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FINAL REPORT - SRDC PROJECT BSS168
SUSTAINING UN-BURNT PRODUCTION SYSTEMS IN COOL WET ENVIRONMENTS

by

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EXECUTIVE SUMMARY

This project was initiated because the Green Cane Trash Blanket (GCTB) system had been rapidly adopted within tropical districts of the Queensland sugar industry between 1984 and 1990, yet there was minimal adoption in the cool and humid districts in northern NSW. Broad adoption in the tropics was interpreted by the community as a signal that the GCTB system was suitable for the whole of the Australian sugar industry; this was particularly the case in northern NSW where there is a high reliance on the tourist industry, with little tolerance of the ash and smoke fall-out associated with the burnt-cane system. Additionally, this region has a significant non-cane affiliated population, which is also not sympathetic to the issues associated with the pre-harvest burning of sugarcane.

In the mid-late 1990s, the NSW sugar industry was also involved in a major R&D and public relations exercise with management of the acid-sulfate soils issue. The potential of additional restrictions in farm management, in terms of regulations to prevent the pre-harvest burning of cane was seen as a "staying in business issue" (P Nielsen, personal comm.), because of the perceived negative impacts that trash retention would have on industry viability. There were no rational data to support the above contention when this project was conceived in 1995. Therefore, the project was designed to acquire data to quantify the impact on productivity and profitability of several trash-management strategies to provide data for development of a policy for fire and trash management in NSW and similar industry environments.

In 1996, sites at South Arm (Harwood area) and Empire Vale (Broadwater area) were planted to Q124. Different trash-management treatments were applied for early and late harvest (early August and early December, respectively) of plant cane at both sites in 1997. Trash-management treatments included trash removal (burning or physical removal of trash), raking trash from the stool, and retention of a full trash blanket. Early established first-ratoon crops were also subjected to rainfed and irrigated moisture regimes. A mid-season harvest treatment was also applied to the South Arm site for second- and third-ratoon crops. Experiments were terminated in 1999 after harvest of third-ratoon crops.

Retention of trash after the early harvest had a negative impact on cane and sugar yield for both sites. However, trash retention had non-significant to positive effects on productivity from mid-season (mid-September) at the drier site in the Harwood area, largely because of the effects of trash on soil-moisture conservation. Trash retention on the heavy clay soils at the higher rainfall site in the Broadwater area was always associated with reduced productivity.

These conclusions on productivity were supported by gross-margin analysis in relation to the burnt two-year production system as a standard.

Capacity of trash retention to assist with conservation of moisture and maintenance of lower soil temperatures was confirmed by measurement of these parameters across trash-management regimes. However, these data were also instrumental in supporting the conclusion that the adverse effects of trash on ratooning, after early harvest, were due to an interaction of possible allelopathic and thermal mechanisms.

Crop-physiology data showed that early harvested trash-retention treatments could achieve similar stalk populations to burnt-cane treatments, but the population development in the GCTB treatments was due to late developing secondary shoots, which resulted in a large proportional population of smaller stalks in the GCTB than in burnt-cane treatments. Excavation of stools of ratoons, established in early August, across trash-management regimes showed that the GCTB system suppressed bud development and was associated with rotting of stubble from the previous crop.

We concluded that the GCTB system was not profitable and, therefore, was unsustainable for harvests in the Harwood and Broadwater areas before mid-September. Raking trash from the stool was a successful strategy for minimising the impact of trash retention on cane yield. The GCTB system could be applied successfully to drier or well-drained areas from mid-season, because of the benefits of moisture conservation. Trash retention always produced a poorer result than did trash removal on the heavy clay soils in the higher rainfall zone at Empire Vale. This result is consistent with observations from Colombia of adverse impacts on yield of phytotoxic substances leached from fresh trash, even in tropical environments. The higher rainfall environments also minimise opportunity for improvement in relative yield of trash retention treatments from moisture conservation by the residues.

These results confirmed the concerns about the negative impact on productivity of the GCTB system held by a significant number of NSW canegrowers. These data (plus trading in carbon credits) may have been instrumental in supporting investigations for total biomass harvest to provide fuel for cogeneration of electricity by NSW sugar mills. A successful outcome in this area would allow emplacement of green-cane harvesting and provide a solution to the difficult issue of subsequent management of crop residues.

The project resulted in a significant program of extension, technical presentations and publications as well as providing a resource for value adding research in the understanding of carbon and nitrogen cycling in the GCTB system, the modelling of trash decomposition, and a student project in controlled conditions.

The project could not have been undertaken without support from SRDC, BSES and the NSW Sugar Milling Cooperative Ltd and the valuable cooperation of the canegrowers (Stuart McSwan and Tony O'Connor).

1.0 BACKGROUND

The green-cane trash-blanket (GCTB) production system was progressively adopted by the Australian sugar industry from the late 1970s, after the introduction of machines with green-cane harvest capability. This development arose because of industry concerns with the large amount of burnt cane subjected to pre-harvest deterioration during the 1976 harvest.

Adoption was rapid in the Mulgrave/Babinda and Herbert regions (the latter progressing from 0% green harvest in 1979 to 27.5% in 1985). By 1995, the Australian industry had achieved 47.4% adoption of green-cane harvest, and this included almost 100% adoption in the Herbert and several other tropical districts. The level of full GCTB adoption is undetermined and at a somewhat smaller level than the GCTB harvest statistics because of the practice of post-harvest burning of residues. Adoption in the Burdekin region was constrained to less than 5% primarily because of issues related to harvestability of large green crops and difficulties associated with furrow irrigation in trash-blanketed fields (Holden and McMahon 1997).

Slow and low adoption in southern districts (Nambour and Rocky Point) were related to reports of slower ratooning and lower productivity under the GCTB system than with burnt systems in cool and wet conditions. Comparative data for burnt and GCTB systems over three harvests (1992-95) for a poorly drained soil in the Isis region and a clay soil at Rocky Point demonstrated slower ratooning under trash, but yield was ranked in the order GCTB>trash-raked-from-stool>burnt (Ridge 1997). These were 'drier than average' seasons, but there was a small and non-significant yield response to drainage improvements by mounding the stool.

Adoption of the GCTB system in northern NSW in 1995 stood at 2.4% (range 0.2-5.4%). This low adoption was driven largely by concerns about adverse impacts of trash on productivity and the same harvesting issues that apply in the Burdekin, but in this case to large two-year old crops. The low adoption of the GCTB system in NSW ran counter to community expectations of the industry in a region with a significant tourist and residential population with little affiliation with the sugar industry. Pressure for wider adoption of the GCTB system was mounting in parallel with criticism of the industry's record of managing acid-sulfate discharge. Industry leaders in NSW interpreted avoidance of forced regulation into adoption of GCTB as a 'staying in business' issue. This project was developed against the background of absence of documented data to support industry perceptions, or information to provide guidance on best-management practice to allow some increased adoption of GCTB in the NSW production system.

2.0 OBJECTIVES

- Quantify the impact of alternative trash-management strategies and irrigation on soil water, temperature and microbiological regimes and productivity in one-year production systems in NSW;

- Contribute data to a modelling framework to provide generic understanding of the impact of trash on soil water and temperature regimes throughout the Australian industry;
- Use project data and extension resources to quantify or dispel respective industry and community concerns about sustainability of green and burnt production systems.

3.0 METHODOLOGY

3.1 Rationale

The NSW production system has had a strong reliance on two-year old cane to sustain yield and CCS. Reliance on two-year cane follows the order Harwood>Broadwater >Condong. Low yield accumulation in annual crops was a function of poor drainage, generally cooler growing conditions than in Queensland, and available varieties. Dramatic improvements to farm and field drainage were effected with adoption of laser levelling technology and, from the late 1980s, superior varieties with annual cropping capacity were being introduced and adopted. Therefore, we chose to apply known best-management practice to this project so that outcomes would be forward looking, rather than retrospective. Thus, we focused solely on the agronomic/productivity aspects of a one-year cropping system and did not address issues associated with capability of machines for green-cane harvest of large lodged crops.

As ‘wet conditions’ were significant issues in reservations about adoption of the GCTB system, we needed to select sites where irrigation could be applied to ensure ‘wet conditions’ for early establishment of ratoons. There was evidence from Colombia (J Torres, pers. comm.) that rainfall events on trash within 2 weeks of harvest were significant in adverse effects on ratooning. This information and logistical issues led us to irrigation regimes to maintain soil at or near field capacity for the first 9 weeks after harvest, rather than those that would impose waterlogged conditions and introduce potential for confounding effects of trash and waterlogging.

3.2 Experiments

Field trials were established at two sites. The site at McSwan's farm at South Arm on Woodford Island (29° 30' 54"S, 153° 11' 08"E) in the Harwood Mill area was established across alluvial and clay soils, with irrigation water piped to the site from a small dam. The site at O'Connor's farm at Empire Vale (28° 54' 41"S, 153° 30' 59"E) in the Broadwater Mill area was established on a cracking clay soil, where irrigation water was applied from a storage tank filled with bore water brought to the site in a tanker. Irrigation was applied from sprinklers (Plate 1) and was scheduled from tensiometers. Soil analysis did not reveal potential for any nutrient disorders at either site.

Plate 1 - Irrigation sprinklers at the South Arm site - August 1996

Table 1
Establishment and harvest dates for trash management experiments at the South Arm and Empire Vale sites in northern NSW

Harvest period and crop class	South Arm - Harwood	Empire Vale – Broadwater
Early season harvest		
First ratoon	9/8/96 - 14/8/97	5/8/96 - 18/8/97
Second ratoon	18/8/97 - 4/8/98	25/8/97 - 10/8/98
Third ratoon	6/8/98 - 24/8/99	10/8/98 - 11/12/99
Mid-season harvest		
Second ratoon	17/9/97 - 29/9/98	
Third ratoon	3/10/98 - 24/8/99	
Late-season harvest		
First ratoon	27/11/96 - 15/12/97	2/121/96 - 15/12/97
Second ratoon	16/12/97 - 7/12/98	18/12/97 - 11/12/98
Third ratoon	8/12/98 - 24/8/99	11/12/98 - 12/12/99

Both sites were land planned prior to planting in October 1995 with the variety Q124. There was some settling of soil at the South Arm site, which caused a small depression around two plots on the alluvial soil. Cane rows were mounded prior to the ‘out of hand’ stage in plant cane and a minimum tillage system was applied to the ratoon crops. Early and late-harvest experiments were established at both sites; early harvest was designed to occur in the second round of the harvest season, usually the first week in August, and the late harvest in late-November to early December (Table 1). A mid-season harvest experiment was also established in 1997 at the South Arm site only; mid-season establishment occurred from mid-September to late-September for second- and third-ratoon crops, respectively (Table 1). Experiments were harvested as first, second and third ratoons in 1997, 1998 and 1999, respectively. All three ‘harvest time’ experiments at South Arm were harvested at one time in late August 1999 to facilitate a plough-out operation, but wet conditions at Empire Vale prevented implementation of a similar strategy and final the harvest of both ‘harvest times’ was delayed to mid-December 1999.

Experiments were established as split-block designs, with irrigation and rainfed treatments as blocks and trash management as the sub-plot treatments. Trash-management treatments were: simulated burnt-cane management; trash raked from the row into the inter-row; and a green-cane trash-blanket. Restrictions of space within soil types at the South Arm site resulted in two replications of each treatment on each soil type for the early harvested first-ratoon crop, and four replications for all other harvests after discontinuance of irrigation treatments. There were four replications of each treatment for the early harvested first-ratoon crop at the Empire Vale site and eight replications for all other harvests.

Gross plot size was 15 m long by six rows wide, with net harvested plot area being 14 m by four rows. Harvest was accomplished with a commercial harvester and a weigh bin on all occasions, except the final harvest at Empire Vale where the Hogarth and Skinner sampling method was applied because of persistent wet field conditions. Trash raking was undertaken with the trash rake developed in BSS144. The simulated burnt-cane treatment was accomplished by raking and removing trash from plots after plant-crop harvest (Plate 1), and by burning trash *in situ* after first-ratoon harvest (Plate 2).

Plate 2 - Trash was burnt *in situ* after the first-ratoon harvest

Shoot populations were monitored in defined 5-m sections of row in two replicates of each treatment until stalk populations stabilised in late summer. The second ratoon of the early harvest trial at South Arm was subjected to an investigation of bud morphology and the timing of emergence of shoots. Two stools were dug from each trash-management treatment, washed free of soil, and examined for bud and shoot activity at 4, 8 and 12 weeks after ratooning and one of the 5-m shoot-population rows had monthly emergence of shoots marked with colour coded tags to allow monitoring of the sequence of shoot emergence.

First-ratoon crops in late-season-harvest trials were sampled at both sites in March 1997 for third-leaf laminae, which were then analysed to determine any impact of trash management on crop nutrient status.

Automatic weather stations were established within 200 m of each site to record daily rainfall, run of wind and solar radiation in addition to air temperature data (maximum, minimum and temperature at 09:00 and 15:00 hours). Each site was instrumented to log moisture and temperature of soils in two replicates of the various treatments, with the exception of the clay soil at South Arm where only one replicate was monitored. Soil moisture was logged from Campbell 6005L2 TDR buried wave-guides, installed at 10 cm depth in the row and inter-row. Soil temperature was logged from Campbell 107B probes buried at 10 cm depth in the row and from one 50-cm-deep probe at each site.

The McSwan site was used by Drs F Robertson and P Thorburn as the southern site in a CRC-Sugar activity to quantify in-field decomposition of trash across the sugar industry and for development of trash decomposition models. Soil from this site was also used by Ian Francis (honours student at UNE) for a growth-chamber study of impacts of trash and thermal regimes on bud germination of sugarcane.

4.0 RESULTS

4.1 Comparison of climate data

Long-term rainfall for the South Arm site was estimated as the 111-year average of Maclean ($29^{o}\,26^{'}$ S, $153^{o}\,13^{'}$ E) and Lawrence ($29^{o}\,29^{'}$ S, $153^{o}\,05^{'}$ E) data, as the field site is located between these two stations. Long-term rainfall for the Empire Vale site was approximated from 107 years of data from Ballina ($28^{o}\,52^{'}$ S, $153^{o}\,34^{'}$ E), as the field site is 6.5 km SSW of the Ballina weather station. Temperature and radiation were recorded from on-site automatic weather stations.

The South Arm site is inland and is in a lower rainfall zone than the near-coastal Empire Vale site (Table 2). Rainfall for the experimental period (Table 3) was close to the annual average for Empire Vale and slightly below average for South Arm for the first-ratoon crop in 1996-97; rainfall was below average for the second-ratoon crop in 1997-98 for both sites, particularly for January to April 1998. Rainfall for the third-ratoon crop in 1998-99 was well above average, particularly in the period January to June 1998; above-average rainfall during the 1999-crushing season caused the major delay to the final harvests at Empire Vale.

The geographic locations of the sites also influenced temperature regimes (Figure 1), with South Arm site generally demonstrating higher maximum and lower minimum daily temperatures than did the Empire Vale site. The South Arm site showed slightly lower daily radiation values than did the Empire Vale site (Figure 3). Apart from any variation in cloudy periods between sites this difference may be associated with the location of the

South Arm field site on the eastern side of Woodforde Island and in the lee of the major north-south ridge that places the site in shadow well before sunset.

Table 2
Average monthly rainfall (mm) for Ballina and Lawrence/Maclean composite

Site	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Year
Ballina	181	200	213	179	201	166	137	100	72	92	103	141	1788
Lawrence/ Maclean	132	150	153	113	105	53	72	47	48	66	89	108	1153

Table 3
Monthly rainfall (mm) for Empire Vale and South Arm for the duration of first-, second- and third-ratoon crops

Site	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Year
Empire Vale													
1996-97	109	65	30	88	226	125	152	147	142	113	347	194	1738
1997-98	336	46	124	101	58	141	51	96	30	286	180	114	1563
1998-99	142	170	109	37	216	141	169	467	389	226	243	388	2697
1999-00	357	210	78	220	151	177	-	-	-	-	-	-	-
South Arm													
1996-97	33	29	24	55	79	101	98	182	126	13	162	66	968
1997-98	37	2	38	82	84	60	40	168	47	139	45	55	895
1998-99	72	56	124	44	84	92	195	238	199	159	150	163	1576

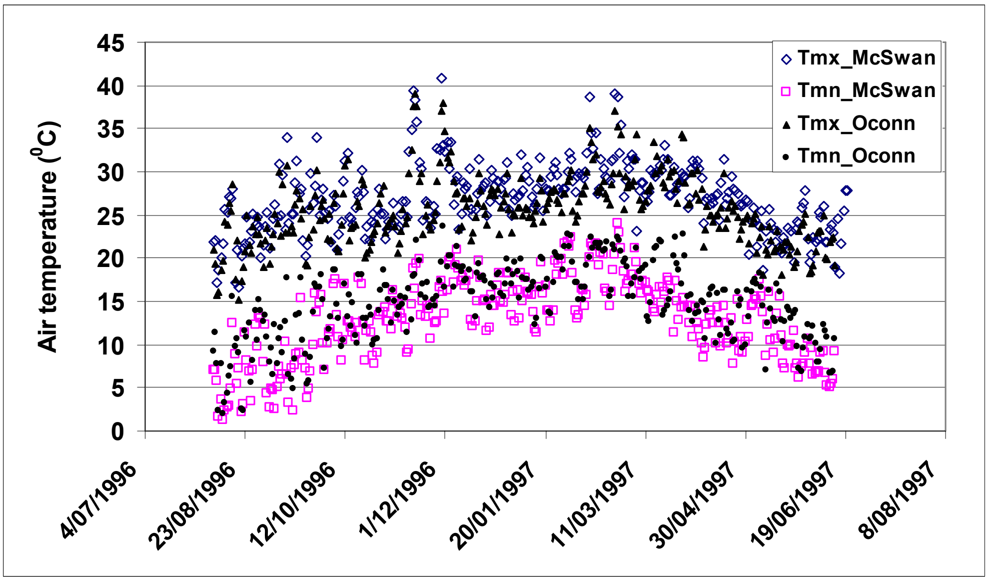


Figure 1 - Daily maximum (Tmx) and minimum (Tmn) temperature from automatic weather stations at the South Arm (McSwan) and Empire Vale (O'Connor) field sites between August 1996 and June 1997.

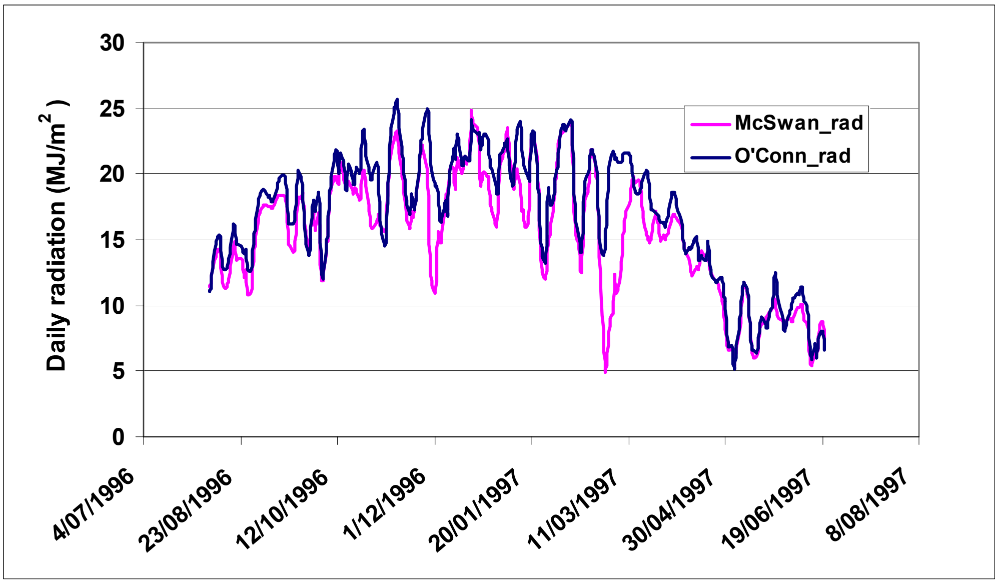


Figure 2 – Five-day moving average for daily radiation (MJ/m^2) from automatic weather stations at the South Arm (McSwan) and Empire Vale (O'Connor) field sites between August 1996 and June 1997

4.2 Yield data

Cane yield, CCS and sugar yield for each harvest period at both sites are detailed in Appendices 1-3, along with relevant statistical data.

4.2.1 South Arm

4.2.1.1 Early-season harvest

First ratoon

Early harvest of the first-ratoon crop showed cane yields from the trash-management treatments were ranked burnt>raked >GCTB (Table A1a). The 4.4 t/ha difference in cane yield between the burnt and raked yield was not significant ($p<0.05$), but retention of a full trash blanket depressed yield significantly by a further 14.1 t/ha below the raked result. There was no significant difference in cane yield between alluvial and clay soils for the first-ratoon crop.

The effect of irrigating in the 12 weeks after harvest was significant only at the 12% level and the interaction between irrigation and trash-management treatments was significant at the 10% level (Table A1b). Rain-fed yield was higher than irrigated yield, with the difference achieving significance ($p<0.10$) for burnt and GCTB treatments. The interaction arose because cane yield for trash management was ranked burnt>raked >GCTB in the rain-fed treatment, but as raked>burnt>GCTB in the irrigated treatment. The irrigated GCTB treatment gave the lowest yield. This effect was probably confounded with poorer surface drainage, caused by soil settling after land planing, in two of the four irrigated GCTB replicates.

The irrigation treatment was not applied to the second-ratoon crop because of the absence of any interaction effects with trash management at the heavier soil site at Empire Vale in the first ratoon and because the first-ratoon irrigation effect at South Arm was significant only at the 12% level. Examination of data for three ratoon crops showed plots allocated to GCTB and irrigation in the first ratoon at South Arm were usually the lowest yielding in each year, again probably due to the drainage.

CCS from raked treatments in first-ratoon cane was significantly higher ($p<0.05$) than in the burnt and raked treatments (Table A1a). No mechanism was evident for this effect and irrigation did not affect CCS (Table A1b).

Sugar-yield trends from trash management in the first-ratoon crop were raked>burnt>GCTB (Table A1a), with the change in ranking from cane yield being due to higher CCS of the raked treatment. While there was a trend to lower sugar yield with irrigation, the effects were not significant (Table A1b). Also there was no significant interaction for irrigation and trash management.

Second ratoon

Trash-management treatments had no significant effect on cane yield for the early harvest of the second-ratoon crop in 1998 (Table A1e). Treatments were ranked raked>burnt >GCTB, with the difference between raked and GCTB yield being only 7.7 t/ha. The effect of soil on yield was significant at the 10% level, as was the soil by trash-management interaction. Yield from the clay soil was superior to the alluvial soil, and the interaction arose because of the change in yield ranking from burnt>raked>GCTB on alluvial soil to raked>GCTB>burnt on the clay soil (Table A1e).

CCS of cane from clay soil, at 11.73 units, was significantly higher than the value of 10.65 from the alluvial soil ($p<0.05$). The soil by trash-management treatment interaction was not significant (Table A1e)

Effects of trash management, soil type and their interaction were all significant ($p<0.05$) for sugar yield. Sugar yield for trash management was ranked raked>GCTB>burnt; sugar yield was higher on clay than alluvial soil, and the interaction was significant because of the change in ranking of the trash-management treatments across soils. On alluvial soil, the ranking was GCTB>raked >burnt and on clay soil it was raked >GCTB>burnt (Table A1e).

Yield of treatments with retained trash was closer to, or superior to, the burnt treatment for the early harvest of the second ratoon because of moisture-conservation benefits of the trash in the drier than average summer growing period in 1997-98.

Third ratoon

The third-ratoon crop was harvested on 24 August 1999. Effects of trash-management treatment and the soil by trash-management interaction were significant for cane yield at the 5% level (Table A1h). Soil type had no significant effect on cane yield. Cane yield was ranked in the order burnt>raked >GCTB, with burnt yields being significantly greater than yields with trash retention. The interaction term was significant because yields on alluvial soil were greater than for clay in bare and raked treatments, but GCTB yield was highest on the clay soil.

There were no significant trash treatment or soil effects on CCS for the early harvest of the third-ratoon crop (Table A1h).

Trash management and the soil by trash-management interaction were significant for sugar yield at the 5 and 10% levels, respectively. Sugar yield was ranked as for cane yield (Table A1h) in relation to trash-management treatment and each step down in yield below the burnt value was statistically significant. The interaction term resulted from the same change in rank order as for cane yield.

4.2.1.2 Mid-season harvest

Second ratoon

There were no significant effects from soil, trash-management treatments or their interaction for cane yield in the mid-season harvest of the second-ratoon crop. Cane yield was however ranked GCTB>raked>burnt (Table A1f), reflecting the benefits of trash retention in a drier summer. A similar effect also occurred for the early harvest in 1998.

The only significant treatment effect for CCS in this harvest came from trash-management treatments, with burnt cane having significantly higher CCS (Table A1f) than the trash-retention treatments ($p<0.05$). This effect may have been associated with greater stress and lower cane yield in the burnt plots.

The effect of trash management on sugar yield was significant only at the 15% level (Table A1f), and treatments were ranked, raked >GCTB>burnt.

Third ratoon

The mid-season harvest was brought forward to 24 August 1999 to facilitate plough-out of the field and termination of the experiment. This strategy would have had only minor impact on results, as the major effect under investigation is the impact of trash management on ratooning and subsequent growth. The third ratoon was established on 8 October 1998.

The only significant effect on cane yield was associated with trash-management treatments ($p<0.05$). Cane yield was ranked in the treatment order, burnt>raked>GCTB, with burnt yields being significantly greater than where trash was retained (Table A1h). This ranking of treatments reflects the wetter than average spring and summer of 1998-99 and lack of opportunity for trash retention to improve yield through moisture conservation.

There were no significant soil or trash-management effects on CCS.

Trash treatments caused the only significant effects for sugar yield ($p<0.05$), with treatments being ranked as for cane yield, burnt>raked>GCTB. Burnt yields were significantly higher than were yields in the GCTB treatment (Table A1h), but differences between burnt and raked or between raked and GCTB were not significant.

4.2.1.3 Late-season harvest

First ratoon

Irrigation was not applied to the developing first-ratoon crop after late-season harvest of plant cane.

Effects for soil type, trash management treatment and their interaction on cane yield were significant at 5, 15 and 10% probability levels, respectively, at this harvest. Yield was higher on the alluvial soil than on the clay soil (Table 4). Trash treatments were ranked in the order GCTB>raked>burnt for cane yield across soils, with GCTB yield being significantly higher than for burnt and raked treatments; the latter were not significantly different. The interaction for trash management and soil type was significant because rank order for yield was GCTB>burnt>raked in the alluvial soil and raked>GCTB>burnt on the clay soil (Table A1d).

CCS from the clay soil, at 15.23 units, was significantly higher ($p<0.05$) than for the alluvial soil at 14.96. Neither the trash-management treatments nor the interaction with soil type achieved significance for CCS.

Both soil type and trash-management treatment registered significant effects ($p<0.05$) for sugar yield. The alluvial soil produced significantly more sugar than did the clay soil. Yield from GCTB treatments was significantly higher than the raked and burnt-cane yields and the latter two were not significantly different (Table A1g).

Second ratoon

There were no statistically significant effects of soil or trash management on cane yield, CCS or sugar yield for this harvest.

There was a large, but not significant, cane yield advantage of alluvial over clay soil for this harvest (124 compared to 106 t/ha). Differences between trash-management treatments for cane yield generally were small on the clay soil (5-8 t/ha), but the GCTB treatment on the alluvial soil was 6.6 and 11.6 t/ha less than raked and burnt cane yields, respectively (Table A1g).

Trends in sugar yield mirrored those of cane yield with respect to soil type and trash-management effects. The second-ratoon crop year was drier than average (Table 3).

Third ratoon

Soil type was the only factor to register a significant impact on cane yield for the third-ratoon harvest, with highest yield coming from alluvial soil (Table A1j). There were only small yield differences between trash-management treatments within soil types (Table A1k), with burnt-cane yield approximately 4 t/ha higher than the trash-retention treatments when averaged over soil types.

There were no significant effects for CCS at this harvest.

Soil type and the soil-type by trash-management interaction had significant effects ($p<0.10$) on sugar yield. The average sugar yield of 13.1 t/ha from the alluvial soil was significantly higher than the 10.9 t/ha from the clay soil. The difference in sugar yield between trash-management treatments, within soil types, was small (Table A1k). The interaction term was significant because of a change in ranking of sugar yield for trash-management treatments in the two soils; the order was GCTB>raked>burnt on the alluvial soil and burnt>raked>GCTB on the clay soil (Table A1k). This order was similar for cane yield, but the interaction was not significant ($p<0.10$).

It is of interest to note that while soil type effects achieved statistical significance in only three of the eight harvests at South Arm (Table 4), the clay soil provided superior yield for two of the three early harvests and for one of the mid-season harvests; yield differentials were less than 10 t/ha. The alluvial soil consistently out-yielded the clay soil for ratooning from late harvest, with yield differentials between 13.2 and 18 t/ha. We interpret this effect as one of improved moisture retention in clay soil assisting crop development in spring and early summer for the early harvested crops, but establishment and early growth of the late-harvested crop being constrained by poor internal drainage for some or all months between December and April.

Table 4
Ranking of cane yield by soil type and difference in yield associated with clay and alluvial soils at South Arm across three ratoon crops

Crop year, class	Harvest period		
	Early season	Mid-season	Late-season
1997-98, 1 ratoon	Clay>alluv, 5.5 t/ha	-	Alluv>clay, 13.2 t/ha, **
1997-98, 2 ratoon	Clay>alluv, 9.5 t/ha, *	Alluv>clay, 4.0 t/ha	Alluv>clay, 18.0 t/ha
1998-99, 3 ratoon	Alluv>clay, 3.1 t/ha	Clay>alluv, 6.0 t/ha	Alluv>clay, 14.7 t/ha, **

*= significant ($p<0.10$), ** = significant ($p<0.05$)

4.2.1.4 Cumulative yield effects across years

Cumulative cane and sugar yield and average CCS for the three ratoon crops at South Arm are summarised in Appendix 3, while average cane yields are depicted in Figure 3a-b.

Early season harvest
Trash-management treatments had a significant effect ($p<0.05$) on cane yield after early season harvest, across the three ratoon-crops (Table A3a). Both burnt and raked cane yield were significantly higher than GCTB yield, but burnt and raked yields were not significantly different (Table A3a). There were no significant effects of trash management on average CCS, but CCS from the alluvial soil was significantly higher ($p<0.10$) than from the clay (12.52 compared to 12.20). The effect of trash management on sugar yield was significant ($p<0.05$) and followed the same order as for cane yield. The GCTB treatment produced 5.6 tonnes less sugar/ha than the burnt treatment over three crops (Table A3a), but the raked treatment produced only 0.5 tonnes less sugar/ha than did the burnt treatment. The soil-type by trash-management interaction was

significant for sugar yield (p<0.12), because burnt- and raked-treatment rankings changed across soil types (Table A3b); the raked treatment gave the highest sugar yield on the clay soil. Thus, we conclude that raking trash from the row is a useful strategy for minimising the adverse effects of trash retention for early harvest in the South Arm environment.

Mid-season harvest
There were no significant effects of soil type or trash management on cane yield across second- and third-ratoon mid-season harvests at South Arm. Both soils produced similar yields (Table A3c), and, while cane yield was ranked burnt>raked>GCTB, the GCTB treatment produced only 6.2 tonnes less cane/ha than did the burnt treatment (Table A3a). The similarity of the yield data is also demonstrated in Figure 3a. Effects of soil type and trash management on CCS were significant at 12 and 5% levels, respectively. CCS was higher on the clay than on the alluvial soil (Table A3c). CCS of raked cane was significantly higher than in GCTB treatments and the latter was significantly higher than for burnt cane (Table A3a). There were no significant effects for sugar yield, but the trash treatments were ranked raked>burnt>GCTB, with only 0.4 tonnes of sugar/ha difference between raked and burnt, and 1.3 tonnes/ha between raked and GCTB.

Late-season harvest
The effect of soil type on cane and sugar yield over three late-season ratoon-crop harvests at South Arm was significant (p<0.05 and 0.10, respectively), with alluvial soil producing 45.9 tonnes more cane/ha and 5.9 tonnes more sugar/ha than the clay soil (Table A3c). As for the mid-season harvest across crops, the difference in cane and sugar yield from the trash-management treatments was minor (Table A3a and Figure 3b for cane yield). Trash-management treatment was significant (p<0.10) for CCS only, with CCS ranked in the treatment order rake>GCTB>burnt; the rake-burnt difference was the only comparison to achieve significance.

4.2.2 Empire Vale

4.2.2.1 Early-season harvest

First ratoon
Irrigation had no significant effect on cane and sugar yield or CCS for the first-ratoon crop on the vertosol soil at Empire Vale. Trash-management treatments had a significant effect (p<0.05), with cane and sugar yield ranked in the order burnt>raked>GCTB (Table A2a). Yield differences of 10.6 tonnes cane/ha between burnt-cane and raked plots and 18 tonnes cane/ha between burnt-cane and GCTB plots were significant, but the difference between raked and GCTB was not significant. The interaction between irrigation and trash management was not significant, with the non-irrigated plots producing slightly more cane and sugar than the irrigated areas for each trash management (Table A2b).

Second ratoon

The early harvest of the second-ratoon crop was not irrigated. There were no significant effects of trash management on cane and sugar yield or CCS. Cane and sugar yields were ranked in the treatment order burnt>raked>GCTB (Table A2c). Cane yield in the burnt treatment was similar to the first ratoon, but yield in the trash-retention treatments was higher in the second-ratoon crop. Rainfall data in Table 3 show that the first 2 months for establishment of the second ratoon had substantially higher rainfall than for the first-ratoon crop, but the main summer growing season for the second ratoon was much drier. Therefore, it is likely that moisture conservation of the trash allowed trash-retention treatments to narrow some of the establishment advantage gained by burnt cane (see 5.1 Comparison of climate data).

Third ratoon

The summer, autumn and winter periods for the third-ratoon crop year at Empire Vale were abnormally wet and the scheduled early season harvest of the third ratoon was delayed until December by the inclement rainfall pattern. Rainfall during establishment and growth resulted in trash retention giving significantly lower ($p<0.05$) cane and sugar yield than for removal of trash by burning (Table A2d). Yield differences between raked and GCTB plots were not significant. There was no significant effect of trash management on CCS, even though there was a large difference between raked and GCTB treatments (Table A2d).

4.2.2.2 Late-season harvest

First ratoon

Late-season harvest of the first-ratoon crop produced a similar trend in cane and sugar yield with the trash-management treatment to that observed at the early season harvest and absolute differences in yield between treatments were also similar. Yield was ranked burnt>raked>GCTB (Table A2a), with the difference between burnt and both trash-retention treatments being significant ($p<0.05$). The difference between the raked and GCTB yields was not significant. There were no significant effects for CCS.

Second ratoon

The drier second-ratoon crop year resulted in higher overall yield for the late harvest than did the first-ratoon crop and, as for the early harvest in the second ratoon, there were no significant trash-treatment effects for cane and sugar yield or CCS. However, unlike the early harvest in 1998, late-harvest cane and sugar yields were ranked GCTB>bare>raked (Table A2c), but the yield range was narrower than for the early harvest.

Third ratoon

The late-season harvest of the third-ratoon crop at Empire Vale resulted in the familiar pattern of trash retention having a significant and negative effect on cane and sugar yield ($p<0.10$) under wet conditions. For this harvest, the yield ranking was burnt>GCTB>raked; yield from the burnt treatment being significantly higher than for both trash-retention treatments (Table A2d). The difference in yield between GCTB and raked trash was not significant. Absolute cane yields were similar to those from the late-season harvest of the first-ratoon crop. There were no significant effects for CCS.

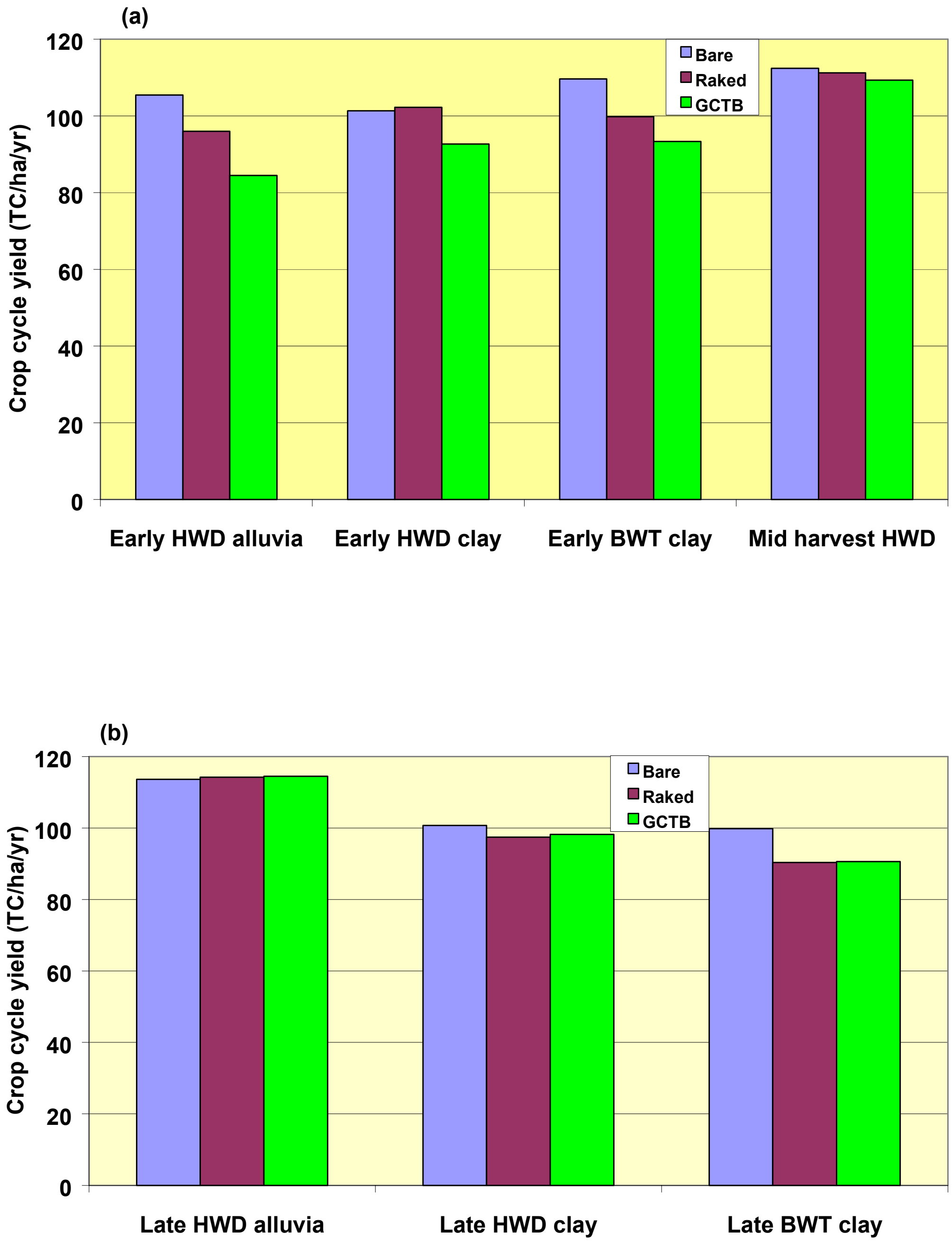


Figure 3 - Average cane yield across ratoon crops for (a) early and mid-season harvests, and (b) late-season harvests at South Arm (HWD) and Empire Vale (BWT).

4.2.2.3 Cumulative yield effects across years

Cumulative yield data from the three ratoon-crops at Empire Vale are consolidated in Appendix 3 and in Figure 3a-b.

Early season harvest
Trash retention had a major and significant cumulative negative effect on cane and sugar yields ($p<0.05$) for early season harvest on the vertosol soil at Empire Vale (Table A3d). The GCTB and raked treatments produced 42.9 and 29.6 fewer tonnes of cane/ha and 7.2 and 5.4 tonnes less sugar /ha, respectively, than the burnt-cane treatment.

This effect of trash retention on yield was similar to that observed at South Arm (Figure 3a).

Late-season harvest
Effects of trash retention after late-season harvest were similar to those described above for the early season harvest at Empire Vale, with trash retention having a major and significant negative effect ($p<0.05$) on cane and sugar yields, compared to burnt cane (Table A3d). Burnt cane produced approximately 28 tonnes more cane/ha and 4 tonnes more sugar/ha than did either of the trash-retention treatments throughout the crop cycle.

The adverse effect of trash on yield from late-season ratoon crops was more severe at Empire Vale than at South Arm. This is attributed to the higher rainfall environment of the former site, where slower establishment of ratoons under trash cannot be compensated later in the year by more rapid growth than in the burnt areas. Compensatory growth in GCTB is a result of moisture conserved by the trash blanket. This effect was noted during the drier second-ratoon crop at Empire Vale, but large negative effects of trash during the first- and third-ratoon crop-years caused the over-all outcome. The science of climate forecasting is not sufficiently accurate to allow prediction of the years for which trash retention might have benefits for heavy clay soils in traditionally higher rainfall zones.

4.3 Analysing the development of yield

4.3.1 Development of the stalk population

Development of the stalk population in the trash-management treatments for first- and second-ratoon crops is summarised by times of harvest for South Arm and Empire Vale sites in Figures 4-10. Development of the ratoon shoot population was much slower under a trash blanket than in burnt cane after early harvest at both sites (Figures 4-7). Raking trash from the row either resulted in a similar rate of shoot development to the burnt treatment (Figure 4), or a situation mid-way between the burnt and GCTB treatments (Figures 5-7). The final stalk population for early season ratoons under GCTB was similar to, but in most cases slightly lower, than the other two trash treatments.

A similar effect of trash on rate of shoot development was evident for the mid-season initiation of a second-ratoon crop in 1997 at South Arm (Figure 8). This was a crop year of lower rainfall and the slower rate of ratooning had no impact on final yield (Table A1f). In fact, trash retention had a positive, but non-significant effect on final cane yield.

Trash retention had minimal effect on development of the shoot population for the late-harvest establishment of the first-ratoon crop at South Arm (Figure 4), but for other late-season establishments the retarding effect of trash on emergence of shoots was evident (Figures 5, 9, 10). Final shoot populations across trash-management treatments were similar for the late-season establishment of the first-ratoon crop, but the GCTB resulted in a slightly lower final stalk population for the second-ratoon crop at both sites (Figures 9-10).

The gradual and slow development of the GCTB stalk population, followed by a small loss of shoots is contrasted with the more rapid development of the shoot population in the burnt system, followed by up to 50% loss of the shoots, due to competition for light.

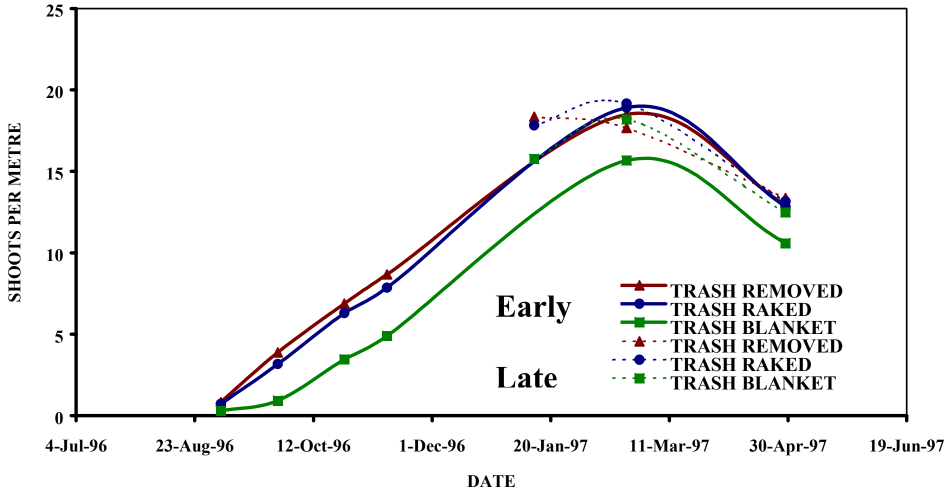


Figure 4 - Development of shoot populations in first-ratoon Q124 at South Arm after early- and late-season harvests in 1996.

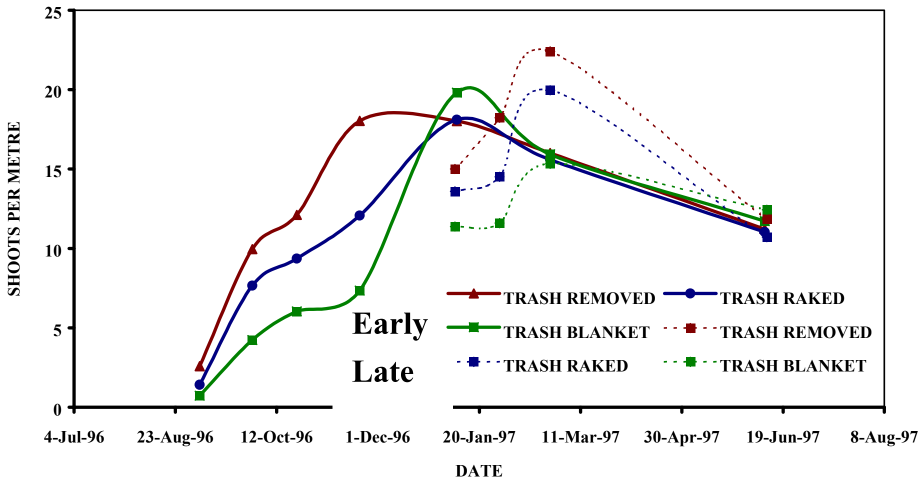


Figure 5 - Development of shoot populations in first-ratoon Q124 at Empire Vale after early and late-season harvests in 1996.

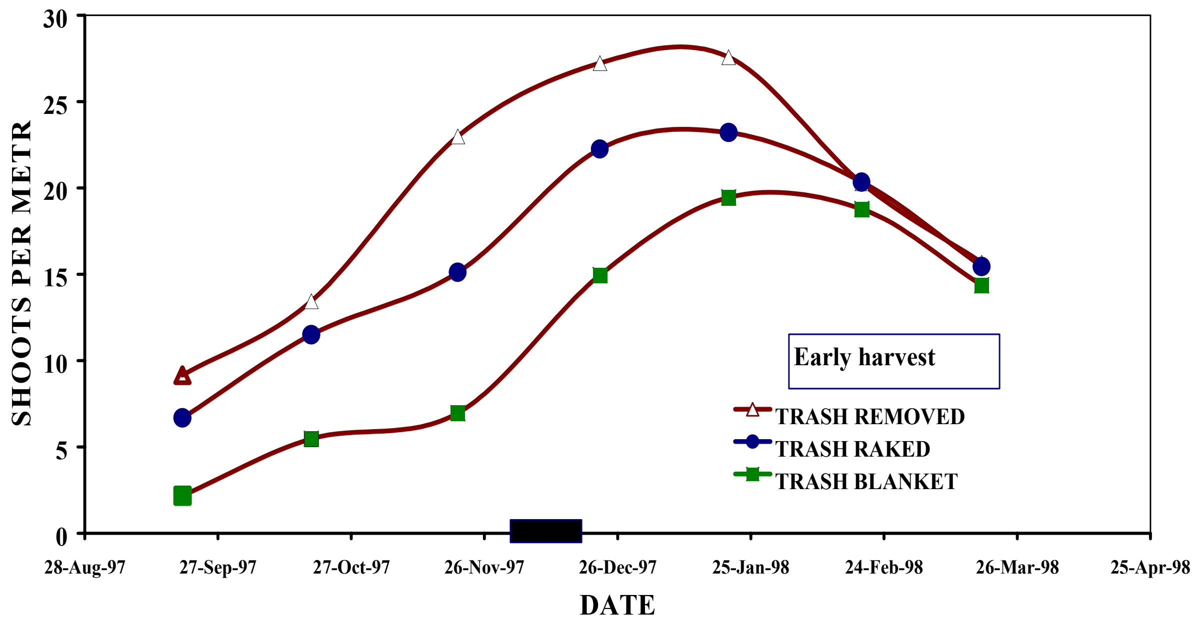


Figure 6 - Development of shoot populations in second-ratoon Q124 at South Arm after early season harvests in 1997.

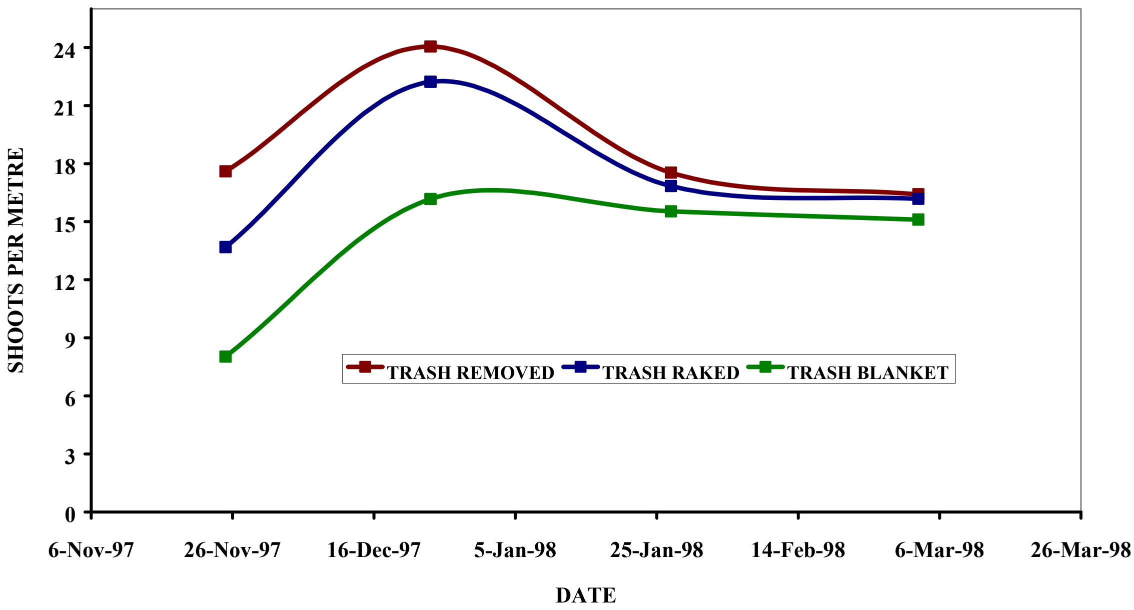


Figure 7 - Development of shoot populations in second-ratoon Q124 at Empire Vale after early season harvests in 1997.

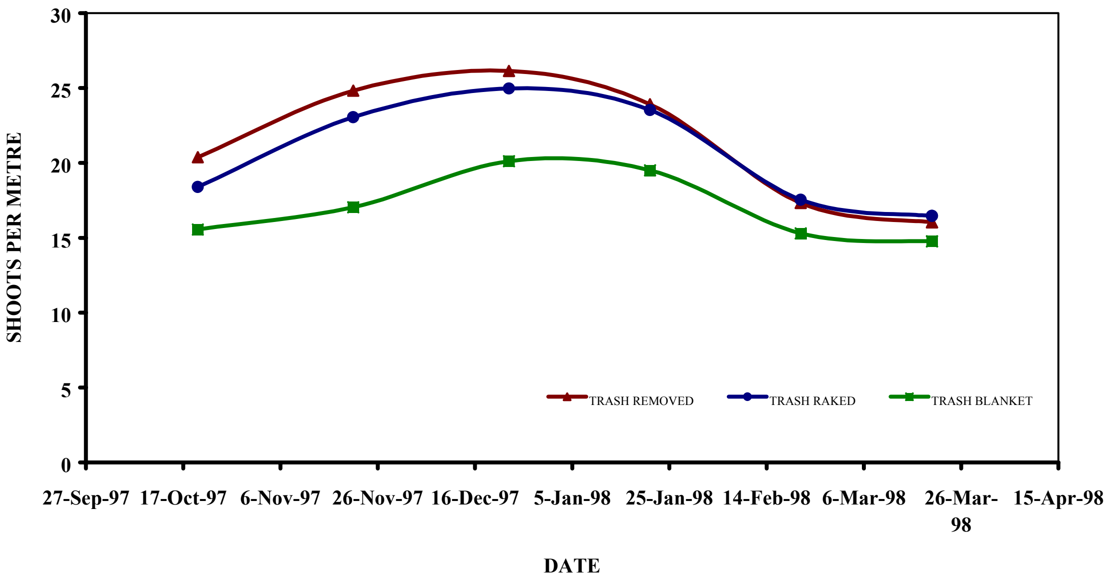


Figure 8 - Development of shoot populations in second-ratoon Q124 at South Arm after mid-season establishment in 1997.

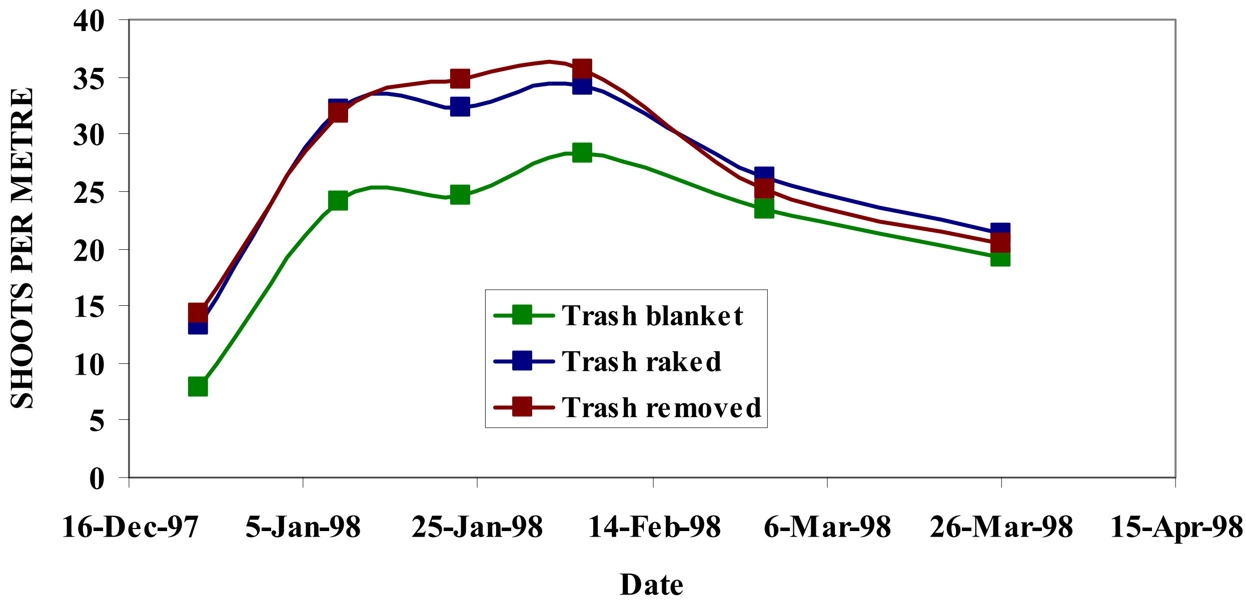


Figure 9 - Development of shoot populations in second-ratoon Q124 after late-season establishment in 1998 at South Arm.

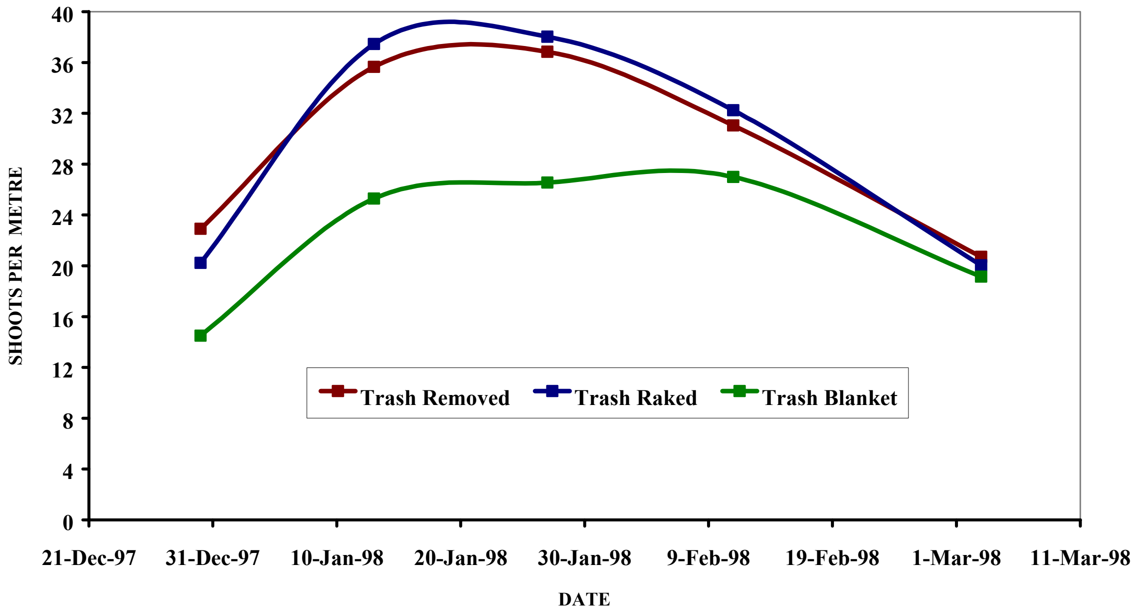


Figure 10 - Development of shoot populations in second-ratoon Q124 after late-season establishment at Empire Vale in 1997.

4.3.2 Dynamics of shoot emergence

Experience with the first-ratoon crop showed slower development of the ratoon shoot population in the presence of trash, than in the burnt cane system. Final stalk populations were often similar across trash-management treatments. More detailed investigations of this dynamic were undertaken during development of the second-ratoon crop at South Arm. A system of colour-coded tags was used to mark shoot emergence in each of the months from August 1997 to March 1998. This study, summarised in Figure 11, confirms the later development of the shoot population under a trash blanket. However, the tagging process revealed that the late development of the shoot population in the GCTB system was not based on late emerging ‘primary shoots’, but on secondary shoots or tillers which developed from the base of the sparse population of primary shoots (Plate 3a-b). While final populations of burnt and GCTB treatments may have been similar, the latter population was boosted by a high proportion of shoots from small and late-developing tillers. This is the crucial observation to support explanation of the yield differences at similar stalk populations.

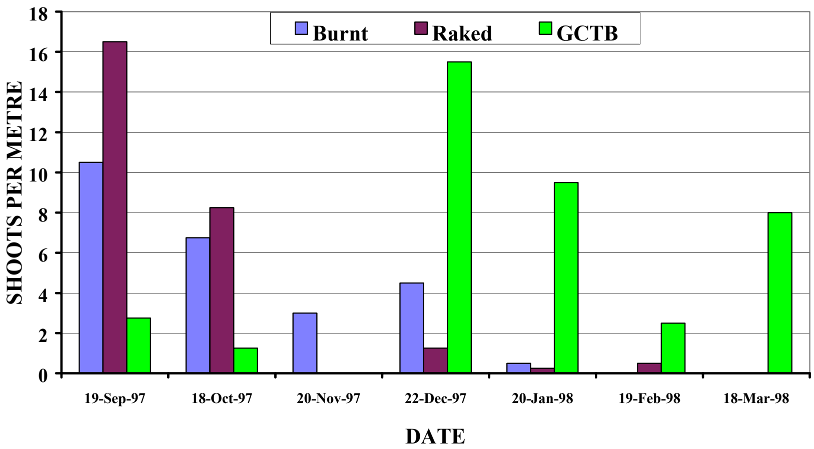
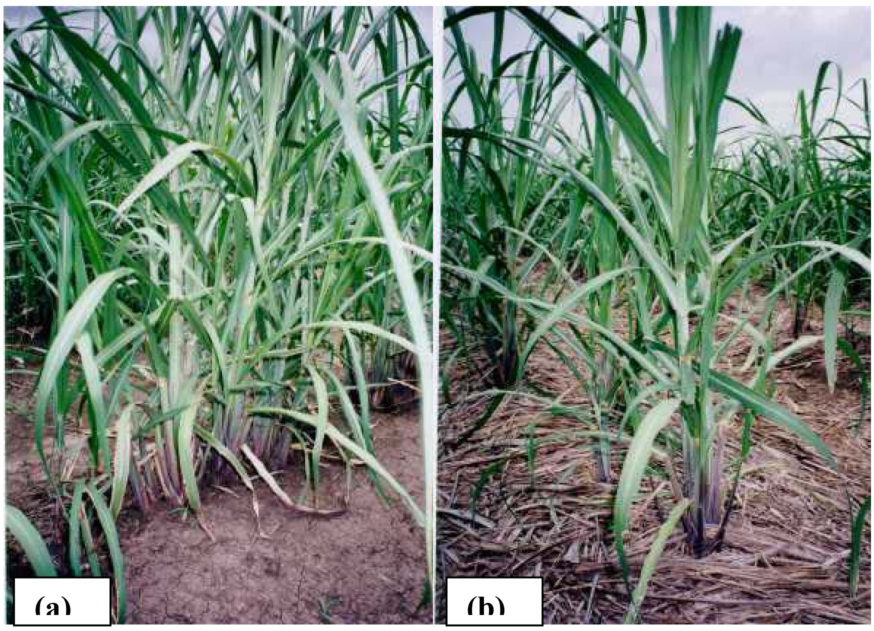


Figure 11 - Emergence of shoots in each month between August 1997 and March 1998 in three trash management treatments, after early season establishment of second-ratoon Q124 at South Arm.



Plates 3(a-b) – Second-ratoon stools of Q124 at Empire Vale in January 1998. (a) Shoots in stools in burnt cane are relatively uniform in size. (b) A sparse population of primary shoots in GCTB plots was increased by the population of secondary shoots (tillers) that developed in December 1997.

Plate 4 - Sparse population of primary ratoon shoots in GCTB plots in November 1997, compared with no-trash plots, at 12 weeks after ratooning for first-ratoon Q124 at South Arm

4.3.3 Thermal time or allelopathic effects on early shoot populations?

Co-monitoring of shoot populations and soil temperature allowed interpretation of shoot population development in relation to thermal time. Liu *et al* (1998) showed that 11.5^{o}C represented a general base temperature for 'germination' or bud burst in sugarcane. While this value was based on air temperature, because of the general availability of data, we applied 11.5^{o}C as a base temperature to soil temperature at 10-cm depth, in the cane row, because air temperature alone is not adjusted for the moderating effects of trash retention on soil temperature - the ultimate controller of biological processes in the soil.

Data from the first-ratoon crop (Figure 11) suggested quite distinct differences between the GCTB system and removal of trash from the row, by raking or total removal of trash by burning, in the influence of thermal time on development of the shoot population. Development of shoots was retarded by the presence of trash for equivalent passage of thermal time, at both South Arm and Empire Vale sites.

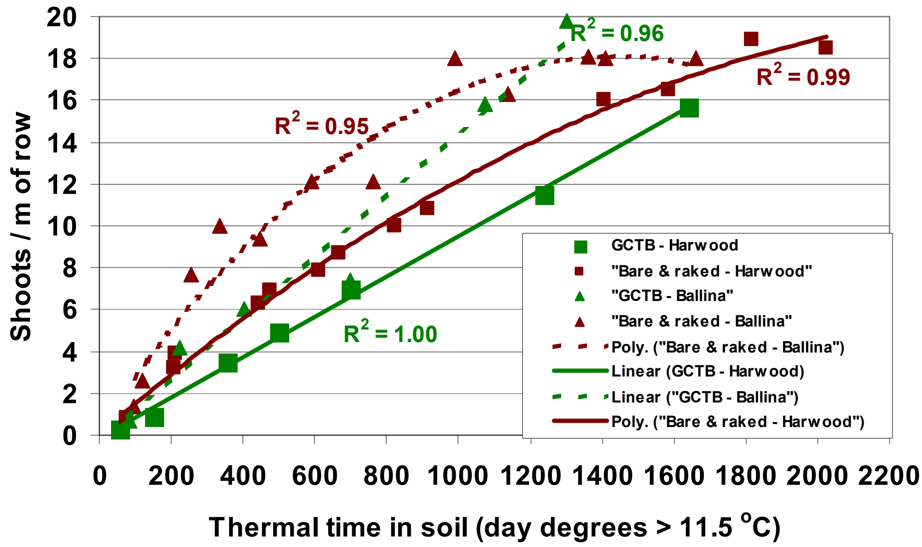


Figure 11 - Association between thermal time in soil and development of the shoot population in first-ratoon Q124 at South Arm and Empire Vale

Interpretation of similar data for the developing second-ratoon crop at South Arm again demonstrated the impact of soil thermal time on shoot emergence, and also a more definite separation of treatment effects (Figure 12). The first- and second-ratoon data are interpreted to support the basic influence of thermal time on shoot emergence, but also to hypothesise the presence of an interaction effect due to trash management.

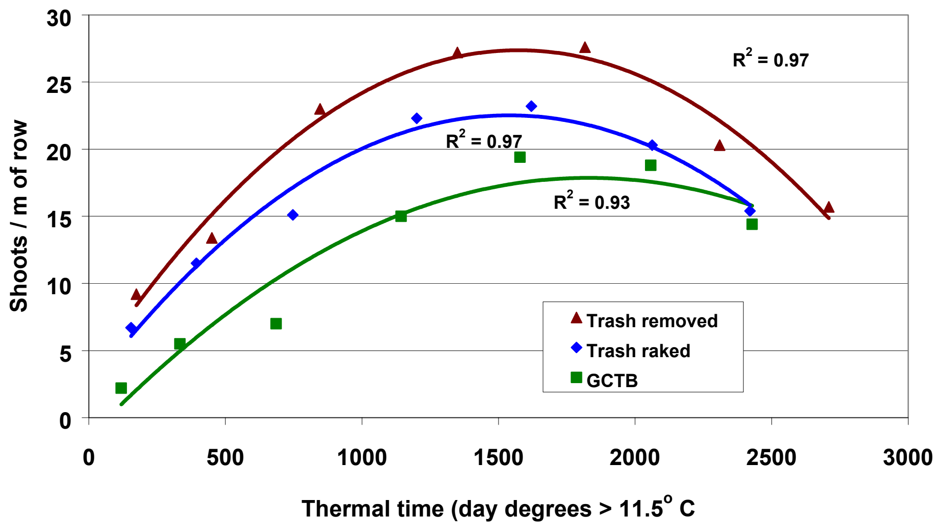


Figure 12 - Effect of thermal time under three trash-management strategies on emergence of shoots in second-ratoon Q124 at South Arm in 1997

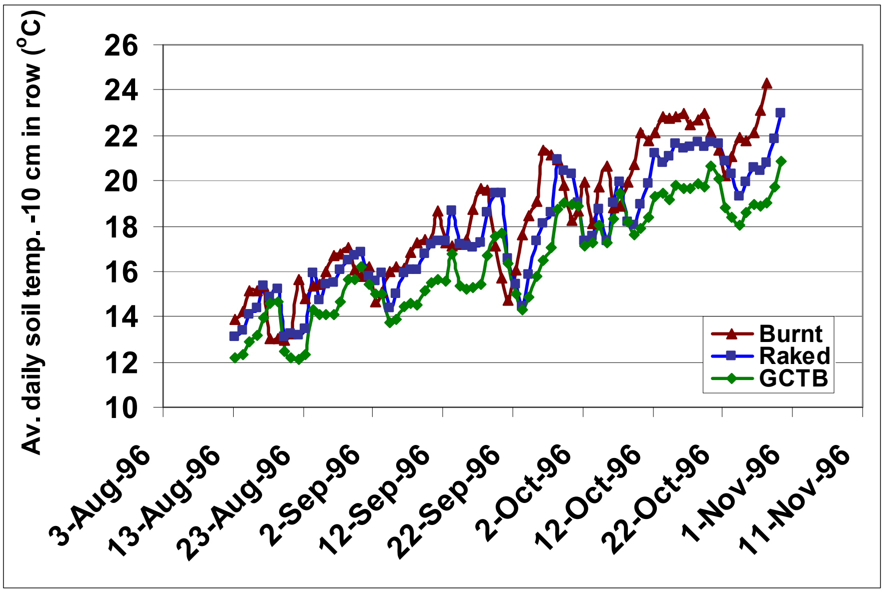


Figure 13 - Influence of trash management strategy on soil temperature at 10-cm depth, in the row, for first-ratoon Q124 at South Arm

Trash retention results in average daily soil temperature being approximately 2°C cooler than in burnt cane after early season harvest (Figure 13). If shoot emergence is only a function of thermal time, it would be reasonable to expect slower emergence of shoots in the presence of trash, as trash retention is associated with lower soil temperatures after early season harvest. Therefore, expression of shoot emergence as a function of thermal time should result in a homogenous data distribution across trash-management treatments. However, data in Figures 11 and 12 show an increasingly clear separation of data distributions on the basis of trash management. Therefore, we propose that allelopathic products, leached from crop residues, interact, particularly with lower temperatures, to suppress emergence of shoots for early season ratooning under trash. Effects of trash were less pronounced for mid- and late-season harvest when conditions were warmer and drier, and where trash was raked from the stool.

Evidence for an allelopathic influence is supported by data from Francis (1998), where residues and soil from the South arm site were used in a germination experiment in a growth chamber at UNE. In this situation the different trash managements did not have an impact on the thermal regime because of an equilibrating thermal environment in the growth chamber. However, shoot emergence was suppressed by the presence of trash. Allelopathic effects of trash were also hypothesised by Hurney and Ridge (1992) and Lovett and Hurney (1992), who identified several phenolic compounds with known phyto-toxic effects in aqueous extracts from trash. Cock *et al.* (1997) indicated that rainfall on trash within 14 days of harvest can cause problems with bud sprouting in sugarcane, even in a tropical environment. Those authors also demonstrated phytotoxic effects of aqueous trash extracts on sprouting of sugarcane buds.

4.3.4 Pathological investigations

Representative stools were excavated from trash- and water-management treatments in the early harvested areas in October and December 1996. The assays of soil for *Pythium* spp. detected *P. spinosium*. This organism is not a significant root pathogen and is usually associated with roots that are under stress. *Pythium* populations were slightly higher in soil from trash-retention treatments, and counts were higher in the soil from Empire Vale than in the soil from South Arm. The pathology laboratory also reported that roots from the irrigated trash treatments at South Arm were associated with higher numbers of *Pythium* isolates and apparently poorer root health than were roots from the rainfed trash treatments.

4.3.5 Observations of stool morphology

A more extensive campaign of stool excavation and observation of stool morphology was undertaken at the South Arm site in the early established second-ratoon crop in 1997. Stools were excavated from each trash-management treatment at 4, 8 and 12 weeks after harvest. Soil was washed from the stool to allow observation and photography of stubble condition, bud and shoot development, and presence of rotting material. The series of photographs in Appendix 4 provides a summary of these observations.

Plates A4-1a and b depict the status of the stool and shoots in the trash removed treatment at 4 weeks after harvest. The plant cane sett and the hierarchy of plant and first-ratoon stalks are shown in Plate A4-1a. The second-ratoon shoots appear to be originating from buds placed in a relatively high position in the stool (the pink tape denotes ground level). Plate A4-2 shows the vigorous development of sucker culms in a stool removed from standing cane adjoining the trial area. Plate A4-6 shows that some of the 'first shoots' to emerge are in fact suckers, whose leaves were sheared during the harvest operation. Plates A4-3 and A4-4 show the poor condition of stubble in the GCTB treatment at 4 weeks after harvest. The original plant cane sett is still visible (directly below the stem of the pointer) and there is advanced rotting of the first-ratoon stubble and little evidence of active buds.

Excavation of stools at +4 weeks showed a high proportion of stools had sustained significant damage during the harvest. Stubble was either cracked (Plates A4-5a and b) or shattered to the junction of first-ratoon and plant-cane stubble. Plate A4-5c shows this damage can be associated with red rot in the stubble. There was no evidence of differential stool damage associated with trash-management treatments. The damage was caused by stalks being pushed over by the knock-down roller on the harvester, before stalks were severed by the basecutter.

By +8 weeks a few shoots had emerged in the GCTB treatment (Plate A4-7), but first-ratoon stubble and roots were in poor condition. Buds on first-ratoon stubble were still viable in the trash-removed treatment (Plate A4-8) and for the observed stools we saw that ratoon shoots were coming from deep in the stool (compared to observations at +4 weeks). First-ratoon roots and stubble were in better condition than those of the GCTB stools. Pink tags are attached to shoots that emerged up to +4 weeks.

Plate A4-9 shows the relative size and vigour of stools at +12 weeks in November 1997. There were no viable buds on the first-ratoon stubble in the GCTB stools (Plate A4-10) and there was evidence of secondary bud sprouting at the base of primary shoots in the trash-raked stools (Plate A4-11 a and b). This development is also evident from the delayed shoot emergence pattern for raked trash in Figure 11. The development of the secondary buds in GCTB plots occurred after +12 weeks (Figure 11). Blue tags are attached to shoots that emerged in the period +4 to +8 weeks. The 0-4 week shoots are now developing the new root system. Buds on first-ratoon stubble were still viable in the raked and trash-removed treatments (Plates A4-11 and 12).

These observations show that stool rooting and loss of viable buds on stubble are major causes of the poor ratooning associated with retention of trash on early harvested cane. The mechanism for the death of buds and subsequent ingress of rots is not clear. However an impact of phytotoxic substances from trash and greater rotting of stubble under trash from harvester damage are two options for consideration.

A small experiment was established in 1998 to investigate impact of condition of basecutter blades and post-harvest application of soil-drench fungicides on any interaction with ratooning under different trash management. Blade condition had no significant effect on stool damage (assessed by the ISSCT method). As for the 1997 observations, we concluded in 1998 that most of the stool damage was associated with the knock-down roller. No significant effects on ratooning were detected for the application of fungicides or from sharp or worn basecutter blades. Early ratooning was, however, slower in trash-raked than trash-removed treatments (there was no GCTB treatment, as raking was thought to be one of the BMP options by this stage of the project). Pre-harvest stalk populations were similar across all treatments.

Therefore, we cannot be sure that presence of trash does not allow greater ingress of rotting organisms into damaged stubble than might occur for the same degree of damage where trash is removed. The failure of soil-drench fungicides (Cane Sett Treatment® and Ridomil®) to reduce differences in early ratooning suggests that the stubble rots in trash-retention treatments may be independent of the stool damage.

4.4 Effect of trash retention on soil moisture status

The benefits of trash retention on conservation of soil moisture are well established. Thompson (1966) reported a long-term benefit of approximately 10 tonnes cane /ha from conservation of residues over the burnt system in rain-fed environments. These data are consistent with unpublished BSES data from the Burdekin region where a trash blanket resulted in 180 mm less scheduled irrigation than for a burnt cane system (1.8 ML/ha by 6-7 tc/ML = 9-12.6 tc/ha). Our monitoring of soil moisture at 10-cm depth in row and inter-row positions confirms the impact of trash on conservation of soil moisture (Figures 14 and 15). The muted response of inter-row moisture as opposed to soil moisture in the row to rainfall at South Arm on 4 September and 2 October 1996 (Figure 14) is a reflection of the severe compaction of inter-rows under the minimum tillage system at the South Arm site. The major response in inter-row soil moisture on 8 and 27 November is in response to two 20-mm rainfall events, and suggests some ponding of moisture in the inter-rows of the GCTB treatment.

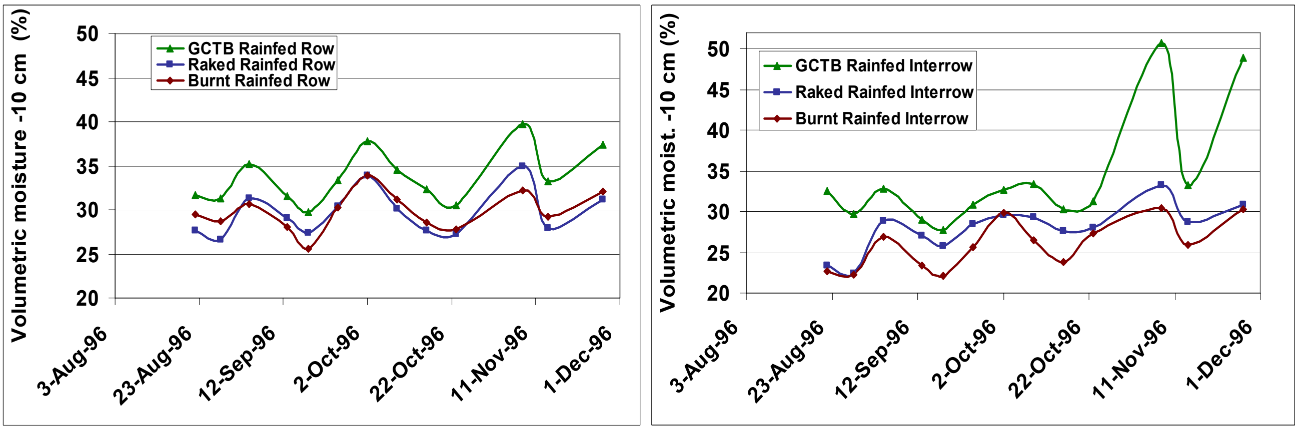


Figure 14 - Impact of trash-management treatment on soil moisture content at 10 cm depth under the row and inter-row of the early established first-ratoon crop at South Arm

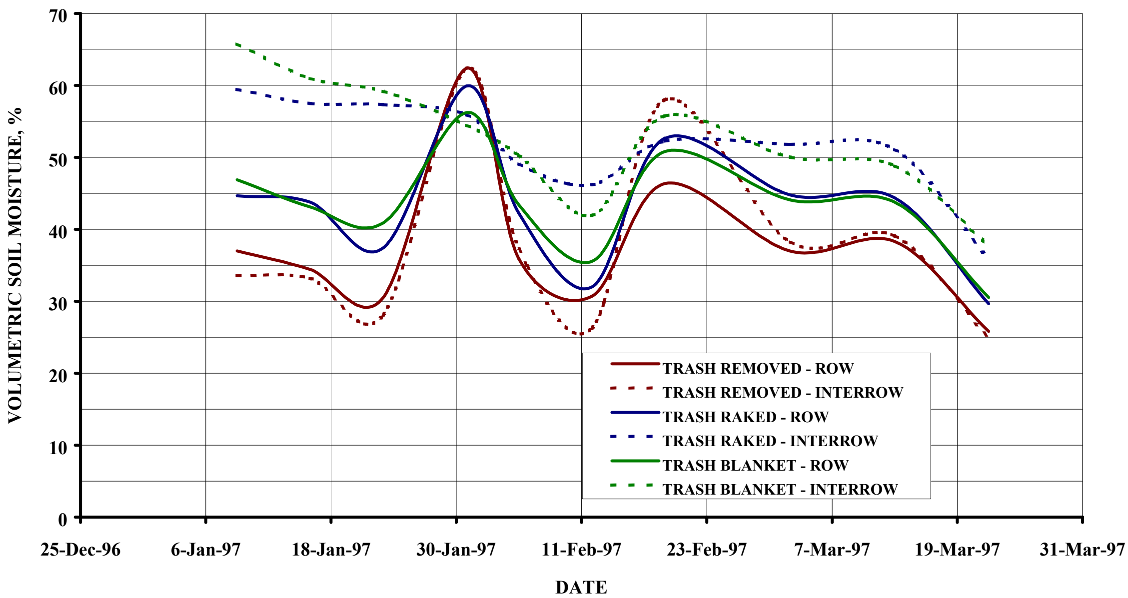


Figure 15 - Impact of trash management treatment on soil moisture content at 10-cm depth under the row and inter-row of the late established first-ratoon crop at Empire Vale

4.5 Economic analysis of yield data

While the community and regulators may attach significant environmental and social benefits to wide adoption of the GCTB system, any additional cost of implementation is borne by the cane grower. The overall outcome of this 3-year experimental program should therefore be summarised with an economic analysis that reflects the relative profitability of the standard two-year burnt-cane system and options for trash management under a one-year production system. The technique of gross-margin analysis was applied to average data for the three ratoon crops at both sites.

4.5.1 Assumptions for gross-margin analysis

- The standard production system was a two-year burnt-cane system, in which cane yield was 1.6 times that achieved for a one-year burnt-cane system (Harwood mill productivity data).
- CCS of burnt two-year cane had an advantage of 0.5 units of CCS over one-year-old cane for early harvest only. The NSW cane-payment formula was applied to the sugar price and CCS to derive a value for cane.
- Sugar prices of $250 and $330 / tonne were used in the analysis.
- Green cane was harvested for $5.50 / t, compared with $4.80 / t for burnt cane (1999 analysis).
- Burnt cane was grown under the minimum-tillage system and received three applications of the pre-emergent herbicide Gesapax-Combi at a cost of $60 /ha /application; trash-raked treatments received only one application of Gesapax-Combi, applied only to the row; the GCTB system received one application of Gramoxone at $26 /ha. The standard system was assumed to receive herbicide on a biennial basis.
- Trash raking was performed for $10 /ha, plus an allowance for depreciation of a $6000 trash rake over 10 years on an 40 ha farm.
- All regimes were assumed to receive the same fertiliser.
- No allowance was made for the additional costs of the burnt system perceived by the community, or for the life style benefits enjoyed by families on GCTB farms.
- Results were expressed as a response (+/-) relative to the standard system.

4.5.2 Results of gross-margin analysis

Gross margins for early harvest of the burnt one-year system were negative or unattractive in relation to the standard system at all sites for the low sugar-price scenario (Figure 16a). The one-year burnt system still had negative gross margins for early harvest for a sugar price of $330 /tonne, but gross margins were more attractive than for the standard system after mid-season harvest, particularly for the South Arm site (Figure 16b).

When sugar was priced at $250 /tonne, the raked system produced negative relative gross margins for early harvest at South Arm and for both times of harvest at Empire Vale (Figure 16a). Similar patterns of response were observed when the sugar price was increased to $330/tonne, but gross margins improved relative to the standard system (Figure 16b). The South Arm site still had a negative gross margin compared to the standard system for both times of harvest.

The GCTB system gave negative relative gross margins for early harvest at South Arm and for both harvests at Empire Vale when sugar was priced at $250/tonne (Figure 16a). The South Arm site returned positive relative gross margins for harvests after mid-season, particularly for the better-drained alluvial soil. Similar patterns, but higher values, of gross margin response were achieved for the GCTB system at the higher sugar price (Figure 16b). Gross margins were quite attractive for all of the situations at South Arm, after mid-season, but GCTB was still unprofitable on the heavy clay at Empire Vale.

From this analysis, we concluded it was unprofitable to adopt the trash-retention systems for early harvest in situations similar to those experienced at the South Arm and Empire

Vale sites between 1996 and 1999. Trash retention was profitable in lower rainfall areas and especially on well-drained soils for crops ratooned after mid-season. Trash retention on heavier soils in lower rainfall zones was only marginally more profitable than the standard system, when sugar prices were low. However, relative profitability improved with the sugar price. The GCTB system had similar, to improved, profitability to the trash raked system; lower yield in some cases in the GCTB system were off-set by lower input costs. Neither of the trash-retention systems resulted in higher gross margins than the standard system on heavy clay soils in the higher rainfall zone at Empire Vale.

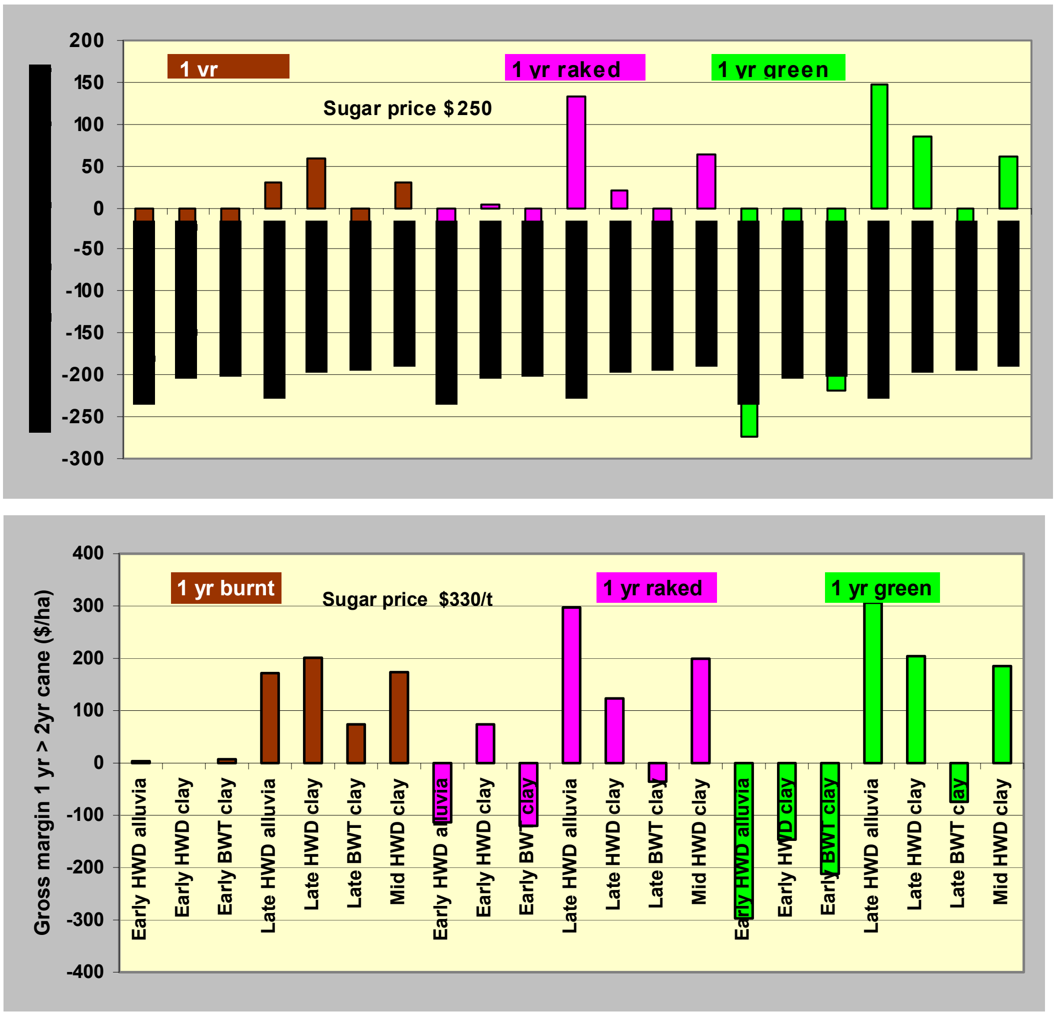


Figure 16 – Gross-margin analysis of the impact of trash-management options in a one-year production system relative to a two-year burnt-cane system for sugar prices of $330 /tonne and $250 /tonne.

5.0 PUBLICATIONS AND PRESENTATIONS

5.1 Publications

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Kingston, G (1997). Update on the green cane system. Australian Sugarcane 1(2): 3-6.

5.2 Presentations

Kingston, G (2002). Experience with the green- cane trash blanket production system in Australia - *industry experience and recent research*. Congress Assoc. de Técncios Azucareros de Centroamérica, POWERPOINT presentation 29 September 2002..

Kingston, G, Davis, R, Aitken, R L, Parsons, D and Klok, J (2002). Adapting the GCTB system to difficult production environments. POWERPOINT presentation. CRC for Sustainable Sugar Production Open Day, Townsville, 6 March 2002

Kingston, Graham, Davis, Rod and Parsons, Don (2000). Is there a place for the GCTB system in cooler southern districts? POSTER for BSES Field Days at Bundaberg, Moreton, Condong, Broadwater and Harwood 10/4 to 18/5/00 and CRC for Sustainable Sugar Production Annual Meeting 6-10/3/00, Townsville.

Robertson, F A (2000). Green cane trash blanketing and soil nitrogen. INCITEC liaison meeting, Mackay, 15 March 2000 and CRC-Sugar technology Transfer Consultative Group meeting, Mackay, 4 April 2000.

Robertson, F A (2000). Trash blanketing - likely effects for soil organic matter and nitrogen. NSW growers bus tours, Condong, Broadwater and Harwood 16-18 March 2000.

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6.0 OUTPUTS RELATIVE TO OBJECTIVES

Objective 1: **Quantify the impact of alternative trash-management strategies and irrigation on soil water, temperature and microbiological regimes and productivity in one year production systems in NSW.**

The agronomic components of this objective were achieved, as demonstrated in the report. There was limited achievement of the microbiological objective, with pathological assessments being confined to the developing first-ratoon crop in 1997. The impact of trash management systems on over all soil biological activity was quantified in a CRC-Sugar activity (Robertson 2002).

Objective 2: Contribute data to a modelling framework to provide generic understanding of the impact of trash on soil water and temperature regimes throughout the Australian industry.

This objective was achieved through involvement of Drs Thorburn and Robertson in their use of the site at South Arm as the southern most site in a range of sites throughout the industry for a study of the impact of temperature and moisture regimes on rates of trash decomposition, carbon and nitrogen cycling. These data have been used to enhance capabilities of the APSIM-Sugar model.

Objective 3: Use project data and extension resources to quantify or dispel respective industry and community concerns about sustainability of green and burnt production systems.

This objective was achieved through the extensive publication and technology transfer activities associated with the project (see listings above).

7.0 OUTCOMES

We concluded that the GCTB system was not profitable and therefore unsustainable for harvests in the Harwood and Broadwater areas before mid-September. Raking trash from the stool was a successful strategy for minimising the impact of trash retention on cane yield. The GCTB system could be applied successfully to drier or well-drained areas from mid-season, because of the benefits of moisture conservation. Trash retention always produced a poorer result than did trash removal on the heavy clay soils in the higher rainfall zone at Empire Vale. This result is consistent with observations from Colombia of adverse impacts on yield of phytotoxic substances leached from fresh trash, even in tropical environments. The higher rainfall environments also minimise opportunity for improvement in relative yield of trash retention treatments from moisture conservation by the residues.

Our results confirmed some of the concerns about the negative impact on productivity of the GCTB system held by a significant number of NSW canegrowers. These data (plus trading in carbon credits) may have been instrumental in supporting investigations for total biomass harvest to provide fuel for cogeneration of electricity by NSW sugar mills. A successful outcome in this area would allow emplacement of green cane harvesting and provide a solution to the difficult issue of subsequent management of crop residues.

8.0 ACKNOWLEDGEMENTS

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APPENDIX 1 **Yield data for GCBT experiments at South Arm, Harwood Mill, NSW 1997-1999**

Table A1(a) - Early season yield data for trash-management treatments for first-ratoon Q124 harvested at South Arm - 14/8/97

Trash treatment	TC/ha	CCS	TS/ha
Burnt	98.3	11.38	11.17
Raked	93.9	11.97	11.24
GCTB	79.8	11.20	8.86
LSD (p<0.05)	9.5	0.47	1.19

Table A1(b) - Early season yield data for trash-management by irrigation treatments for first-ratoon Q124 harvested at South Arm- 14/8/97

Irrigation treatment	Trash treatment		
	Burnt	Raked	GCTB
	TC/ha		
Rain	106.7	95.1	91.9
Irrigation	85.9	92.7	67.6
LSD (p<0.10)	11.0		
	CCS		
Rain	11.02	11.94	10.66
Irrigation	11.75	12.01	11.74
LSD (p<0.10)	0.54		
	TS/ha		
Rain	11.77	11.35	9.80
Irrigation	10.57	11.13	7.92
LSD (p<0.10)	1.68		

Table A1(c) - Early season cane-yield data for trash-management treatments by soil type for first-ratoon Q124 harvested at South Arm - 14/8/97.

Soil type	Trash treatment		
	Burnt	Raked	GCTB
Alluvial	98.0	91.7	75.5
Clay	98.7	96.0	84.0
LSD	NS		

Table A1(d) - Late season yield data for trash-management treatments by soil type for first-ratoon Q124 harvested at South Arm - 15/12/97

Soil type	Trash treatment		
	Burnt	Raked	GCTB
	TC/ha		
Alluvial	116.7	114.1	123.9
Clay	102.3	107.3	105.5
LSD (p<0.15)	6.2		
	CCS		
Alluvial	14.78	15.06	15.04
Clay	15.06	15.05	15.57
LSD (p<0.05)	0.99 (between rows)		
	TS/ha		
Alluvial	17.21	17.20	18.65
Clay	15.41	16.12	16.40
LSD (p<0.05)	0.98 soils, 0.86 trash management		

Table A1(e) - Early season yield data for trash-management treatments by soil type for second-ratoon Q124 harvested at South Arm - 4/8/98

Soil type	Trash treatment		
	Burnt	Raked	GCTB
	TC/ha		
Alluvial	84.6	79.5	77.2
Clay	84.9	100.5	87.4
LSD (p<0.10)	10.8		
	CCS		
Alluvial	9.93	10.87	11.17
Clay	11.10	12.17	11.92
LSD (p<0.05)	1.86		
	TS/ha		
Alluvial	8.38	8.56	8.62
Clay	9.39	12.14	10.34
LSD (p<0.05)	1.17		

Table A1(f) - Mid-season yield data for trash-management treatments for second-ratoon Q124 harvested at South Arm - 29/9/98

Trash treatment	TC/ha	CCS	TS/ha
Burnt	116.0	13.76	15.95
Raked	124.6	14.56	18.17
GCTB	125.8	14.15	17.79
[1]LSD ($p<0.05$) [2]LSD ($p = 0.15$)	NS	0.34 [1]	1.67 [2]

Table A1(g) - Late-season yield data for trash-management treatments by soil type for second-ratoon Q124 harvested at South Arm - 7/12/98

Soil type	Trash treatment		
	Burnt	Raked	GCTB
	TC/ha		
Alluvial	124.6	129.6	118.0
Clay	108.7	100.5	108.9
LSD	NS		
	CCS		
Alluvial	12.48	13.27	12.76
Clay	12.59	13.71	13.09
LSD	NS		
	TS/ha		
Alluvial	15.48	17.28	15.05
Clay	13.84	13.80	14.37
LSD	NS		

Table A1(h) – Mid-season yield data for trash-management treatments for third-ratoon Q124 harvested at South Arm - 24/8/99

Trash treatment	TC/ha	CCS	TS/ha
Burnt	108.8	14.00	15.2
Raked	97.8	14.26	13.9
GCTB	92.8	14.02	13.0
LSD ($p<0.05$)	9.8	NS	1.5

Table A1(i) – Mid-season yield data for trash-management treatments by soil type for third-ratoon Q124 harvested at South Arm - 24/8/99

Soil type	Trash treatment		
	Burnt	Raked	GCTB
	TC/ha		
Alluvial	108.6	96.0	85.8
Clay	109.1	99.6	99.7
LSD ($p<0.05$)	13.8(between columns)		
	CCS		
Alluvial	13.72	14.34	13.88
Clay	14.28	14.17	14.16
LSD	NS		
	TS/ha		
Alluvial	14.89	13.75	11.92
Clay	15.56	14.14	14.11
LSD ($p<0.05$)	2.06 (between columns)		

Table A1(j) – Late-season yield data for soil types across trash-management treatments for third-ratoon Q124 harvested at South Arm - 24/8/99

Soil type	TC/ha	CCS	TS/ha
Alluvial	100.1	13.05	13.05
Clay	85.4	12.68	10.86
LSD ($p<0.10$)	12.6	NS	1.74

Table A1(k) – Late-season yield data for trash-management treatments by soil type for third-ratoon Q124 harvested at South Arm - 24/8/99

Soil type	Trash treatment		
	Burnt	Raked	GCTB
	TC/ha		
Alluvial	99.6	98.9	101.7
Clay	91.2	84.6	80.3
LSD ($p<0.17$)	6.6		
	CCS		
Alluvial	12.77	13.13	13.25
Clay	12.63	13.26	12.16
LSD ($p<0.17$)	0.66		
	TS/ha		
Alluvial	12.73	12.98	13.44
Clay	11.55	11.20	9.83
LSD ($p<0.10$)	1.36		

APPENDIX 2 **Yield data for GCBT experiments at Empire Vale, Broadwater Mill, NSW 1997-1999**

Table A2(a) - Early season yield data for trash-management treatments for first-ratoon Q124 harvested at Empire Vale - 18/8/97

Trash treatment	TC/ha	CCS	TS/ha
Burnt	108.1	14.63	15.82
Raked	97.5	14.55	14.17
GCTB	90.1	14.52	13.18
LSD ($p<0.05$)	9.4	NS	1.38

Table A2(b) - Early season yield data for trash-management by irrigation treatments for first-ratoon Q124 harvested at Empire Vale- 18/8/97

Irrigation treatment	Trash treatment		
	Burnt	Raked	GCTB
	TC/ha		
Rain	109.6	99.0	90.3
Irrigation	106.6	96.1	89.8
LSD ($p<0.05$)	13.3 (trash treatments only)		
	CCS		
Rain	14.42	14.62	14.53
Irrigation	14.84	14.49	14.52
LSD	NS		
	TS/ha		
Rain	15.81	14.46	13.11
Irrigation	15.82	13.89	13.04
LSD ($p<0.05$)	1.95 (trash treatments only)		

Table A2 (c) – Late-season yield data for trash-management treatments for first-ratoon Q124 harvested at Empire Vale - 15/12/97

Trash treatment	TC/ha	CCS	TS/ha
Burnt	91.5	15.25	13.95
Raked	78.3	15.43	12.09
GCTB	75.2	15.30	11.52
LSD ($p<0.05$)	6.8	NS	1.14

Table A2(d) - Early season yield data for trash-management treatments for second-ratoon Q124 harvested at Empire Vale - 19/8/98

Trash treatment	TC/ha	CCS	TS/ha
Burnt	107.4	12.81	13.75
Raked	104.8	12.51	13.13
GCTB	98.2	12.43	12.19
LSD	NS	NS	NS

Table A2(e) - Late-season yield data for trash-management treatments for second-ratoon Q124 harvested at Empire Vale - 11/12/98

Trash treatment	TC/ha	CCS	TS/ha
Burnt	111.9	14.63	16.36
Raked	107.5	14.58	15.80
GCTB	114.4	14.55	16.69
LSD	NS	NS	NS

Table A2(f) - Early season yield data for trash-management treatments for third-ratoon Q124 harvested at Empire Vale - 11/12/99

Trash treatment	TC/ha	CCS	TS/ha
Burnt	113.4	14.28	16.19
Raked	97.0	13.55	13.12
GCTB	91.7	14.56	13.34
LSD ($p<0.05$)	11.0	NS	1.57

Table A2(g) – Late-season yield data for trash-management treatments for third-ratoon Q124 harvested at Empire Vale - 11/12/99

Trash treatment	TC/ha	CCS	TS/ha
Burnt	97.3	14.80	14.34
Raked	82.2	14.39	11.83
GCTB	84.1	14.66	12.36
LSD ($p<0.10$)	12.0	NS	1.80

APPENDIX 3 Cumulative yield data for GCBT experiments at South Arm and Empire Vale NSW across harvests from 1997-1999

Table A3(a) - Early season cumulative yield data for trash-management treatments from 1997-1999 in Q124 harvested at South Arm

Trash treatment	TC/ha	CCS	TS/ha
Burnt	310.1	12.14	38.5
Raked	297.2	12.67	38.0
GCTB	265.7	12.28	32.9
LSD (p<0.05)	23.1	NS	2.4

Table A3(b) - Early season cumulative yield data for trash-management treatments by soil type from 1997-1999 in Q124 harvested at South Arm

Soil type	Trash treatment		
	Burnt	Raked	GCTB
	TC/ha		
Alluvial	316.2	287.9	253.4
Clay	304.1	306.6	278.0
LSD (p<0.20)	20.4		
	CCS		
Alluvial	11.98	12.41	12.22
Clay	12.30	12.94	12.34
LSD (p<0.10)	0.66		
	TS/ha		
Alluvial	38.9	36.3	31.3
Clay	38.0	39.8	34.5
LSD (p<0.10)	2.55		

Table A3(c) - Mid-season cumulative yield data for trash-management treatments by soil type from 1997-1999 in Q124 harvested at South Arm

Soil type	TC/ha	CCS	TS/ha
Alluvial	221.1	13.99	30.9
Clay	222.8	14.23	31.8
LSD (p<0.12)	NS	0.28	NS

Table A3(d) - Mid-season cumulative yield data for trash-management treatments across soil types from 1997-1999 in Q124 harvested at South Arm

Trash treatment	TC/ha	CCS	TS/ha
Burnt	224.8	13.88	31.2
Raked	222.5	14.41	32.1
GCTB	218.6	14.01	30.8
LSD ($p<0.05$)	NS	0.26	NS

Table A3(e) – Late-season cumulative yield data for soil types across trash-management treatments from 1997-1999 in Q124 harvested at South Arm

Soil type	TC/ha	CCS	TS/ha
Alluvial	342.3	13.62	46.7
Clay	296.4	13.68	40.8
[1]LSD ($p<0.05$) [2]LSD ($p = 0.105$)	40.0 [1]	NS	5.9 [2]

Table A3(f) – Late-season cumulative yield data for trash-management treatments from 1997-1999 in Q124 harvested at South Arm

Trash treatment	TC/ha	CCS	TS/ha
Burnt	321.6	13.38	43.1
Raked	317.5	13.91	44.3
GCTB	319.1	13.64	43.9
LSD ($p<0.10$)	NS	0.38	NS

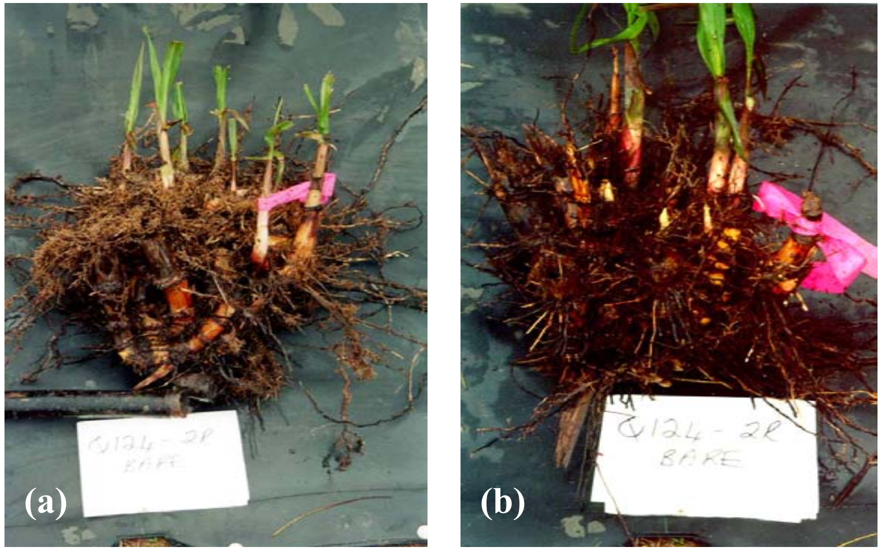
Table A3 (g) - Early season cumulative yield data for trash-management treatments from 1997-1999 in Q124 harvested at Empire Vale

Trash treatment	TC/ha	CCS	TS/ha
Burnt	328.9	13.91	45.8
Raked	299.3	13.54	40.4
GCTB	280.0	13.84	38.6
LSD ($p<0.05$)	22.9	NS	3.1

Table A3 (h) – Late-season cumulative yield data for trash-management treatments from 1997-1999 in Q124 harvested at Empire Vale

Trash treatment	**TC/ha**	**CCS**	**TS/ha**
Burnt	299.4	14.87	44.5
Raked	271.1	14.76	40.1
GCTB	271.7	14.89	40.4
LSD (p<0.05)	18.2	NS	3.2

APPENDIX 4 **Photographic record of stool morphology in Q124 second-ratoon at South Arm for +4, +8 and +12 weeks after ratooning on 4 August 1998**



Plates A4-1a,b. Stool from trash removed treatment in September 1998 at + 4 weeks; (a) shows hierarchy of plant and first-ratoon stalks; (b) shows new roots and bud development. Pink tape represents ground level.

Plate A4-2. Note suckers and bud development on stool from standing cane adjoining cane in Plates A-1a,b.

Plate A4-3. GCTB in Q124 at +4 weeks and rotting stubble.

Plate A4-4. Comparison of freshly cut stool and GCTB stool at +4 weeks.

Plates A4-5a,b,c. Stool damage in second-ratoon Q124 at +4 weeks; (a) GCTB, (b) shows stalk split by knock-down roller, (c) shows red rot in split stalks.

Plate A4-6. Cut leaf sheath indicates some of the first shoots to emerge are suckers that were 'topped' during the harvest.

Plate A4-7. GCTB stool in second-ratoon Q124 at +8 weeks. There are few primary shoots and no new roots.

Plate A4-8. Stool of Q124 from trash removed treatment at +8 weeks. Note activity of primary shoots low in the stool, buds on first-ratoon stalks are still viable and old roots near the surface are in better condition than in GCTB (Plate A4-7)

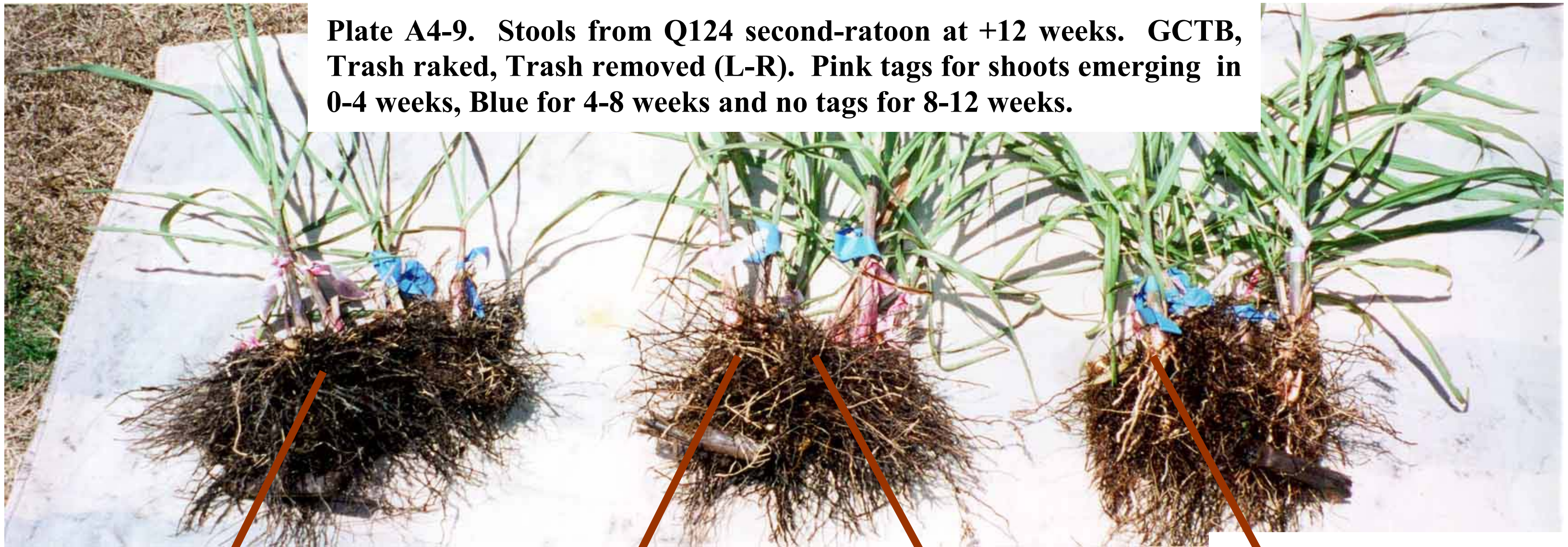


Plate A4-9. Stools from Q124 second-ratoon at +12 weeks. GCTB, Trash raked, Trash removed (L-R). Pink tags for shoots emerging in 0-4 weeks, Blue for 4-8 weeks and no tags for 8-12 weeks.

Plate A4-10. GCTB, no viable buds in stool and no secondary shoots.

Plates A4-11a,b. Trash raked stools. (a) lower buds still viable and secondary buds swelling at pen, (b) shoot roots developing

Plate A4-12. Trash removed stool with primary and secondary shoots; lower buds are still sprouting.