pleystowe | | | | | | | | | | | |
| | TCH | | | | | | TSH | | | | | |
| | | Intercept | M | 0 Rating | 1 rating | 9 rating | % loss | Intercept | M | 0 rating | 1 rating | 9 rating | % loss |
| 1999 | P | 63.693 | -3.9092 | 63.693 | 59.7838 | 24.601 | **58.9** | 10.395 | -0.6372 | 10.395 | 9.7578 | 4.023 | **58.8** |
| | 1R | 106.28 | -2.5167 | 106.28 | 103.7633 | 81.113 | **21.8** | 17.406 | -0.3114 | 17.406 | 17.0946 | 14.292 | **16.4** |
| 2003 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |

| Year | Trial | Racecourse | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TCH | | | | | | TSH | | | | | |
| | | Intercept | M | 0 Rating | 1 rating | 9 rating | % loss | Intercept | M | 0 rating | 1 rating | 9 rating | % loss |
| 1999 | P | | | | | | | 17.815 | -0.5946 | 17.815 | 17.2204 | 11.869 | **31.1** |
| | 1R | | | | | | | | | | | | |
| 2003 | P | | | | | | | | | | | | |
| | 1R | 65.029 | -0.8257 | 65.029 | 64.2033 | 56.772 | **11.6** | | | | | | |

| Year | Trial | Plane Creek | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TCH | | | | | | TSH | | | | | |
| | | Intercept | M | 0 Rating | 1 rating | 9 rating | % loss | Intercept | M | 0 rating | 1 rating | 9 rating | % loss |
| 1999 | P | 104.65 | -2.3628 | 104.65 | 102.2872 | 81.022 | **20.8** | | | | | | |
| | 1R | 102.49 | -2.8447 | 102.49 | 99.6453 | 74.043 | **25.7** | 14.382 | -0.4621 | 14.382 | 13.9199 | 9.761 | **29.9** |
| 2003 | P | | | | | | | | | | | | |
| | 1R | | | | | | | | | | | | |

| Year | Trial | Proserpine | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TCH | | | | | | TSH | | | | | |
| | | Intercept | M | 0 Rating | 1 rating | 9 rating | % loss | Intercept | M | 0 rating | 1 rating | 9 rating | % loss |
| 1999 | P | 81.054 | -2.9377 | 81.054 | 78.1163 | 51.677 | **33.8** | 13.509 | -0.4649 | 13.509 | 13.0441 | 8.86 | **32.1** |
| | 1R | | | | | | | | | | | | |
| 2003 | P | | | | | | | | | | | | |
| | 1R | 74.468 | 3.8249 | 74.468 | 78.2929 | 112.717 | **-44.0** | 12.497 | 0.7185 | 12.497 | 13.2155 | 19.682 | **-48.9** |