Research reports

Costs of major pests and diseases to the Australian sugar industry

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Summary

An estimate of the annual control and production loss costs attributable to major sugarcane pests and diseases in the Australian sugar industry was calculated using pest and disease incidence data derived from Cane Protection and Productivity Board surveys and published empirical sugarcane disease loss relationships.

The total cost of major diseases and pests in the 1996 crop was $111m. Pest and disease control costs accounted for 9% of the total cost estimate, and largely comprised insecticides used to control canegrubs in northern and southern cane growing areas. Of the major pests and diseases considered, soil-borne pathogens were estimated to cause the most substantial cost of $83m. The next most important pest and diseases were canegrubs ($11.1m), ratoon stunting disease ($6.3m) and sugarcane rust ($3.6m).

Introduction

Sugarcane is grown along the eastern coast of Australia, across an area from northern New South Wales to far north Queensland, and also in the Ord River irrigation area of Western Australia. The industry had a total gross return of $1.85 billion dollars in 1996 (ABARE 1996). A substantial proportion of Australian sugar is exported and the industry has grown significantly over the last five years.

Sugarcane diseases, along with vertebrate and insect pests, continue to be important threats to the productivity of sugarcane grown in all Australian production regions. There have been numerous reports outlining the potential impact of canegrubs (Bull 1986, Bull and Allsopp 1988, Chandler *et al.* 1993, Allsopp *et al.* 1995), soil borne pathogens (Magarey *et al.* 1995), ratoon stunting disease (Dominiak *et al.* 1992), rodents (Wilson 1989), and other sugarcane pests (Allsopp *et al.* 1993). Traditionally, the control of pests and diseases has centred around the application of pesticides, disease-free planting material and breeding of disease-resistant sugarcane cultivars.

Over recent years there has been increasing attention to the development of bio-insecticides (Dall *et al.* 1995), integrated pest management techniques (Allsopp *et al.* 1995), and crop rotations (Garside *et al.* 1995) to combat these constraints. Costs of pests have been estimated for Queensland by Cane Protection and Productivity Board (CPPB) (1997), the costs of soil-borne disease constraints were noted by Magarey *et al.* (1995) and the economic impact of ratoon stunting disease (RSD) in the Herbert River district was assessed by Croft *et al.* (1995b). There has, however, been no systematic industry-wide cost assessment of the broad range of pest and diseases which threaten productivity of the industry.

In this paper the costs of control and associated production losses for major pests and diseases were calculated using CPPB (1997) data, estimates of disease and pest incidence in New South Wales (NSW) and published disease loss relationships. The study was conducted to gauge the relative importance of major pests and diseases, determine regional pest and disease priorities, and identify areas for future research, development and extension programmes.

Methods and materials

There are CPPB personnel based in all mill districts of the Queensland sugar industry. As part of routine activity, CPPB officers survey the causes of crop failure, monitor pesticide usage and provide disease-free planting material. At the end of the growing season, officers report pest-related production loss costs, costs associated with pesticide usage and disease incidence in each region. These findings are summarized in the annual CPPB conference proceedings report, such as CPPB (1997) for the 1996 crop.

Published empirical disease yield loss relationships and estimates of pest and disease incidence in NSW were incorporated with CPPB (1997) data to generate industry wide production losses for major pests and diseases. Assumptions we used throughout this costing study to estimate the value of production losses and control costs are outlined in the areas affected, yield loss, unit price and control cost parts of the methods section.

Pest and disease costs were estimated for the northern (Mossman-Ingham), Burdekin, central (Mackay) and southern (Bundaberg-NSW) sugar production regions. Each of these regions have different climatic conditions, farming practices, and are subject to varying pest and disease constraints. Costs are not estimated for the Ord River area, as this production area represented a small percentage of the 1996 Australian crop.

Areas affected

The areas of Queensland sugarcane affected by canegrubs (primarily *Dermolepida albohirtum*, *Lepidiota consobrina*, and *Lepidiota frenchi* in northern, Burdekin and central areas, *Lepidiota negatoria* and *Antitrogus parvulus* in the south), rodents (*Rattus sordidus*), and pigs were documented in CPPB (1997). Pests are only a minor cause of production loss in NSW, and damage was estimated for rhopaea canegrubs (*Rhopaea magnicornis*) in selected growing areas. McGuire (personal communication) estimated that 1422 ha in NSW were affected by the grub in the 1996 growing season.

The areas in Queensland that were subject to infection by ratoon stunting disease (RSD), rust and chlorotic streak during 1996 were outlined by CPPB (1997). RSD is a major disease of sugarcane grown in NSW. A study investigating RSD prevalence in NSW (Roach *et al.* 1992) found that, on average, between 21–38% of sugarcane samples taken from the field were RSD positive. Following the results of this study, RSD was assumed to affect 30% of farms in NSW.

The incidence of soil-borne pathogens is not reported on an annual basis for Queensland or NSW production areas. Field trials by Magarey and Croft (1995) indicated that soils in 13 different sites throughout Queensland contained pathogens that retarded the productive capacity of sugarcane. A range of pathogens, which include *Pythium* spp. and *Pachymetra chaunorhiza*, restrict sugarcane growth. Numerous other unidentified species have been implicated in the complex of soil-borne pathogens and are the subject of on-going research (Magarey *et al.* 1995). Given the widespread incidence of the complex, we assumed that soil pathogens caused a reduction in sugarcane production across all growing areas in 1996.

Yield losses

The yield losses in Queensland sugarcane caused by canegrubs, rodents, wallabies and other pests were documented in CPPB (1997) (Table 1). In addition to canegrub losses in Queensland, rhopaea canegrub were estimated to cause production losses across selected areas of the NSW industry. These grubs were assumed to cause a 20% yield loss (tonnes cane ha^{-1}) in affected sugarcane. Studies of other canegrub species, such as greyback canegrub (*D. albohirtum*) (Chandler *et al.* 1993), southern one-year canegrub (*Antitrogus consanguineus*) (Bull 1986), and noxia canegrub (*Lepidiota noxia*) (Bull and Allsopp 1988), found that yield losses of this magnitude could be expected in sugarcane subject to infestation.

Infection by RSD reduces the productive capacity of the sugarcane plant as the causal bacterium, *Clavibacter xyli* subsp. *xyli*, limits xylem activity. Productivity losses vary according to prevailing environmental conditions and susceptibility of sugarcane cultivars. A range of studies has documented losses as a result of infection. Steindl (1961) recorded losses of 10–25% (tonnes cane ha^{-1}) in differing sugarcane crops, with crop age being the major factor influencing yield losses. In Florida, losses of 5–7% (tonnes cane ha^{-1}) (Irey 1986, Dean and Davis 1989) have been observed, while in South Africa yield losses averaged 21% (tonnes cane ha^{-1}) in a trial that involved eight cultivars (Bailey and Bechet 1986). An average yield loss of 15% (tonnes cane ha^{-1}) was included in our study, as this estimate was used by Croft *et al.* (1995a) to value the economic loss associated with RSD infection in Australia.

Chlorotic streak is a disease that affects sugarcane grown in wet conditions. The causal pathogen has not been identified, but the disease causes substantial yield losses. Under wet conditions, the disease reduced germination of the cultivars Q66, Q67 and Pindar by 10, 16 and 22%, respectively (Egan 1962). A recent trial described by Nielsen *et al.* (1986) found that a maximum yield loss of 24% (tonnes cane ha^{-1}) was evident in chlorotic streak affected sugarcane. Magarey and Croft (1998) indicated that the severity of losses depend on the resistance of a cultivar, and an average yield loss of 15% (tonnes cane ha^{-1}) was included in our costings.

There has been limited research into the yield losses associated with sugarcane rust (*Puccinia melanocephala*) infection of Australian sugarcane. Bernard (1980) indicated that yield losses associated with rust vary according with environmental

Table 1. Areas affected, average yield losses and total production losses for major pests and diseases in the 1996 Australian sugarcane crop.

	North (Mossman-Ingham)	Burdekin (Burdekin River districts)	Central (Mackay)	South (Bundaberg-NSW)	Total
Industry demographics					
Area harvested (ha)	134 637	64 387	112 680	87 274	398 978
Tonnes cane harvested (million t)	12.6	7.5	11.1	8.2	39.5
Average cane yield (t ha^{-1})	94	117	99	94	99
Canegrubs					
Area affected (ha)	1930	1585	175	2882	6572
Yield loss (t ha^{-1})	19	30	27	27	26
Loss of cane (tonnes)	37 070	48 180	4760	78 463	168 473
Pigs					
Area affected (ha)	1665	65	85	65	1880
Yield loss (t ha^{-1})	17	24	37	23	18
Loss of cane (tonnes)	27 790	1590	3150	1490	34 020
Ratoon stunting disease					
Area affected (ha)	5950	134	1140	6552	13 776
Yield loss (t ha^{-1})	14	18	15	14	14
Loss of cane (tonnes)	83 825	2356	16 929	92 489	195 598
Rust					
Area affected (ha)	10 350	1850	180	4350	16 730
Yield loss (t ha^{-1})	9	12	10	9	10
Loss of cane (tonnes)	97 208	21 685	1782	40 935	161 611
Chlorotic streak					
Area affected (ha)	5170	450	10	4405	10 035
Yield loss (t ha^{-1})	14	18	15	14	14
Loss of cane (tonnes)	72 836	7912	148	62 180	143 076
Soil-borne diseases					
Area affected (ha)	134 637	64 387	112 680	87 274	398 978
Yield loss (t ha^{-1})	8	11	9	8	9
Loss of cane (tonnes)	1 138 075	679 260	1 003 960	739 160	3 560 455

conditions and were estimated to cause 10–20% losses under good growing conditions. The productivity loss associated with this disease is very difficult to estimate because of the confounding effects of weather and interaction with varieties in differing locations. An average loss of 10% (tonnes cane ha^{-1}) was included for rust in our costing.

Soil pathogens also cause significant production losses. Numerous trials have found that there is a substantial yield increase in sugarcane after the soil has been fumigated with methyl bromide. An average yield increase of 18% (tonnes cane ha^{-1}) was recorded from 13 field trials outlined by Magarey and Croft (1995). The use of methyl bromide kills soil pathogens, along with releasing soil nitrogen and reducing weed competition. Following the yield increases observed in fumigation trials, 9% (tonnes cane ha^{-1}) yield loss was assumed to result from the activity of soil-borne pathogens.

Sugarcane price

Production loss costs (Table 2) were calculated by multiplying production losses by a unit price per tonne of lost sugarcane of \$20, \$27, \$23 and \$25 in the north, Burdekin, central and south, respectively. Unit prices were derived from CPPB (1997) production loss cost estimates and represents farm-gate cane price less harvesting costs. For the purposes of the analysis, the unit price for NSW cane farmers was assumed to be similar to that of southern Queensland. Production loss costs for rats were based on sugar losses, and taken from CPPB (1997).

Control costs

Growers control diseases by utilizing disease-free planting material, treating planting material with fungicide and by employing appropriate farm hygiene. To assess the use of fungicide in the Queensland industry, CPPB (1997) estimates of fungicide use in Queensland were incorporated in the costing framework. Fungicide is primarily employed to control pineapple disease (caused by *Ceratocytis paradoxa*). Magarey and Croft (1998) indicated that there have been no yield loss studies to assess the productivity loss associated with this disease, and therefore, production loss costs were not assessed. Approximately 79 343 ha, or 20% of the Queensland harvested area were treated with fungicide. Assuming a similar adoption of fungicide for NSW, approximately 3694 ha were estimated to be treated with fungicides, at an average cost of \$14 per hectare.

The use of hot-water treated or 'clean' planting material is a major strategy used by sugar farmers to prevent the spread of diseases. To estimate the cost of this practice, CPPB (1997) estimates of approved planting material usage in the 1996 crop were analysed. The additional cost of using clean seed was estimated to be $24 per hectare. This cost was derived from Croft *et al.* (1995a) and includes an allowance for CPPB operation of the disease-free seed plot, the purchase of disease-free planting material, labour associated with planting material collection and additional hygiene procedures. The utilization of clean planting material prevents the spread of numerous sugarcane diseases. Because RSD is generally regarded as the most serious disease that can be spread in untreated cane, the cost of clean planting material was incorporated in the RSD control cost.

Farm hygiene costs were derived from a study by Croft *et al.* (1995a) where the costs associated with thoroughly disinfecting harvesters were estimated to cost the grower $6 per harvested hectare. The adoption of this practice is not widespread in the industry and we assumed that 15% of the 1996 harvest was undertaken using sterile harvesters. Farm hygiene prevents the spread of numerous sugarcane diseases. Because RSD is generally regarded as the most serious disease that can be spread on farm machinery, the cost of hygiene was incorporated as an RSD control cost.

Growers use a number of insecticides to control canegrubs and in some areas baits are used to suppress rat populations. These costs were reported in CPPB (1997) and are included in Table 2. The development of disease resistant sugarcane varieties has been a major strategy utilized to overcome the impact of soil-borne pathogens. It is extremely difficult to ascertain the costs of the breeding program attributable to the breeding of soil-borne pathogen resistance, and this cost has not been included in the analysis.

Table 2. Major pest and disease control and production loss costs in the 1996 Australian sugar crop ($m).

	North (Mossman-Ingham)	Burdekin (Burdekin River districts)	Central (Mackay)	South (Bundaberg-NSW)	Total
Canegrubs					
Control	2.9	0.4	1.1	2.7	7.1
Damage	0.7	1.3	0.1	1.9	4.0
Combined cost	3.6	1.7	1.2	4.6	11.1
Rats					
Control	0.1	0.0	0.0	0.0	0.1
Damage	1.9	0.0	0.1	0.0	2.1
Combined cost	2.0	0.0	0.1	0.0	2.2
Pigs					
Control	0.0	0.0	0.0	0.0	0.0
Damage	0.6	0.0	0.1	0.0	0.7
Combined cost	0.6	0.0	0.1	0.0	0.7
Sub total – pests	**6.2**	**1.7**	**1.4**	**4.6**	**14.0**
RSD					
Control	0.5	0.3	0.6	0.4	1.8
Damage	1.7	0.1	0.4	2.3	4.5
Combined cost	2.2	0.4	1.0	2.7	6.3
Rust					
Control	0.0	0.0	0.0	0.0	0.0
Damage	2.0	0.6	0.0	1.0	3.6
Combined cost	2.0	0.6	0.0	1.0	3.6
Pineapple disease					
Control	0.4	0.3	0.2	0.2	1.1
Damage	0.0	0.0	0.0	0.0	0.0
Combined cost	0.4	0.3	0.2	0.2	1.1
Chlorotic streak					
Control	0.0	0.0	0.0	0.0	0.0
Damage	1.5	0.2	0.0	1.5	3.2
Combined cost	1.5	0.2	0.0	1.5	3.2
Soil borne					
Control	0.0	0.0	0.0	0.0	0.0
Damage	23.2	18.3	23.3	18.4	83.2
Combined cost	23.2	18.3	23.3	18.4	83.2
Sub total – diseases	29.3	19.8	24.5	23.8	97.4
Total	35.5	21.5	25.9	28.4	111.4

Results

Of the major pests and diseases assessed, soil-borne pathogens caused the highest loss of production (Table 1). The assumed widespread incidence of disease was largely responsible for the large volume of lost production. Approximately 3.6 million tonnes of sugarcane were estimated to be lost by the presence of soil-borne pathogens. This magnitude represents 9% of total industry production in 1996. The loss of production as a result of rodent infestation was reported on a loss of sugar basis, and the effect of these pests on sugarcane yields is not reported in Table 1. The value of rodent sugar losses are, however, included in Table 2 using CPPB (1997) data.

Ratoon stunting disease and canegrubs caused the next largest losses in sugarcane production. These curtailed production by 195 598 t and 168 473 t, respectively, in 1996. RSD losses were greatest for the southern region, combining the growing areas of southern Queensland and northern NSW. Surveys in northern NSW (Roach *et al.* 1995) have found that RSD incidence is widespread in this area. Canegrub losses were also most substantial in the southern production region. A number of canegrub species are endemic (Allsopp *et al.* 1993) in this region and losses can be severe where cane is not protected with controlled-release insecticides.

On a per hectare affected basis, production losses associated with canegrubs were greatest. The average yield loss in canegrub affected sugarcane was 26 (tonnes cane ha^{-1}), 18 (tonnes cane ha^{-1}) for pigs and 14 (tonnes cane ha^{-1}) for each of the diseases RSD and chlorotic streak. Average loss to canegrubs per affected hectare was highest in the Burdekin region. Chandler *et al.* (1993) reported that greyback grubs in the Burdekin have the potential to cause substantial losses, and an average loss of 30 tonnes of cane per infested hectare is estimated in Table 1.

The per hectare production losses related to disease infection were calculated to be lower than that of insect and vertebrate pests. Of the diseases analysed, RSD and chlorotic streak caused the most significant losses in affected crops. Despite having a lower impact on yield, soil-borne pathogens caused the greatest overall industry production losses. These diseases occurred across 398 978 hectares, or an area 29 times the size of the RSD affected area.

The pests and diseases which generated the highest sugarcane production losses also generated the most substantial combined control and production loss costs (Table 2).

Although soil-borne pathogens attracted insignificant control costs, the combined control and production loss costs of these diseases were the highest at $83m in 1996, which was eight times greater than the second most costly constraint, canegrubs.

The annual cost of canegrubs included substantial control and damage costs. CPPB (1997) estimated that $7.1m was spent on canegrub insecticides in 1996. The use of insecticides was greatest in the northern and southern regions, where damage costs were also the highest. The use of control measures to reduce rodent and pig damage were limited. Some chemical baits were distributed by farmers in the northern and central regions to control rodents, but this practice is not widespread.

Control measures only comprised a small proportion of disease and pest total costs. In 1996, control measures amounted to a total cost of $10m or 9% of the cost of major pests and diseases. Disease control costs were a minor component of total disease costs. The use of fungicide to control pineapple disease was $1.1m, and use of farm hygiene and clean planting material to reduce the spread of RSD was $1.8m. The breeding of disease resistant sugarcane cultivars is an ongoing area of research and development in the sugar industry. This cost was not included in the costing estimate.

Discussion

Soil-borne pathogens were estimated to be the most costly pest or disease, costing the industry $72.1m more than canegrubs, the second most economically significant constraint on production. In recognizing the importance of soil borne pathogens, the sugar industry is investing in research to further understand soil biology (Magarey *et al.* 1995), determine the potential for using alternate crops to manage soil pathogens and assess the scope for chemical control of the diseases (Garside *et al.* 1995).

The costs of pests and disease vary from year to year, presumably affected directly or indirectly by seasonal conditions, but the overall costs have increased only marginally during the 1990s. Over the past five years, the increase in production losses associated with canegrubs is perhaps the most significant trend. Most of this increase is attributable to increased damage by greyback canegrubs in the Burdekin region. Two factors appear to have caused this upturn, a general increase in numbers of the species during an outbreak section of long-term population cycles (Robertson *et al.* 1997), and deceased efficacy of the insecticide used for its control (Robertson *et al.* 1998). New management techniques are currently being developed to reduce this damage (Allsopp *et al.* 1995). Another important increase has been of damage caused by sugarcane weevil borer (*Rhabdoscelus obscurus*), associated with the increased adoption of trash-retention techniques in northern Queensland (Robertson and Webster 1995).

The impact of weeds has received limited attention in the sugar industry. Preliminary cost estimates provided by McLeod (1996) suggested that the combined control and production loss costs attributable to weeds was $62.7m in the 1996 crop. Trials outlined by McMahon (1989) have demonstrated that the failure to control weeds in the early stages of crop growth caused sugarcane yields to be reduced by 13–30%. Given the magnitude of the weed constraint, surveys and experiments that provide objective measures of the nature of this constraint should be undertaken.

To conclude, it should be noted that the annual costs of pests, weeds or diseases do not give an indication of the potential industry benefits that research designed to decrease the impact of these constraints would yield. A range of other parameters such as the probability of a pest or disease control project succeeding, magnitude of industry adoption of project results and the decrease in damage, need to be estimated. The potential impact of exotic diseases and pests on the sugar industry should also be analysed to highlight research that may not reduce current losses, but minimize future costs to the industry.

Cost-benefit evaluation is a process that incorporates these parameters to estimate the potential returns on investment. By assessing the scope for reducing the magnitude of pest, weed and disease costs, the potential industry benefits from targeted research and extension can be determined. Cost-benefit analysis has been widely used in other rural industries to help set research priorities and illustrate the potential benefits from research and technology transfer (Anderson and Parton 1983).

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References

Allsopp, P.G., Chandler, K.J., Samson, P.R. and Story, P.G. (1993). 'Pests of Australian sugarcane'. (BSES, Brisbane).

Allsopp, P.G., Robertson, L.N., Chandler, K.J. and Walker, P.W. (1995). Management of canegrubs: future directions. Proceedings Australian Society Sugar Cane Technologists Conference, pp. 88-97.

Anderson, J.R. and Parton, K.A. (1983). Techniques for guiding the allocation of resources among rural research projects: state of the art. *Prometheus*, pp. 180-201.

Australian Bureau of Agriculture and Research Economics (ABARE) (1996). Australian commodity statistics 1996, ABARE, Canberra.

Bailey, R.A. and Bechet, G. (1986). Effect of ratoon stunting disease on the yield and components of yield of sugarcane under rainfed conditions. Proceedings South African Society Sugar Cane Technologists Conference, pp. 143-7.

Bull, R.M. (1986). New chemicals for the control of canegrubs. Proceedings International Society Sugar Cane Technologists Conference, pp. 626-36.

Bull, R.M. and Allsopp, P.G. (1988). Control of *Lepidiota noxia* in southern Queensland. Proceedings Australian Society Sugar Cane Technologists Conference, pp. 26-9.

Bernard, F.A. (1980). Cane tonnage losses in B4362 due to rust disease in two areas with different climates. Proceedings First Inter-American Sugar Cane Seminar, Florida, pp. 65-7.

Cane Protection and Productivity Board. (1997). Summary of cane pest and disease data. Proceedings of Conference, Unpublished Report.

Chandler, K.J., McGuire, P.J., McMahon, G.G. and Schultz, R.J. (1993). Greyback canegrub control with suSCon Blue controlled release insecticide. Proceedings Australian Society Sugar Cane Technologists Conference, pp. 222-30.

Croft, B.J., Page, J.R., Bull, J.K. and Beattie, R.N. (1995a). Economic comparison of disease-free and cultivar resistance as control strategies for ratoon stunting disease of sugarcane in Australia. Unpublished Discussion Paper, BSES, Tully.

Croft B.J., Kerkwy, R. and Kauppila, N. (1995b). Widespread RSD incidence in the Herbert district. Proceedings Australian Society Sugar Cane Technologists Conference, pp. 116-22.

Dall, D., Lai-Fook, J., Robertson, L. and Walker, P. (1995). Micro-organisms associated with mortality in greyback grubs. Proceedings Australian Society Sugar Cane Technologists Conference, pp. 106-9.

Dean, J.L. and Davis, M.J. (1989). Yield loss caused by ratoon stunting disease of sugarcane in Florida. Proceedings American Society Sugar Cane Technologists Conference, pp. 66-72.

Dominiak, B.C., Sinnamon, L.R., Jones, C.D. and Taylor, P.W.J. (1992). RSD control in Bingera mill area and problems encountered. Proceedings Australian Society Sugar Cane Technologists Conference, pp. 37-42.

Egan, B.T. (1962). Results of chlorotic

streak trials in North Queensland. Proceedings Queensland Society Sugar Cane Technologists Conference, pp. 121-5.

Garside, A.L., Magarey, R.C. and Nable, R.O. (1995). Growth of different plant species in fumigated / sterilised and untreated sugarcane soils with varying cropping histories. Proceedings Australian Society Sugar Cane Technologists Conference, pp. 123-39.

Irey, M.S. (1986). Yield comparison of healthy and ratoon stunting disease infected cane of six commercial sugarcane cultivars in Florida. Proceedings American Society Sugar Cane Technologists Conference, pp. 24-31.

McMahon, G. (1989). Weeds reduce cane yield in early growth stage. BSES Bulletin 27, BSES, Brisbane.

McLeod, R.S. (1996). Annual costs of weeds, pests and diseases to the Australian sugar industry. Unpublished Consultants Report, Sugar Research and Development Corporation, Brisbane.

Magarey, R.C. and Croft, B.J. (1995). A review of root disease research in Australia. Proceedings International Society Sugar Cane Technologists Conference, pp. 505-13.

Magarey, R.C. and Croft, B.J. (1998). A review of yield losses caused by Australian and selected exotic sugarcane diseases. Proceedings Australian Society Sugar Cane Technologists Conference, pp. 76-84.

Magarey, R.C., Yip, H.Y., Bull, J.I. and Johnson, E.J. (1995). Recent studies into the biology of yield decline. Proceedings Australian Society Sugarcane Technologists Conference, pp. 128-33.

Nielsen, P.J., Kauppila, E.E. and Roach, B.T. (1986). An evaluation of the effect of chlorotic streak disease on sugarcane crops in the Herbert River district. Proceedings Australian Society Sugar Cane Technologists Conference, pp. 135-9.

Roach, B.T., Parsons, D.H. and Nielsen, P.J. (1992). Incidence and control of ratoon stunting disease in sugarcane in New South Wales. Proceedings Australian Society Sugar Cane Technologists Conference, pp. 43-50.

Robertson, L.N., Dall, D.J., Lai-Fook, J. and Kettle, C.G. (1997). Population dynamics of greyback canegrub (*Dermolepida albohirtum*) in north Queensland sugarcane (Scarabaeidae: Melolonthinae). *In* 'Soil Invertebrates in 1997', eds. P.G. Allsopp, D.J. Rogers and L.N. Robertson, pp. 140-144. (Bureau of Sugar Experiment Stations: Brisbane).

Robertson, L.N., Chandler, K.J., Stickley, B.D.A., Cocco, R.F. and Ahmetagic, M. (1998). Enhanced microbial degradation implicated in rapid loss of chlorpyrifos from the controlled-release formulation suSCon Blue in soil. *Crop Protection* 17, 29-33.

Robertson, L.N. and Webster, D.E. (1995). Strategies for managing cane weevil borer. Proceedings Australian Society of Sugar Cane Technologists Conference, pp. 83-7.

Steindl, D.R.L. (1961). Ratoon stunting disease. In 'Sugarcane diseases of the world', eds. J.P. Martin, E.V. Abbott and C.G. Hughes, pp. 433-59. (Elsevier, Amsterdam).

Wilson, J. (1989). 'Rodent management in sugarcane'. (BSES, Brisbane).