

EFFECT OF BREAKS FROM SUGARCANE MONOCULTURE ON GROWTH AND YIELD OF SUBSEQUENT SUGARCANE CROPS

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Sugar Yield Decline Joint Venture

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Abstract

Long-term rotation experiments were established at five sites (Tully, Ingham, Ayr, Mackay and Bundaberg) in sugar growing areas of coastal Queensland, Australia in 1993 and 1994. The rotations or breaks consisted of either pasture, crop other than sugarcane, or bare fallow for various periods of time ranging from 6 to 42 months. The type of break established three basic soil management strategies. Under the pasture break the soil experienced no disturbance and plant growth; under the other crop break annual disturbance and plant growth; while under the bare fallow no disturbance and no plant growth.

At least part of each of these experiments was returned to sugarcane in 1997 or 1998. During the break periods, and immediately prior to returning to sugarcane, changes in soil chemical, physical and biological properties were measured. The growth and yield of sugarcane is being measured at each site for the plant and several ratoon crops. In all experiments the effect of breaks/rotations was to increase yield of sugarcane by from 14 – 84% compared with sugarcane monoculture. The type of break and its duration had some effect on the magnitude of the response but all breaks had a positive effect on yield at all sites.

The basis of the yield response was an improvement in early shoot development following a break, which was clearly associated with biological factors in the soil affecting soil health. However, the magnitude of the final yield response was also dependent on subsequent crop management. At sites where high inputs of radiation, water and nutrients were available the response to breaks was less than at sites where the crop was rainfed, had limited radiation, or was on poorer soils. The implications of these studies are discussed in terms of the development of a more sustainable farming system for sugarcane.

Introduction

The problem of yield decline (*the loss of productive capacity of sugarcane growing soils under long-term monoculture*) has been a part of the Australian sugar industry for most of the twentieth century (Maxwell, 1900; Bell, 1935, 1938, Garside *et al.* 1997a). However, the impact of yield decline was not fully considered until the Australian sugar industry recorded a productivity plateau for the twenty-year period from 1970 – 1990 (SRDC, 1995). It was assumed that this productivity plateau was largely due to yield decline. Consequently, a number of organisations involved in research and development for the Australian sugar industry established a Joint Venture in 1993 to research the

issue. Although subsequent studies (Smith, 1991; Leslie and Wilson, 1996; Garside *et al.* 1997a) have revealed that the phenomenon of yield decline is only a component of the productivity plateau, it does occur and does cause substantial productivity losses.

In a previous paper to this conference, Garside (1997) outlined the formation and structure of the Sugar Yield Decline Joint Venture (SYDJV) and discussed the approach being taken to researching the issue of yield decline. Briefly, the SYDJV was established between the Sugar Research and Development Corporation, the Bureau of Sugar Experiment Stations, and CSIRO in July 1993. The Queensland Government Departments of Primary Industries and Natural Resources joined in 1995. The initial term given to the SYDJV was six years to June 1999. Subsequently, the SYDJV has been renewed for a further six years to June 2005.

As described by Garside (1997), the SYDJV started with the premise that yield decline was a complex issue associated with the long-term monoculture causing a number of factors to be out of balance in the farming system. Further, these factors and their relative importance were likely to vary in response to soil and environment. It was not clear as to whether the problem caused by the long-term monoculture was simply one associated with a single species being grown for long periods, the manner in which the species was grown, or a combination of both. However, there was little doubt that root pathogens were involved (Magarey and Croft, 1995). Further, it seemed likely that soil chemical and physical, as well as other biological properties, were involved. The problem was thus tackled in large scale experiments where different types of breaks to the monoculture, for different periods of time, were used as research tools. Five such experiments were established along the Queensland coast at Tully, Ingham, Burdekin, Mackay and Bundaberg. In this paper the growth and yield of sugarcane following the different breaks is discussed. In addition the results of short term glasshouse fumigation studies on soil from the rotation experiments are related to the field response.

Materials and Methods:

Rotation Experiments:

Details of experimental design and management are described fully in Garside *et al.*, (1999, 2000). Briefly, breaks of other crop, pasture or bare fallow were imposed on long-term sugarcane land for various periods of time. Control treatments of continual sugarcane were also included. All treatments were then re-

planted to sugarcane at the same time with the continual sugarcane treatments being either fumigated with methyl bromide just prior to being re-planted or left untreated. During the break periods and immediately prior to re-planting to sugarcane soil chemical (Moody *et al.*, 1999, Skjemstad *et al.*, 1999), physical (M.V. Braunack, pers. comm.) and biological properties (Pankhurst *et al.*, 1999, 2000) were monitored. Basic design was a randomised block with three replications in each case. When returning to sugarcane, plots were often split to different rates of nitrogen as shown in Table 1.

Basic experimental details are provided in Table 1. Essentially, long-term sugarcane land was acquired at each location and experimental design was applied. Breaks were imposed by removing cane at a particular time prior to the planned re-planting of sugarcane. For example, the Mackay site was acquired in September 1994 and re-planted to cane in August 1997. Hence the 30 month breaks were established in December 1994, the 18 month breaks in December 1995 and the 9 month breaks in December 1996. Further, not all break types and durations were applied at all sites. For example, at Mackay and Ingham there was no 9 or 18 month bare fallow and no 9 month pasture, while at Bundaberg, the 12 month breaks included both grass and legume crops, legume pasture, grass pasture and bare fallow. At Burdekin and Tully all breaks were of 42 month duration when they were returned to sugarcane.

Although break species used at each site did vary; other crops, pasture or bare fallow set up three basic soil management treatments in all experiments. Treatments involving other crops, which included at least annual plantings of species such as soybean, peanut, maize, and navy bean experienced traffic, tillage and plant growth. Treatments with pasture, which comprised a mixture of signal grass (*Brachiaria decumbens*) and pinto peanut (*Arachis pintoi*) at all sites except Bundaberg, where grass and legume pastures were planted separately, experienced plant growth but neither traffic nor tillage after they were established. Bare fallows experienced no traffic, no tillage and no plant growth after they were established.

Full details of the management of the breaks and subsequent cane crops are provided in Garside *et al.* (1999, 2000). Briefly, the cropping plots were harvested each year with the grain removed from the whole plots in some instances but only from a sample area in others. The pastures were sampled regularly for dry matter production and the dry matter returned by slashing the whole plot. On average there were four pasture samples per year at each site and the dry matter production was of the order of 15–20 t/ha/year. The bare fallows were maintained by regular spraying with glyphosate for weed control. There was no fertiliser applied to any of the break plots at any site.

When returning to sugarcane land preparation was the same across treatments in each experiment with disc ploughing, rip-

Table 1. Cultural details for the histories at each rotation experiment.

	Tully	Ingham	Mackay	Bundaberg	Burdekin
Date acquired	Sep-93	Sep-94	Sep-94	Oct-95	Oct-94
Original cane variety	Q115	Q124	CP 44 - 101	CP51 21 and Q144	Q117
Soil Type ¹	Yellow Kandosol	Chromosol	Red Chromosol	Yellow Chromosol	Melanic Tenosol
Break duration	42 month	9, 18 & 30 month	9, 18 & 30 month	12 month	42 month
Date breaks removed	15/07/1997	27/07/1997	26/07/1997	23/08/1996	24/07/1998
Fumigation date and rate	26/9-6/10/97	19/09/1997	19/08/1997	4/09/1996	24/08/1998
	900 kg methyl bromide/ha	900 kg methyl bromide/ha	900 kg methyl bromide/ha	1000 kg methyl bromide/ha	1500 kg methyl bromide/ha
Plot size	24m * 30m	16.5m * 25m	15.6m * 25m	10.5m * 30m	9m * 19m
Cane planting date	14/10/1997	29/09/1997	28/08/1997	14/10/1996	21/08/1998
Cane variety	Q117	Q117	Q117	Q124	Q117
Basal fertiliser	20P, 100K	20P, 100K	20P, 100K	44N, 5P, 28K, 6S	10 P, 0 or 50N
Side dressing/ N rates	0 or 140 N @ 63 dap	0, 70, 140 or 280N @ 66 dap	0, 70, 140 or 280N @ 102 dap	100N, 12P, 63K, 13S	0, 130 or 180N @ 90 dap
1 After Isbell (1996).					

ping and cultivation. For fumigation, methyl bromide was applied to prepared land under plastic sheeting at the rates and dates listed in Table 1. The plastic sheeting was removed 48 hours after application and planting was carried out during the next two weeks. Cane was planted in 1.5m rows.

The Burdekin and Bundaberg experiments were fully irrigated, the Mackay experiment supplementary irrigated, and the Tully and Ingham experiments were rainfed.

A range of other soil chemical, physical and biological properties were measured on soil from each of the treatments at each site. Details are not provided here but are available in Bramley *et al.* (1996) and Moody *et al.* (1999) (soil chemical properties), Pankhurst *et al.* (1999, 2000) (soil biological properties) and M.V. Braunack (personal communication) (soil physical properties).

Glasshouse Fumigation Experiments:

Fumigation pot experiments were conducted on soil collected from all sites immediately prior to returning to sugarcane. Details are provided in Bell *et al.* 2000. Briefly, soil was collected from the individual replicate plots for each history in the field at each site, before replicates were bulked and passed through a 6 mm sieve. Half the soil was air-dried. The remainder was placed under black plastic sheeting and fumigated using methyl bromide at a rate equivalent to 1000 kg/ha for a period of 24h. The sheeting was then removed and the soils aired. Clay pots containing moist soil equivalent to 1.4 kg of oven dry soil were used for the study, with 3-5 replicate pots used for each combination of history and fumigation. Fertiliser was added to each pot (0.35 g urea and 0.34 g KH_2PO_4), after which pots were planted with single germinated plants of the relevant sugarcane variety (Q124 for Bundaberg and Q117 for the other sites). Pots were transferred to air conditioned benches in the glasshouse at Tully Sugar Experiment Station, where plants were grown for a period of 35-45 days at 25-30°C. Plant roots and shoots were then harvested, oven-dried and weighed.

Measurements and Data Collection:

Within a week of fumigation being completed and the plastic cover being removed, all plots were soil sampled for mineral nitrogen using depth increments of every 10 cm to 40 cm, and thereafter every 20 cm to 1 m. Three cores were taken per plot and these were combined to give one sample per depth per plot.

Shoot/stalk number was recorded from a consistent 10 m of row in each plot at 2 – 3 week intervals until such time as there was little change. This usually occurred some 6 months after planting.

An interim yield harvest was taken from each experiment at around 8 – 9 months after planting. Sample quadrats were taken from all plots at Tully, Bundaberg and Burdekin but only from the 0 N plots at Mackay and Ingham. Sample size was 2 rows x 3 m at Tully, Ingham, Mackay and Burdekin and 5 rows x 2 m at Bundaberg. The number of stalks harvested and total fresh weight was recorded and a sub-sample of 20 stalks were split into millable stalk and green leaf plus cabbage. Dead leaf was discarded. Millable stalk was defined as that part of the

cane below the fifth dewlap from the top. Weights of each were recorded and the ratio of millable stalk to leaf plus cabbage was used to determine the weight of millable stalk in the sample. Six whole stalks were set aside for determination of sucrose concentration. This was done following juice extraction using the cutter grinder and Carver press (10 t for 1 minute) at Tully, Ingham, Mackay and Burdekin and a small mill at Bundaberg.

At final harvest all plots were harvested using similar methodology to that described above. Sample size at final harvest was 2 rows x 5 m. Otherwise procedures for determining millable stalk yield and sucrose concentration were as described for the interim harvest.

Results and Discussion

Cane Yield

In all rotation experiments the lowest yields were recorded with plough-out/re-plant in the plant crop (Table 2). The highest yielding treatments varied with site, but were either following bare fallow, pasture breaks or fumigation. Crop breaks generally yielded slightly less. The Bundaberg, Mackay and Tully experiments have had the first ratoon harvested, and in Bundaberg the second ratoon. In Table 2 the comparisons are made between plough-out/re-plant, fumigated plough-out/re-plant and the mean yield from the breaks. The general picture that emerges is that in most experiments the highest yields in the plant crop were obtained with fumigated plough-out/re-plant, although there were exceptions. For example, in the Burdekin experiment, where all the breaks were 42 months, the mean yield from the breaks was as high as for fumigated plough-

Table 2 - Cane Yield (t/ha) for plough-out/re-plant, fumigated plough-out/re-plant and the mean for breaks for each rotation experiment.

Site	PO/RP	Fum PO/RP	% Increase over PO/RP	Mean of Breaks	% Increase over PO/RP
Bundaberg					
Plant	113	144	27	122	8
R1	121	137	13	134	11
R2	103	113	10	115	12
Mackay					
Plant	63	104	65	99	57
R1	92	93	1	107	16
Tully					
Plant	52	86	65	76	46
R1	76	72	-5	74	-3
Ingham					
Plant	49	81	65	63	29
Burdekin					
Plant	119	152	28	151	27

out/re-plant. Similarly, in Mackay there was little difference. However, once into the ratoon crops the relative advantage of fumigation over breaks tends to decrease suggesting that the fumigation response is relatively short lived compared with the break effect (Table 2). In two experiments, Bundaberg and Mackay, the improved yields following the breaks have carried through to the first and second ratoon and first ratoon, respectively (Table 2). Observations, indicate that similar responses will be recorded in the third, second and first ratoons at Bundaberg, Mackay and Burdekin, respectively, when harvesting is carried out in 2000. That no responses were recorded at Tully and Ingham after the plant crop were associated with very wet seasonal conditions and waterlogging masking any potential responses. In fact, the Ingham experiment was abandoned after the plant crop, as it failed to ratoon.

The effect of individual breaks varied between sites but the general pattern was for bare fallow, fumigation and pasture breaks to produce higher yields than cropping breaks in the plant crop. However, in the first ratoon the relative advantage of fumigation and bare fallow tended to disappear, with the yields of these treatments being no better than plough-out/re-plant. However, the cropping and pasture breaks tended to produce significantly higher yields than plough-out/re-plant in the first ratoon. For example, yields for the plant and first ratoon crop in the Mackay experiment clearly demonstrate these effects (Table 3).

Table 3 - Break Effects on Cane Yield (t/ha) at the Mackay Rotation Experiment

Treatment	Plant Crop	% Increase over PO/RP	First Ratoon	% Increase over PO/RP
PO/RP	63	nil	92	nil
PO/RP (Fum)	104	65	93	1
9 M Crop Break	88	40	116	26
18 M Crop Break	86	37	109	18
30 M Crop Break	98	56	104	13
18 M Pasture Break	99	57	112	22
30 m Pasture Break	106	68	100	9
30 M Bare Fallow	116	84	102	11

Lsd 5% = 15 (plant crop), 13 (first ratoon)

Two of the five experiments were fully irrigated on relatively fertile soils in high radiation environments, Bundaberg and Burdekin. In these experiments the response to fumigation was considerably less than at the other sites (28% vs. 65% - Table 2). Overall there was no effect of breaks or fumigation on sucrose content in any of the experiments.

Crop Growth and Yield Accumulation

General Pattern of Response

At all sites, the basis of the yield responses was established very early in the life of the sugarcane crop through differential early shoot establishment. In every experiment the rate of shoot development and ultimate shoot/stalk numbers was always less

in plough out/re-plant than any of the breaks. Further, the duration of the break appeared to have a more important effect on shoot establishment than the break type. For example, the data for Mackay shows greater early shoot numbers following 30 month breaks than shorter breaks (Fig. 1). The very large early advantage in shoot numbers for the breaks over plough-out/re-plant was moderated later in the growing period, but the eventual stalk numbers were still considerably more following the breaks.

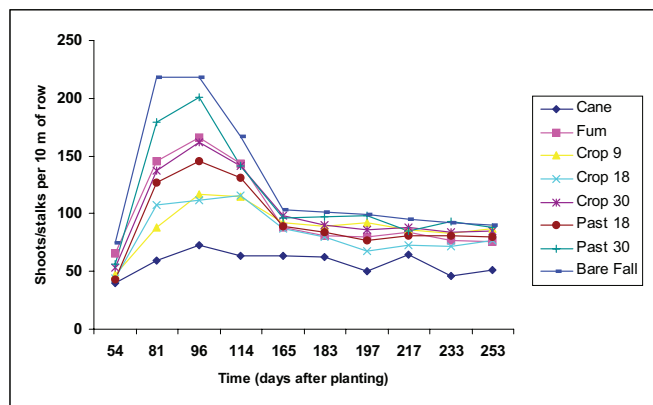


Figure 1: Temporal changes in shoot/stalk number per 10 m of row for variety Q117 planted after a range of different types and durations of breaks, fumigation and continual cane at Mackay. Lsd 5% between break types at each sample date = 15 (day 54), 48, 59, 42, 18, 15, 18, 20, 18, 18 (day 253)

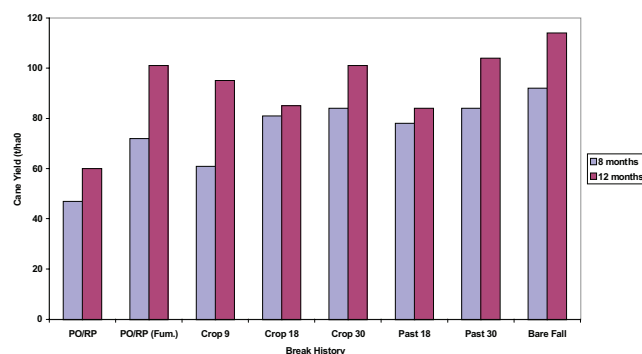


Figure 2: Cane yield (t/ha) at 8 and 12 months for the Mackay rotation experiment. Lsd 5% = 15 (8 months), 18 (12 months).

Yields at 8 months tended to closely follow early stalk development but there was a re-arrangement of the order of yields at 12 months at all sites (Fig. 2 – data for Mackay for example). Essentially those treatments that displayed good early shoot development (Fig. 1) and high yields at 8 months (Fig. 2) tended to have a reduced growth rate in the final four months (Fig. 2) and vice-versa. This suggests that a limitation of resources later in the growing period may be adversely affecting final yield in treatments with good early growth.

Early Growth Effects

The relationship between early shoot numbers and cane yields at 8 and 12 months with shoot dry weight was further explored in the fumigation pot experiments. Field soil from each treatment in each rotation experiment was collected and either fumi-

gated or not fumigated before being used to establish short term (35 – 45 days) pot experiments. Shoot dry matter in unfumigated soil in the pot experiments was strongly correlated with field shoot number at 70 – 90 days after planting (Figure 3 – Burdekin experiment for example) and with dry matter production after 8 months (Figure 4 – Burdekin experiment for example). However, correlations were either much weaker or had disappeared entirely by 12 months (Figure 5 – Burdekin experiment for example). Further, growth in fumigated break soil in the glasshouse was not correlated with growth in the field indicating that biotic factors were associated with these early growth differences in the field. More detail is provided in Bell *et al.* (2000).

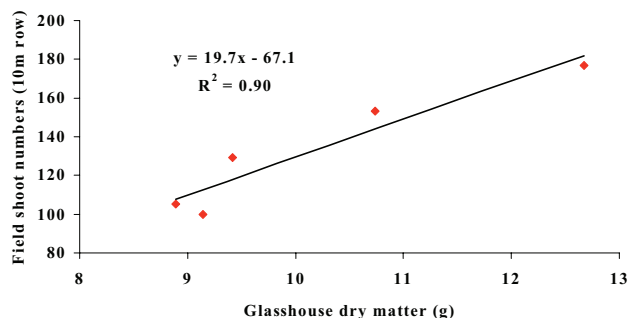


Figure 3: Relationship between growth in unfumigated soil in the glasshouse and maximum shoot number in the field for the Burdekin rotation experiment.

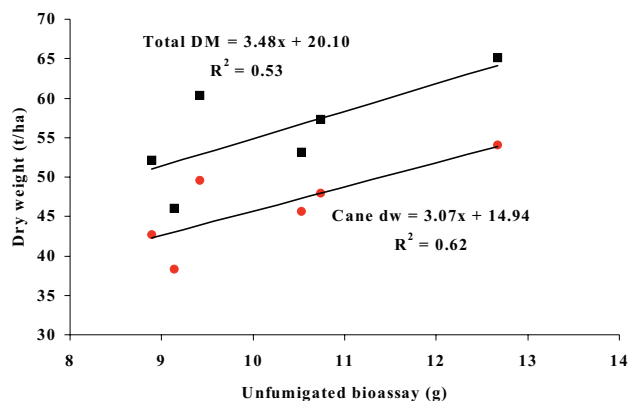


Figure 4: Relationship between growth in unfumigated soil in the glasshouse and total and cane dry weights at 8 months of age in the field in the Burdekin rotation trial.

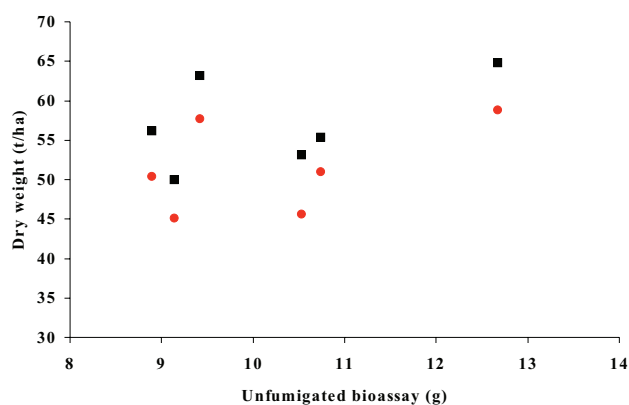


Figure 5: Relationship between unfumigated soil in the glasshouse and total and cane dry weights at final harvest in the field in the Burdekin rotation trial

Further support for biotic factors being involved in these early growth responses is provided by the analysis of soil biota, reported by Pankhurst *et al.* (1999), following the various breaks in these experiments. In general, breaks reduced the number of deleterious microorganisms, increased the number of beneficial microorganisms, and provided a better balanced soil biota than that present under continual sugarcane. Pasture breaks in particular produced the best balance of soil biota. Pankhurst *et al.* (1999) noted that under both fumigated plough-out/re-plant and bare fallow there was a much smaller and less diverse population of biota than under cropping or pasture breaks. They suggested that the positive responses in sugarcane growth in the plant crop following these treatments may have been due to substantial reductions in detrimental soil biota. Conversely, the relative reduction in yield in these treatments in the first ratoon (Tables 2 and 3) may have been due to a rapid build up of detrimental biota in the absence of a more balanced biota, as for the pasture and crop breaks.

Effect of Nitrogen:

The cropping breaks in all of these experiments were largely legume based and the pasture was a combined grass/legume mixture. When the Bundaberg, Mackay, Ingham and Tully experiments were returned to sugarcane constant nitrogen rates and timing of application were applied across all treatments to avoid confounding. However, this provided the possibility of biasing against plough-out/re-plant on the basis of nitrogen availability and this may have resulted in differential early establishment. Hence, when the Burdekin experiment was returned to sugarcane each plot was split to four different nitrogen rates (Table 1). These combined with different levels of starting soil nitrogen (Fig. 6) established a range of soil nitrogen at planting. These differential nitrogen levels had no significant effect on early crop establishment (up to day 58 - Fig. 7). However, between days 58 and 80 there was a major increase in shoot number through the development of secondary tillers (Fig. 7). Nitrogen appears to have had a major effect on secondary tiller development, particularly in the plough-out/re-plant treatment. Further, shoot numbers were reduced in all treatments from 80 days after planting (Garside *et al.*, 2000 and Fig. 1). Nitrogen acted to reduce the magnitude of this shoot loss (Fig. 8). This effect of nitrogen on tillering and subsequent shoot maintenance substantially reduced the yield differential between breaks and plough-out/re-plant (Table 4).

Table 4 – Effect of nitrogen rate on mean cane yield (t/ha) following breaks and plough – out/re - plant in the Burdekin rotation experiment

N Rate (kg/ha)	Yield Plough – Out/Re-Plant	Mean Yield Breaks	% Increase from Breaks
0	98	141	43
50	112	152	42
0 + 180	132	158	20
50 + 130	136	154	13

General Discussion:

The results from these studies clearly show that the long-term sugarcane monoculture is having an adverse effect on sugarcane productivity. In every rotation experiment carried out in this series, breaks have clearly outyielded plough-out/re-plant. Further, the effect is carrying through to the ratoon crops. In the Bundaberg experiment, where three cane crops have now been harvested since the breaks were returned to sugarcane, the annual average yield increase for a break of 12 months has been of the order of 10% (Table 2). Observations are suggesting that a similar yield response will be recorded in the third ratoon when it is harvested this year. In the legume cropping break in this experiment, two legume crops were grown during the 12 month break period, a crop of peanuts yielding 6.9 t/ha nut-in-shell and a crop of navy beans yielding 1.7 t/ha. The combined gross margins for these two crops was in excess of \$4,000 per hectare, obviously a very economical return to the grower from foregoing one crop of sugarcane. In the other experiments where longer breaks were incorporated (e.g.

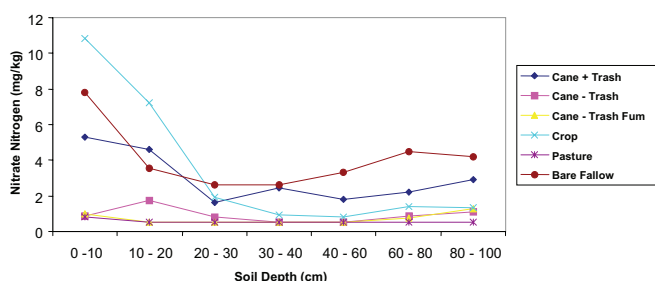


Figure 6: Soil nitrate nitrogen levels for different breaks in the Burdekin Rotation experiment prior to re-planting to sugarcane. Lsd 5% for increasing depth increments = 8.6, 5.8, 1.8, 1.5, 2.2, 4.2, 4.4, respectively.

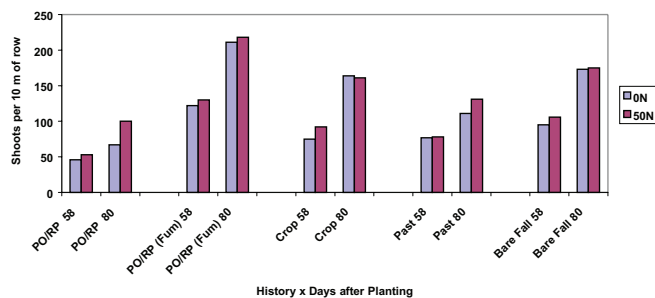


Figure 7: Shoots per 10 m of row at 58 and 80 days after planting (DAP) the Burdekin rotation experiment with 0 or 50 kg/ha basal nitrogen fertiliser. Lsd 5% (N rates in history) = nsd (58DAP), 32 (80 DAP).

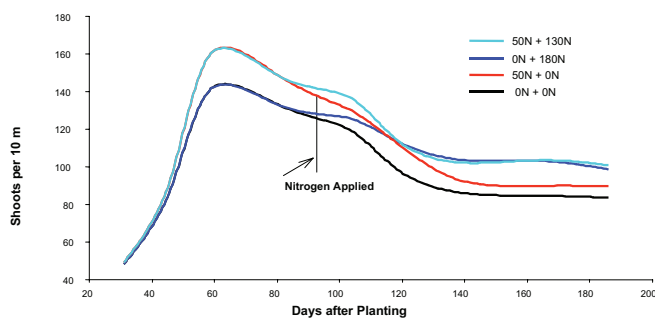


Figure 8: Effect of nitrogen rate and timing on shoot/stalk maintenance in the Burdekin rotation experiment

Mackay) the magnitude of the break effect was increased substantially in the plant crop (57%) and although reduced was still substantial in the first ratoon (16%) (Table 2). Similarly, the 42 month break in the Burdekin resulted in a plant crop yield increase of 26% over plough-out/re-plant. Again, observations are indicating differential yield responses in both experiments in the next ratoon.

The yield response to breaks appears to be manifested through two phases in crop development, an establishment phase and a subsequent growth phase, which appear largely dependent on different factors. The establishment phase, which in these experiments occurred over the first 60 – 80 days after planting, is characterised by substantial differences in primary shoot establishment between plough-out/re-plant and various breaks. This phase appears to be largely independent of soil type, environment and management as it occurred in all of these experiment across different soils, environments and management inputs. The data presented here suggests that this phase is clearly associated with biotic factors. However, it is not clear whether these biotic factors are simply a result of the sugarcane monoculture, an effect of how that monoculture is practiced, or a combination of both. Degraded soil chemical and physical properties have been shown to occur under intensive sugarcane monoculture in both Australia (Bramley *et al.*, 1996, Garside *et al.*, 1997b) and South Africa (Meyer *et al.*, 1996, Van Antwerpen and Meyer, 1996). It is certainly possible that the biotic factors involved in poor soil health may, in part, be an effect of degraded soil chemical and physical properties and this warrants further investigation.

In the post establishment or subsequent growth phase it appears that the initial effect of reduced early shoot development can be compensated for through a high level of crop management. For example, in the Burdekin experiment, which experienced high levels of solar radiation, was fully irrigated and had different rates of nitrogen applied, the yield differential between the breaks and plough-out/re-plant changed from 43% with no nitrogen to 13% when 180 kg/ha was applied in two applications of 50 and 130 kg/ha. In other studies in the Burdekin environment, Muchow *et al.* (1994) measured only a 6% yield increase between fumigated and unfumigated sugarcane when 270 kg/ha N was applied in three applications. Similarly, Garside and Nable (1996), in paired site studies, showed no difference in yield between plough-out/re-plant cane and cane grown after a two year pumpkin break, despite large differences in early shoot development.

The general pattern that emerges is that the yield decline phenomenon (the adverse effect of long-term monoculture or poor soil health) is likely to occur in all sugarcane growing areas in Australia and probably elsewhere. However, the magnitude of its impact on crop yield will be dependent on crop management. The data presented here is suggesting that the long term monoculture will only have a small impact on final yield in high input production systems. That is not to say that soil health problems are not occurring in high input systems, more so that their effect is being masked. Further, other factors may well emerge in high input systems to adversely effect productivity. For example, major canegrub problems in the Burdekin are being related to the farming system that is currently practiced

(Robertson and Walker, 1996). Regardless, in areas with more marginal soils, limited water/irrigation, and reduced capacity to provide an optimum nutrient regime the impact of reduced soil health is likely to be substantial. A considerable amount of world sugarcane production is carried out under less than optimum conditions. It is in these situations that more attention to soil health through breaking the monocultural system is likely to improve productivity and sustainability.

Acknowledgments

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