YIELD DECLINE RESEARCH IN THE AUSTRALIAN SUGAR INDUSTRY

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Abstract

The paper reviews the subjects of yield decline and the productivity plateau in the Australian sugar industry. Yield decline is an important production constraint estimated at costing between $200 and $400 million per year. A Joint Venture involving four research providers was established in 1993 to research yield decline. The Joint Venture is taking a farming systems approach aimed at understanding the factors responsible for the phenomenon. The initial results of studies into soil chemical, physical and biological properties on old and new land and following the breaking of the sugarcane monoculture with rotation species are discussed. In addition some innovative approaches to the management of fallow legumes are proposed.

Keywords: yield decline, productivity, Joint Venture, Australia

Introduction

Yield decline is defined as *the loss of productive capacity of soils under sugarcane monoculture.* Although not always known as yield decline, the phenomenon has been recognised in the Australian sugar industry for most of this century (Maxwell, 1900; Bell, 1935, 1938). In more recent times, yield decline has been nominated as one of the major causes of an industry-wide productivity (sugar yield/harvested hectare) plateau that occurred between 1970 and 1990 (Anon, 1991). However, as discussed below, it is now believed that the yield decline phenomenon played a relatively minor part in this productivity plateau (Leslie and Wilson, 1996; Garside *et al.,* 1997a).

Nonetheless, numerous studies have demonstrated that the *productive capacity of the soil* is reduced by sugarcane monoculture. This is evidenced by yield responses to fumigation of the order of 20% (Bell, 1935; Egan *et al.,* 1984; Muchow *et al.,* 1994; Magarey and Croft, 1996; Garside *et al.,* 1995) on new land compared with old land (Anon, 1935; Garside and Nable, 1996) and following breaking of the monoculture with rotation crops (Beiske, 1965; Chinloy and Hogg, 1969).

In this paper a brief discussion of the 1970 to 1990 productivity plateau is provided. In addition, the recent history of yield decline in the Australian sugar industry, and how this provided the impetus for the establishment of the Sugar Yield Decline Joint Venture, are discussed. Further, the research approach being adopted by the Joint Venture is described and some of the initial research findings, including some encouraging results with fallow legumes, are detailed.

The productivity plateau, 1970-1990

During the twentieth century there was a steady increase in productivity (sugar yield/harvested hectare) in the Australian sugar industry, until 1970. However, for the period 1970 to 1990 productivity plateaued (Figure 1). The magnitude of productivity changes for the 20 years periods 1899-1919, 1920-1940 and 1947-1970 have been 0,6, 0,7 and 0,9 tons of cane/ha/year and 0,09, 0,15 and 0,15 tons of sugar/ha/year respectively (Hogarth, 1972). By contrast, for the period 1970 to 1990, sugarcane yield increased at the rate of 0,01 t/ha/year whereas commercial cane sugar (ccs) actually decreased (Smith, 1991).

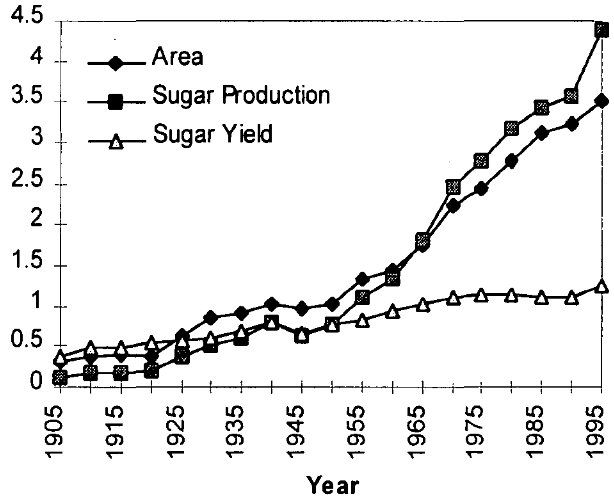

Figure 1. Area (00 000 ha), sugar production (000 000 t) and sugar yield (10 t/ha) for the Australian sugar industry 1905-1995. Data are averages for consecutive five year periods. (*Source:* SRDC, 1995.)

As suggested above, it was once thought that the yield decline phenomenon played a significant part in the productivity plateau. However, more contemporary analyses (Leslie and Wilson, 1996; Garside *et al.,* 1997a) indicate that changes to the farming system are likely to have been largely responsible for productivity losses, although many of these changes have probably resulted in profitability increases. Of specific note are:

- the abandonment of forced fallowing
- the introduction of chopper harvesters
- green cane harvesting
- more ratoons
- herbicide usage
- major disease outbreaks
- nutritional excesses and deficiencies.

Previous research on yield decline

The recent history of yield decline dates back to 1967, when northern poor root syndrome (NPRS) was recognised as a problem in sugarcane on Queensland's wet tropical coast (Egan *et al.,* 1984). The Bureau of Sugar Experiment Stations (BSES) has had a dedicated programme to research yield decline since this time. This programme initially investigated an extensive range of agronomic, nutritional, entomological and pathological issues as possible causes, and eventually isolated the root pathogen *Pachymetra chaunorhiza* which, when controlled by the use of resistant sugarcane varieties, led to yield increases of up to 40% (Magarey, 1993). However, even greater responses (>100%) were obtained when soil from the same site was fumigated with methyl bromide, suggesting that factors other than *P. chaunorhiza* root rot were involved (Croft *et al.,* 1984). Further, when *P. chaunorhiza* susceptible and resistant sugarcane varieties were grown on fumigated and unfumigated soil at the same site, the resistant variety outyielded the susceptible variety but still showed a 36% yield response to fumigation ([1]unpublished data).

More recently, it has been established that substantial sugarcane yield responses to fumigation can be measured in all sugar growing areas of Queensland, whether *P. chaunorhiza* is present or not (Magarey and Croft, 1996). However, the discovery of *P. chaunorhiza* (Croft and Magarey, 1984) along with major responses to fumigation clearly indicated that root pathogens were involved and that the severity of their effect was favoured by long term monoculture (Croft *et al.,* 1984).

Subsequent research by the BSES concentrated on isolating other pathogenic fungi, with limited success (Magarey *et al.,* 1995). Consequently, the approach that assumes root pathogens are the primary cause of yield decline has been questioned. Indeed, it has been suggested that a build-up of root pathogens may simply be the ultimate expression of other factors being out of balance in the farming system (Garside, 1996). This concern led to the establishment of the Sugar Yield Decline Joint Venture in order to provide a suite of expertise to research the issue.

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Joint Venture approach to researching yield decline

The Sugar Yield Decline Joint Venture is comprised of four research agencies involved in sugar research and development in Australia: the Sugar Research and Development Corporation (SRDC), the Bureau of Sugar Experiment Stations (BSES), the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Queensland Department of Primary Industries (QDPI). The first three organisations established the Joint Venture in 1993, and the QDPI became a partner in 1995. Basically, the SRDC provides operating funds for the Joint Venture while the other three organisations provide staff and infrastructure.

The objectives of the Joint Venture are to:

- identify causal factors and their contribution to yield decline in sugarcane
- develop solutions to minimise or alleviate the impact of such causal factors on productivity in sugarcane
- promote the use of appropriate technologies developed by the Joint Venture.

The Joint Venture started with the premise that yield decline was a complex issue associated with a number of factors being out of balance in the farming system, and that these factors and their relative importance were likely to vary in response to soil and environment. Further, only two pieces of previous evidence were fully accepted; yield decline was associated with long term monoculture, and root pathogens were certainly involved. Consequently, the Joint Venture is attempting to consider all aspects of the farming system in approaching the yield decline problem. A three phase approach is being implemented based around *identifying, understanding* and *overcoming/managing* the problem.

At present the research is still largely in the *identifying* phase, with major focus on:

- studying differences in soil chemical, physical and biological properties and their effect on sugarcane growth in paired old and new land sites
- new land after it is first planted to and continues to grow cane (rundown studies)
- old land after it has grown rotation crops for different periods of time.

The next phase will involve more detailed studies to better *understand* the impact of factors that emerge from the *identification* phase. Within the broad area of soil biology, root pathogens, nematodes, soil invertebrates, soil microbial biomass and microflora and fauna dynamics are being studied.

In addition to this largely identification phase, two specific areas are being researched by the Joint Venture. A project on root growth and development is under way (Reghenzani and Grace, 1996; Magarey and Grace, 1997), given the critical linkage function of the root system between the source of yield decline (soil) and the effect (top production). The other specific project is focusing on strategic tillage to measure the effect of substantial reductions in the number and type of cultivations used to establish plant cane.

Progress

Initial studies have focussed on sugarcane monoculture in an attempt to identify soil properties that are different in the monocultural cropping system, compared with land that has never grown or only recently been planted to sugarcane, or has had the monoculture broken with rotation crops.

Paired old and new land sites

The major thrust in the initial year of the Joint Venture (1993-94) involved studies aimed at *identifying* differences in soil chemical, physical and biological properties, and crop growth and yield between old and new land sites in three areas of north Queensland. These are the Burdekin, Herbert and Tully areas, which have a range of soil types and experience a diversity of climatic conditions. Yield decline has been recorded in each of these areas. Results from this work have been, or are in the process of being published, *viz.* crop growth and yield (Garside and Nable, 1996), soil chemical properties (Bramley *et al.*, 1996), soil physical properties (Ford and Bristow, 1995a, 1995b), soil biological properties (Magarey *et al.*, 1997; Pankhurst *et al.*, 1996; and [2] unpublished data), and soil organic matter (Skjemstad *et al.*, 1995). The results of these studies are summarised by Garside *et al.* (1997c).

In brief, the pattern that emerges from these paired sites is that soil properties are more degraded on old than new sugarcane land. Crop yields were either the same on old and new land, or lower on old land. For at least some of the sites, old land was shown to be more acid, to have lower cation exchange capacity, to have more exchangeable aluminium and manganese, to have less copper and zinc, to have less microbial biomass, to have greater soil strength, to have lower infiltration and water holding capacity and to have more root pathogens. Further, it was apparent that the importance of a particular factor varies with soil type and environment and is likely to be influenced by crop management. For example, at the Kalamia site in the Burdekin delta, substantial soil compaction (up to 4 Mpa) was measured on old land on what is regarded as a highly fertile alluvial soil. Other measurements in this area on similar soils confirmed that compaction is widespread in the Burdekin delta ([3] unpublished data). However, the area still produces some of the best industry yields, probably because of the availability of adequate irrigation. Essentially, the potential adverse effects of soil degradation may be being hidden by water management.

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Rotation experiments

A second approach to solving the problem of yield decline is through breaking the monoculture with different crops for different periods of time. Five experiments have been established in major sugarcane growing areas of Queensland: Tully, Herbert, Burdekin, Mackay and Bundaberg. In most instances, breaks of bare fallow, alternative crop, and pasture along with continual sugarcane have been established for periods of 6, 18, 30, and 42 months. These basic break treatments are designed to provide diverse soil management, *viz.* no plant growth and no soil disturbance (bare fallow), plant growth and no soil disturbance (pasture), plant growth and soil disturbance (alternative crop). Detailed monitoring of soil chemical, physical and biological properties is being carried out to measure the effects of the different breaks on soil properties. When the experiments are returned to sugarcane, continual cane plots will be split between fumigation and no fumigation.

The first of these experiments will be replanted to sugarcane in the second half of 1997. In addition, some short term breaks (six months) have been established with a range of legume treatments. Results from these studies are now becoming available and are discussed below.

Rundown experiment

This experiment was established in 1996. New land was selected and planted to sugarcane, and the same procedure will follow for the next four years. In the year 2001 the experiment will be replanted with sugarcane. Studies of the changes in soil chemical, physical and biological properties are being carried out during the rundown phase, and sugarcane growth and yield will be measured when the experiment is replanted to sugarcane.

Fallow legume experiments

Legumes, particularly cowpea (*Vigna unguiculata* var. Meringa), are traditionally grown during summer on the wet tropical coast of Queensland as a fallow between the plough-out of old ratoons in spring and the replanting of sugarcane the following autumn/winter. Legumes are grown for two reasons; firstly to provide a diverse break crop from sugarcane and so relieve the build-up of disease, and secondly, to provide a source of fixed nitrogen for the following sugarcane crop. Further, they provide ground cover for erosion control over the heavy summer rainfall period.

Results with Meringa cowpea have been variable. In many crops, waterlogging and associated root diseases such as *Phytophthora vignae* and *Pythium myriotylum* (Croft, 1988) have caused significant plant death, and this has led to weed infestation. In addition, ineffective killing of the old stubble often resulted in many legume crops being heavily infested with sugarcane. This largely negates one of the major reasons for planting a fallow, which is to reduce the populations of sugarcane diseases.

The variable results with cowpea encouraged the search for alternative legumes that would be more robust under wet season conditions. In rotation experiments being established as part of the Joint Venture, many of the rotation species being used are legumes, and an effort is being made to maximise their growth in order to enhance their potential as break crops. Initial experiments in the 1993-94 season indicated that the growth, yield and nitrogen input from a fallow legume could be substantially enhanced by improved management and better adapted species than Meringa cowpea ([4] unpublished data). This work was expanded in an experiment in 1994-95 to further investigate different fallow treatments, legume species and improved management practices (Garside *et al.*, 1996). The fallow treatments were replanted to sugarcane in 1995, with the plant crop being harvested in July 1996 (Garside *et al.*, 1997b).

Methods

Details of experiment procedures and fallow treatments are provided in Garside *et al.* (1996, 1997b). Briefly, the site had been under long term sugarcane until August 1994, when preparations for the summer fallows commenced after the cane harvest. Seven fallow treatments including continual sugarcane, bare fallow, farmer fallow, RM1 mungbean (*Vigna radiata*), cowpea, peanut (*Arachis hypogaea*) and soybean (*Glycine max.* L. Merrill) were included. Continual sugarcane consisted of leaving the previous cane growing in these plots over the summer but managing cane growth by regular slashing and leaving the leaf material on the soil surface. In all other treatments the cane was removed by several workings between August and November 1994. Bare fallow was maintained plant-free by regular sprayings with glyphosate (Roundup) during the summer fallow period. Farmer fallow consisted of cowpea broadcast onto a flat soil surface and incorporated by discing, a traditional practice for establishing legume fallows. The other four treatments, RM1 mungbean, cowpea, peanut and soybean were grown on 0,75 m ridges and sprayed with a pre-emergence herbicide, metolachlor (Dual) at 2,5 L/ha of product.

Data for dry matter and nitrogen contents of the fallow treatments were reported by Garside *et al.*(1996). Briefly, when the fallows were incorporated they contributed the following amounts of nitrogen: farmer fallow 50 kg/ha, peanuts 80 kg/ha, RM1 mungbean 84 kg/ha, cowpea 140 kg/ha and soybean 310 kg/ha. These amounts are based on the incorporation of the entire crop (no grain being harvested) in all but peanuts. Had the entire peanut crop been incorporated, the nitrogen contribution would have been 170 kg/ha instead of 80 kg/ha.

Sugarcane variety Q138 was planted on September 26, 1995, into plots that had carried the seven different fallow treatments during the previous 1994-95 wet season. There were four replications of a random block design. Each plot was split to two rates of nitrogen fertiliser: 0 or 140 kg/ha N applied as urea. Of the 140 kg/ha, 40 kg/ha N was applied at planting and the remainder when the crop was filled in on November 27. Sugarcane was hand harvested on July 8 and 9, 1996, at less than 10 months of age. The early harvest was necessary to avoid some plots lodging and confounding the biological yield.

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Results and Discussion

Cane and sugar yield

There were significant (p<0,05) fallow treatment, nitrogen, and fallow treatment x nitrogen effects for cane yield (Table 1, Figure 1), and nitrogen and fallow treatment x nitrogen effects for sugar yield (Table 2, Figure 2). There was no overall fallow treatment effect on sugar yield except that cane after soybean significantly (p<0,05) outyielded cane following bare fallow.

Table 1
Cane yield (t/ha) following seven different fallow histories fertilised with 0 or 140 kg N/ha, and fallow histories and nitrogen rate means.

Fallow history	Yield (t/ha)	N rate (kg/ha)	Yield (t/ha)
Cane	88	0 kg N/ha	81
Bare fallow	74	140 kg N/ha	98
Farmer fallow	85	LSD 5%	4,3
Cowpea	95		
Mungbean	93		
Peanut	89		
Soybean	102		
LSD 5%	11,8		

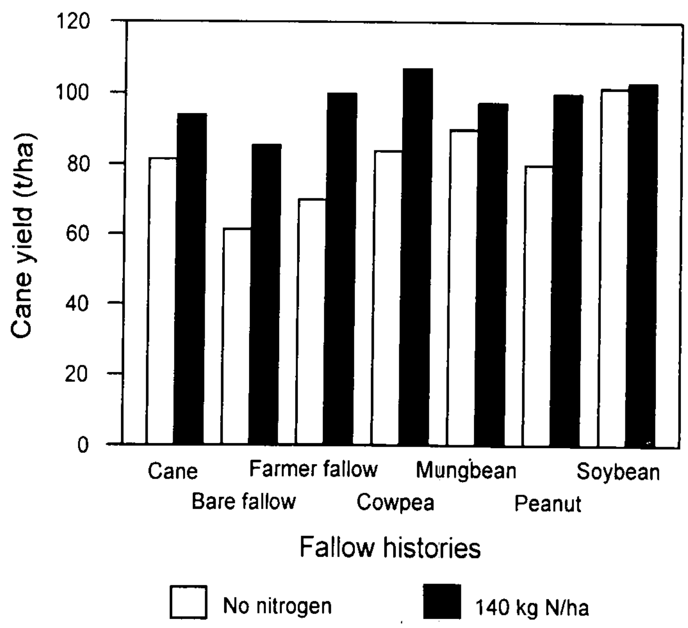

Figure 2. Cane yield (t/ha) following seven different fallow histories fertilised with either 0 or 140 kg N/ha (LSD 5% = 11,4 for histories x nitrogen).

Table 2
Sugar yield (t/ha) following seven different fallow histories fertilised with 0 or 140 kg N/ha, and fallow history and nitrogen rate means.

Fallow history	Yield (t/ha)	N rate (kg/ha)	Yield (t/ha)
Cane	9,81	0 kg N/ha	9,31
Bare fallow	9,31	140 kg N/ha	11,02
Farmer fallow	9,90	LSD 5%	0,61
Cowpea	10,58		
Mungbean	9,99		
Peanut	10,20		
Soybean	11,37		
LSD 5%	1,91		

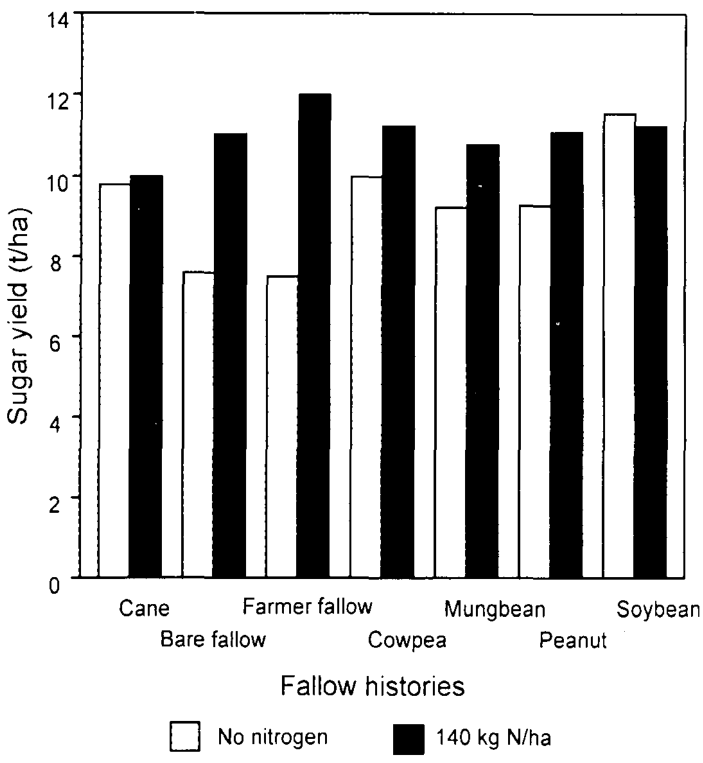

Figure 3. Sugar yield (t/ha) following seven different fallow histories and fertilised with either 0 or 140 kg N/ha (LSD 5% = 1,62 for histories x nitrogen).

In the absence of applied nitrogen, cane and sugar yields tended to increase commensurate with the amount of nitrogen contributed to the system by the previous fallow treatment. For example, without fertiliser nitrogen, the lowest cane yield (62 t/ha) was recorded following the bare fallow and the highest (100 t/ha) following soybean. Other treatments provided intermediate yields. Further, the significant response to applied nitrogen was mainly due to large responses in treatments where the fallow contribution was small. For example, in both the bare and farmer fallows the response to applied nitrogen was of the order of 40%, whereas it was 24% following peanuts, and nil following soybean. The latter was responsible for the significant history x nitrogen interaction.

The large difference between treatments in cane yield (38% greater for soybean than bare fallow) was not as pronounced for sugar yield, with cane after soybean producing only 18% more than cane after bare fallow. The smaller difference in sugar yield was largely associated with increased ccs in the bare fallow treatment.

Influence of fallow treatments on yield decline

All treatments with the exception of cane after cane can be deemed to have provided a break from the continual monoculture. As there was no significant difference ($p<0,1$) in sugar yield between the fallow treatments when 140 kg/ha N was applied, and most were significantly superior ($p<0,1$) to cane after cane with 140 kg/ha N, the mean of the fertilised fallow treatments (11,2 t/ha) compared with fertilised cane after cane (9,9 t/ha) provides an estimate of the effect of sugarcane monoculture on sugar yield, *viz.* 1,3 t/ha. In fact, the difference here may be an underestimate compared with a plough-out/ replant as the cane after cane treatment did experience a break in this experiment, being ploughed out on May 29, four months before cane was planted across the experiment.

Influence of management of the fallow

The results of this experiment demonstrate that there are advantages to having ground cover during the wet season fallow period. Further, there are additional advantages to having the ground cover as a well managed legume fallow with the most suitable species for that particular situation. Without additional nitrogen fertiliser, bare fallow produced the lowest cane and sugar yields, closely followed by farmer fallow. When cowpea was managed on ridges with weed control, cane and sugar yields increased by 14 t/ha (70 to 84 t/ha) and 2,1 t/ha (7,76 to 9,86 t/ha) compared with the farmer fallow. A further yield increase of 16 and 1,64 t/ha of cane and sugar, respectively, occurred when cowpea was replaced by soybean.

Conclusions

Yield decline is a significant problem in the Australian sugar industry, having been variously estimated as costing the industry between $200 to $400 million/annum. The causes are not fully understood, although there is little doubt that root pathogens are involved. However, instead of focussing on the identification and control of specific root pathogens, the Yield Decline Joint Venture is taking a long term approach aimed at understanding how to manage the farming system in order to prevent soil pathogens becoming a dominant factor. The end result may be that it is not possible to manage soil pathogens through the farming system without incurring productivity losses. However, at this stage there is insufficient data to make objective judgements. Regardless, the teasing apart of the cane growing system to identify factors that are adversely affecting productivity is likely to lead to a more sustainable management system that will benefit both sugar production and resource maintenance.

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