Managing yield decline in sugarcane cropping systems

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Sugar Yield Decline Joint Venture

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Abstract

This paper summarises the results from ten years of yield decline research carried out by the Sugar Yield Decline Joint Venture in the Australian sugar industry. The research concludes that, although the ultimate expression of yield decline may be through adverse effects of pathogens on sugarcane root systems, yield decline is a complex issue caused by a number of factors being out of balance in the sugarcane cropping system. Soil degradation has been the result of the long-term sugarcane monoculture and how it has been practiced. Specific research has shown that the long-term monoculture, uncontrolled traffic from heavy machinery and excessive tillage along with practices that deplete organic matter all contribute to yield decline. It is argued that changes to the cropping system that will conserve organic matter, break the monoculture, control traffic and minimize tillage are the most appropriate ways to combat yield decline. The technology is now available to incorporate these changes into the cropping system and a more sustainable, profitable and environmentally responsible cropping system is proposed. The proposed system is not prescriptive and many acceptable variations will be just as suitable providing the basic principles of organic matter conservation, breaking the monoculture, controlling traffic and minimizing tillage are no compromised.

Introduction

Yield decline is an issue that has plagued sugarcane production systems worldwide for more than half a century. Initially, yield decline was regarded as an apparent decline in the productive capacity of cane varieties due to genetic shift (Arceneaux and Hebert, 1943; Coleman, 1974). However, much of the recorded decline was subsequently related to ratoon stunting disease (King and Steindl, 1953) because no evidence of genetic shift within varieties was produced (Mangelsdorf, 1959; Moore *et al*., 1993).

In more recent times, yield decline has been clearly associated with soil degradation caused by the long-term monoculture of sugarcane and how that monoculture has been practiced. In the Australian sugar industry yield decline has been defined as… t*he loss of productive capacity of sugarcane growing soils under long-term monoculture* (Garside *et al*., 1997a). Yield decline appears to have been part of the Australian sugar industry for most of its history as declining yields under sugarcane monoculture were recorded as early as 1900 (Maxwell, 1900), while Bell (1935, 1938) attributed these declining yields to fertility decline and root pathogens . However, the impact of yield decline on an industry wide basis was not fully realized until a productivity plateau occurred from 1970 – 1990 (SRDC, 1995). It was thought that this productivity plateau was largely due to the intensification of the monoculture brought about by the removal of assignment restrictions during the 1970's (Wegener, 1985), which promoted the adoption of a plough-out/re-plant system at the expense of fallowing. Previously, growers had only been able to harvest 75% of their assigned area in any one year and had, by default, been forced into fallowing 25% of their land, usually with a legume for green manuring.

Concomitant with the increase in plough-out/re-plant was the emergence of the sugarcane root disorder, poor root syndrome (Egan *et al*., 1984). Studies into the cause of this disorder focused on pathogenic fungi and resulted in the isolation of the root pathogen *Pachymetra chaunorhiza* as one of the causes. Yield increases of up to 40% were recorded in *Pachymetra* resistant varieties (Magarey, 1994). Even greater yield increases (> 100%) were recorded when long-term sugarcane soil was fumigated with methyl bromide (Croft *et al*., 1984). However, when *Pachymetra* resistant and susceptible varieties were grown on fumigated and non-fumigated sugarcane soil the resistant variety out yielded the susceptible variety but still showed a 36% response to fumigation, clearly indicating there was more than *Pachymetra* associated with the disorder (A.P. Hurney, unpublished data). However, a subsequent research program aimed at isolating other pathogens met with limited success (Magarey *et al*., 1995). Regardless, there was little doubt that soil biological factors were an important component of yield decline.

On careful examination of changes to the sugarcane production system in Australia in the 1960's and 1970's it becomes clear that components of the system, other than monoculture intensification, also changed during that period. For example, there was substantial expansion onto poorer quality land, mechanical harvesting and haul-out with heavy machinery traversing paddocks became accepted practice, more ratoons were grown, machinery became available to more intensively cultivate the soil, and there was a substantial increase in the use of nitrogen fertilizer.

The Sugar Yield Decline Joint Venture (SYDJV) was established in 1993 to research the issue of yield decline, and although previous studies had indicated that root pathogens were involved (Magarey and Croft, 1995), the group was given a much wider charter than specifically investigating root pathogens. Further, it was essential to know whether yield decline was associated with a single species being grown for long periods, the cultural practices employed to grow it, or a combination of both.

The SYDJV started with the premise that the issue was complex and most likely associated with a number of soil properties being degraded and/or out of balance in the cropping system. This paper summarises the approach taken to investigate the issue, the results of over a decade of research and development by the SYDJV, and demonstrates how those outcomes are being used to reduce the impact of yield decline and develop a more sustainable, profitable and environmentally responsible sugarcane cropping system.

Identifying degraded soil properties: Evaluation of paired old and new land sites

Initial studies within the SYDJV involved the evaluation of paired old (grown sugarcane for at least 20 years under a burnt cane system) and new (virgin land or first year under sugarcane) land sites to identify differences in soil properties. Essentially the results showed that old sugarcane land was degraded in chemical (Bramley *et al*., 1996; Skjemstad *et al*., 1995), physical (Ford and Bristow, 1995 a, b) and biological (Holt and Mayer, 1998; Pankhurst *et al*., 1996; Magarey *et al*., 1997) properties, although soil property differences varied between sites in line with soil type, climate and management. Further, cane yields were lower on old land (Garside and Nable, 1996; Garside *et al*., 1997b). The main soil factors varying between old and new land were summarized by Garside *et al*. (1997b). These factors included old land being more acid, having lower levels of organic carbon, lower cation exchange capacity, more exchangeable aluminium, lower levels of copper and zinc, more plant parasitic nematodes, more root pathogens, less microbial biomass, greater soil strength (more compacted) and lower water infiltration rate and storage capacity. The number of diverse factors that emerged as being degraded in long-term sugarcane land clearly suggested that, overall, soil degradation was the cause of yield decline, the problem was complex and would not be overcome unless all the factors were addressed to some extent. The likelihood of making major gains by tackling these properties individually, as had traditionally been done in the sugar industry, was daunting and unlikely to provide practical solutions. The approach taken by the SYDJV was to investigate how the system might be improved in a practical way, and in so doing have a positive effect on degraded soil properties. It was decided that if the monoculture could be broken (rotations or break species), excessive tillage reduced for plant cane establishment (minimum/zero-tillage) and heavy traffic (harvester, haul-out) isolated from cropping rows thus reducing compaction (controlled traffic) there would be a good chance of improving the cropping system. Initially, experiments in these three areas were carried out separately. Prior to the commencement of the SYDJV the traditional system of burning cane prior to harvest was being questioned as an appropriate practice and green cane harvesting leaving a trash blanket (GCTB) was being established in some areas as an accepted practice. The inclusion of GCTB into the cropping system appears to have arrested the downward trend in organic matter levels, at least in the surface soil (Wood 1986, 1991).

Research on components of the cropping system

Green cane trash blanketing

The Australian sugar industry was based on a burnt cane harvesting system from the 1930's in order to protect cane cutters from Weils disease caused by *Leptospirosis* found in rat urine in green cane systems. The advent of large scale mechanical harvesting in the 1970's substantially reduced exposure to *Leptospirosis* and the need to burn became less necessary. Although some growers on the wet tropical coast started experimenting with a green cane trash blanket (GCTB) system because of concerns with soil degradation and productivity decline (Wood, 1985) the large majority only started to embrace the concept during a period of low rainfall and low prices in the mid-1980's (Wood, 1991). Regardless of the initial motives for adopting GCTB, substantial improvements in profitability through labour and cost savings, reduced tillage and less crop loss under wet harvesting conditions have been obvious benefits of the change (Smith, 1993). In addition to these practical benefits other identified benefits include improvements in soil organic matter, nutrient retention, more biodiversity, soil water retention and reduced costs of weed and insect control (Garside *et al*., 1997a). Tillage has now virtually disappeared from the system for ratoon cane production since GCTB has become established.

Historically, GCTB had a rather checkered entrance into the sugarcane production system. Many benefits in terms of improvements in soil properties and logistical considerations were identified, but initial yield results were variable with many comparisons with burnt cane systems confounded by a range of factors that biased results in one direction or the other. Further, growers expressed concerns regarding productivity declines, harvesting difficulties and the need to change cropping practices and these concerns slowed the transition from a burnt cane system to GCTB (Norrish, 1996). However, there is now little doubt that GCTB is well established in the industry and benefits are accruing, both in terms of productivity and sustainability, as growers become more skilled in managing green cane. Almost 80% of the Australian industry now cuts green and that number is increasing annually. It is interesting to speculate as to what productivity and sustainability may have been achieved directly from the GCTB system had it been allowed to develop steadily and been carefully monitored for changes in soil properties. Possibly, at least some of the degraded soil properties measured in the initial SYDJV paired site studies discussed above may not have been major issues in an established GCTB system. The studies by Wood (1985, 1986, 1991) suggest this is likely to have been the case.

Breaking the monoculture

Long and short-term rotation experiments aimed at breaking the monoculture and measuring the effect on sugarcane growth and yield were initiated by the SYDJV in 1993 and 1994. When the rotation experiments were returned to sugarcane large yield improvements (20 – 30%) were recorded from breaking the monoculture with legume crops, such as soybeans or peanuts, pasture and bare fallow (Garside *et al*., 1999, 2000a, 2001, 2002a). These yield increases were associated with improvements in chemical (Moody *et al*., 1999) physical (Braunack *et al*., 2003) and biological (Stirling *et al*., 1996, 1999, 2001; Pankhurst *et al*., 1999, 2000, 2003) soil properties, particularly the latter. Since the results of these rotation experiments have emerged there has been a substantial increase in the area planted to well managed legume crops in the sugar industry. As well as conducting these rotation experiments the SYDJV carried out research into the most suitable legume species to rotate with sugarcane and the best management practices to maximize the benefits from those legumes (Garside and Bell, 2001). Traditional legume fallows were poorly managed cowpea crops that suffered from poor establishment, severe weed competition, waterlogging, and root diseases (Croft 1988, Garside *et al*., 1996). Legumes provide both a source of fixed nitrogen (a good soybean crop negating the need for any inorganic nitrogen fertilizer in the plant crop) and improvements in soil health (Garside *et al*., 1996, 1997c, 1998; Noble and Garside, 2000; Garside and Bell, 2001). The nitrogen benefits can be maximized if the legume is surface mulched as opposed to traditional incorporation as the nitrogen is mineralized more slowly and thus more is available when needed by the following sugarcane crop (Garside *et al*., 1997c; Noble and Garside, 2000; Bell *et al*., 2003; Garside and Berthelsen, 2004). Further, there is increasing interest in developing crops like soybean and peanuts as complimentary cash crops in the sugarcane cropping system (Bell *et al*., 1998).

When each of eight long-term rotation experiments was returned to sugarcane the effect of the breaks was compared with continual sugarcane monoculture and continual sugarcane monoculture where the soil was fumigated with methyl bromide between sugarcane crops (Garside *et al*., 1999, 2000a, 2002a; Bell *et al*., 2000). In most instances these experiments were carried into the ratoons. In general, the highest yields were obtained from the longest duration breaks although short breaks of only six months produced substantial yield increases. Further, there was an overall trend for pasture breaks to provide a greater yield response than cropping breaks which in turn provided a greater response than bare fallows (Garside *et al*., 1999, 2000a, 2002a). The reasons for these different responses are unclear but they may be associated with the effects of different management practices in terms of tillage and organic matter inputs. Land was conventionally prepared between cropping breaks (tillage, plant growth and organic matter input), managed by periodic mowing and leaving the residue on the surface with the pasture breaks (no tillage, plant growth and organic matter input), and managed with herbicides in the bare fallow (no tillage, no plant growth and no organic matter input).

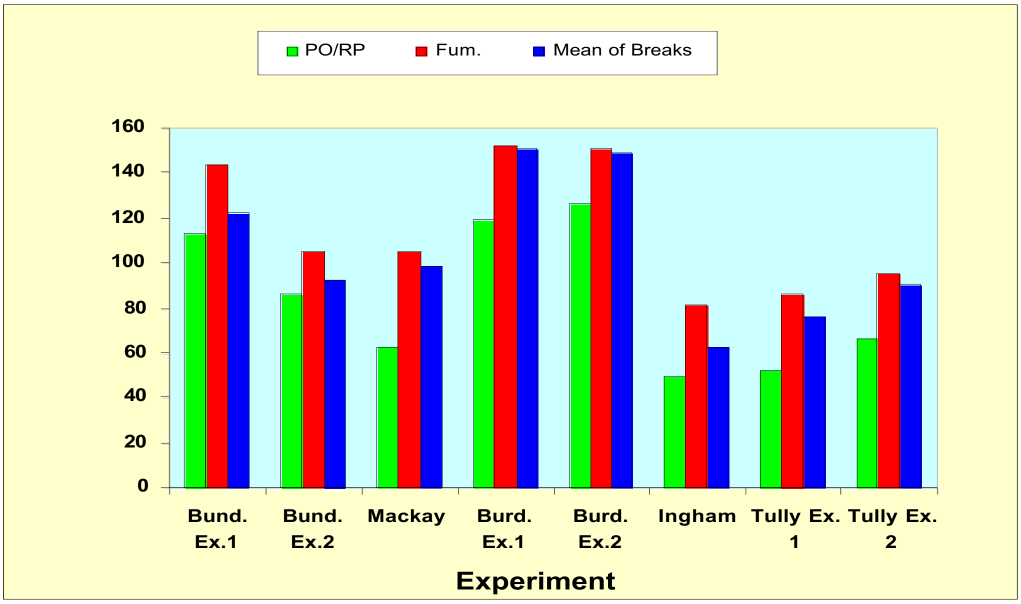
The effect of fumigation was to produce higher yields than the breaks in the plant crop (Figure 1) but lower yields than the breaks in the first ratoon (Figure 2). The percent response to fumigation and breaks is shown in Table 1. These responses are probably associated with fumigation removing all biota from the system but providing an environment conducive to the rapid re-establishment of sugarcane biota while the breaks provided a more diverse soil biota that survived for a longer period after the return to sugarcane (Pankhurst *et al*., 1999).

Controlled traffic and minimum/zero tillage

The SYDJV also commenced researching minimum tillage and controlled traffic as compaction resulting from heavy traffic associated with harvester and haul-out machinery was recognized as a substantial problem (Braunack *et al*., 1999; Braunack and McGarry, 1998; Braunack, 1998; Braunack and Peatey, 1999, Garside *et al*., 2000c). Experiments where no tillage was compared with numerous passes, as in the traditional system, produced no yield losses provided a fallow was included (Braunack *et al*.; 1999, Garside *et al*., 2000c), and substantial cost savings in terms of labour, tractor hours and fuel (Willcox *et al*., 2000). In addition improvements in soil physical and biological properties were measured (Braunack and Magarey, 2002). In other studies the effect of controlled traffic in terms of isolating crop and traffic rows resulted in a number of advantages, including substantial reductions in soil compaction (Braunack and Peaty, 1999; Braunack and Hurney, 2000; Bell *et al*., 2001).

A major problem with compaction in the sugarcane cropping system has been brought about by mis-matched row and wheel spacings.

Figure 1. Effect of continual cane, continual sugarcane planted in fumigated soil and the mean of a number of breaks on plant cane yield (t/ha) for several rotation experiments



Traditionally the sugarcane crop has been grown on 1.5 m rows whereas harvesting and haul-out equipment has wheel spacings of between 1.8 – 1.9 m. With this combination and less than fastidious operators, wheel encroachment on cropped areas causing compaction and yield loss from later ratoons is largely unavoidable (Norris *et al*., 2000; Bull *et al*., 2001; Robotham, 2003). The adverse effects are more pronounced under wet harvesting conditions (Garside, 2004). The perseverance with 1.5 m spacing has been based on a perception that yields will be reduced if row spacing is widened. However, recent row spacing and plant density studies have shown that sugarcane possesses a degree of environmental plasticity and that it is possible to adopt row spacing to match wheel spacing without loss of yield and thus allow controlled traffic to be implemented (Garside *et al*., 2002b; Garside *et al*., 2004; Robotham and Garside, 2004). In recent studies dual rows on 1.85 m spacing have been shown to yield as well as 1.5 m single rows (A.L. Garside and B.G. Robotham, unpublished data).

Combining green cane trash blanketing, breaks to the monoculture, minimum tillage and controlled traffic into the sugarcane cropping system

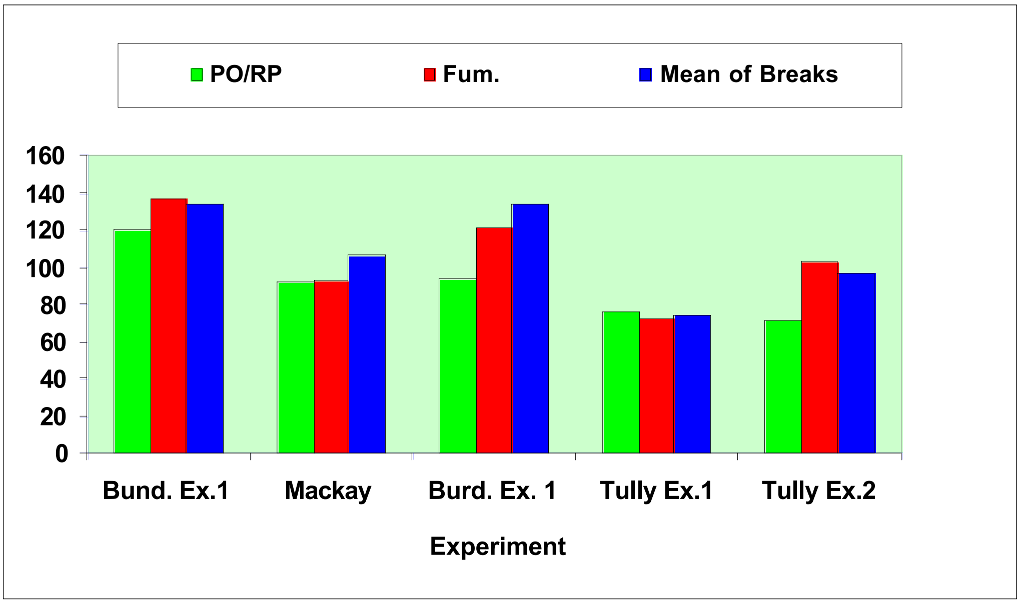
Each of green cane harvesting, legume breaks, minimum tillage and controlled traffic have been demonstrated to improve sugarcane yields and/or reduce the cost of production. However, substantial benefits are likely to accrue if they can be collectively incorporated into a sugarcane cropping system. Essentially, the SYDJV program is now dedicating much of its time to developing such a cropping system. The system envisaged is based around row spacings compatible with wheel spacings of the heaviest equipment (harvester and haul-outs) to avoid stool damage and minimize compaction near the cane row. The appropriate spacing at present is 1.8 – 1.9 m but spacing is entirely dependent on matching row and wheel spacings. Minimum tillage or direct planting is being combined with controlled traffic (Robotham, 2003) to reduce operational costs, minimize damage to soil physical properties, minimise adverse effects on soil biota, and conserve organic matter. Raised beds are being used in wetter areas to minimise potential adverse effects of waterlogging. Legume breaks are included to break the monoculture and provide a different root system to sugarcane, to manage root pathogens, and to provide a source of biologically fixed nitrogen. Further, by using minimum tillage, cane trash can be conserved between cane cycles further improving soil organic matter, soil physical properties and water holding capacity.

The results of large scale experiments established to integrate these components into a cropping system are just starting to emerge and are showing that the proposed system is feasible with no major impediments. At this stage only plant crops have been harvested from these cropping system experiments and although yields have not been substantially increased (except for the response to legume breaks) there have been substantial cost savings associated with the establishment of legume breaks and the following sugarcane crop through minimum tillage/direct planting (Garside, 2002; Bell *et al*., 2003; Garside *et al*., 2004). Substantial benefits are expected to emerge in later ratoons as the benefits of controlled traffic are realized.

Table 1. Percent response in cane yield to growing cane on continual sugarcane soil following fumigation and following breaks to the monoculture

Crop	% Response in sugarcane yield compared with continual cane	
	Fumigation	Mean of Breaks
Plant	42	29
First Ratoon	16	21

Figure 2. Effect of continual cane, continual sugarcane planted in fumigated soil and the mean of a number of breaks on first ratoon cane yield (t/ha) for several rotation experiments



The changes proposed to the cropping system are being supported by the development of appropriate equipment such as bed formers, double disc opener no-tillage planters and appropriate harvester modifications to suit dual rows and to match row spacing and wheel tracks (Norris *et al*., 2000; Robotham, 2000a &b). Machinery is available to direct plant legumes into sugarcane residue. A specific focus of the machinery development program has been to keep initial machinery changes to a minimum, thus minimizing capital investment and facilitating adoption. Indications from cane growers who have made the change are that the costs are insignificant and that adopting the proposed system opens the possibility of substantial machinery savings through downsizing tractors and disposing of redundant tillage equipment.

Benefits of a changed sugarcane cropping system

The changed cropping system being promoted is still in its development phase but enough confidence is being shown by many sugarcane growers in Australia to adopt at least components of the system while a small number at this stage are embracing the whole system. The system is based upon the basic agronomic principles that organic matter is the key to healthy soil, monocultures are undesirable, compaction should be avoided as much as possible, and excessive tillage destroys organic matter, soil structure, soil biota and is very costly.
The benefits that can be envisaged by adopting such a system include:

• Legume breaks provide a better-balanced biology, control root pathogens, biologically fix nitrogen and greatly reduce the need for fertilizer nitrogen, improve cane growth and yield.
• Isolation of cane and crop areas through matching wheel and row spacing can guide harvester and haul-out tracking and thus reduce the impact of compaction.
• Minimum/zero tillage, which conserves organic matter, improves soil structure, doesn't disrupt beneficial soil biota, and reduces runoff and erosion.
• Eliminates the need to till to remove compaction.
• Reduces the impact of waterlogging.
• Improves the timeliness of operations.
• Savings in fuel and labour costs.
• Indications that weeds will become less of a problem and herbicide use reduced with continual trash cover.

Conclusions

The proposed cropping system that is being developed is underpinned by substantial research into the factors that have been identified as contributing to yield decline in sugarcane, and research into how those factors can be best managed. The system discussed above should in no way be regarded as prescriptive. Numerous variations to components will almost certainly provide similar outcomes as long as the basic principles of organic matter maintenance, breaking the monoculture, reducing tillage, and controlling traffic are not compromised. The system has elements of cost savings and thus improved profitability (Dent *et al*., 2003, Garside *et al*., 2004); improved maintenance of the soil resource and improved sustainability; and reductions in soil disturbance, fertilizer inputs and fuel useage, all important environmental considerations. There are also good indications of improved yields.

The applicability of the system to sugar industries other than Australia has not been considered in this paper. The Australian industry is somewhat unique in that it is the most mechanized sugarcane cropping system in the world and a substantial amount of the problems facing the industry with regard to yield decline are associated with a lack of control of heavy machinery. However, many other sugar industries are becoming more mechanized and there is no reason to believe that problems caused by heavy in-field traffic in

Australia will not occur elsewhere. Certainly, mechanical loading and haul-out are now common in most sugar growing areas and the damage caused by these operations will be dependent on how well that traffic is controlled. Further, all sugar industries are strongly monoculture based and the long-term effects of a monoculture is likely to be yield decline. Hence, the system discussed here, or at least components of it, will almost certainly be applicable to sugar industries worldwide.

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