SUGAR PRODUCTIVITY—TIME TO MAKE AN OMELETTE

By

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Sub-District Target Yield, Record And Contest-Winning Yield.**

Abstract

SUGAR PRODUCTIVITY IS directly linked to the profitability of the sugar industry through the simple formula: *Profitability = (Sugar price x Sugar yield) – expenses.* The adoption of new technologies developed in the 1930–1950 period resulted in a rapid increase in sugar yield between 1950 and late 1970s. This rapid increase in sugar yield stalled soon after that and has since almost flat-lined. This is despite a 200% increase in research publication output, directed at sugar productivity drivers, as recorded on the ASSCT website in the past 26 years, compared with the preceding 60 years. In this paper, we examine sugar productivity drivers, considering the key ones limiting sugar production and whether they can be better managed, increased or manipulated. A term 'sub-district target yield' is introduced for use as a realistic productivity target for local growers. A method for determining the sub-district target yield is briefly outlined and priorities set for addressing key industry issues to increase sugar productivity over the next 10 years.

History of sugar productivity in Australia

Productivity gains

'*Yields of raw sugar 130 years ago were abysmal — the 1880s averaged … 3.6 tonnes sugar per hectare …, and the 1890s averaged … 4.1 T.S.H.'* (Egan, 2015).

The Australian sugar industry has nearly tripled raw sugar yield since early days in the industry with an average of 11.8 tonnes of sugar per hectare (TSH) over the last 10 years (Sugar Research Australia, 2016). Interestingly, average increase in barley, wheat, potato and maize yield in the same period was 2.0, 3.3, 4.3 and 3.1, respectively (ABS, 2013).

Sugar yield is a combination of cane yield and CCS and these vary enormously year to year, primarily due to the impact of climate (Everingham *et al.*, 2015, Table 1).

Table 1—Australian sugarcane productivity statistics from 2006–2015.
(Adapted from Sugar Research Australia, 2016).

Season	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average
Cane yield (TCH)	90.4	87.9	86.3	83.1	90.0	76.3	86.8	82.0	87.1	91.2	86.1
CCS	13.3	13.5	13.9	14.6	12.8	13.3	14.0	14.0	13.9	13.8	13.7
Sugar yield (TSH)	12.0	11.9	12.0	12.1	11.6	10.1	12.1	11.5	12.1	12.6	11.8

In general, cane yield increased steadily in the 1950 to late 1970 period, after which the cane yield increases slowed or even plateaued (Fig. 1). Conversely, CCS tended to decline in the 1930 to late 1980 period, after which it levelled off or may even be lightly increasing. Egan (2015) noted that it fluctuated wildly due to drought in late 1950s-early 1960s.

Yield plateau

Smith (1991) reported the rate of change in cane and sugar yields in the 1899–1988 period, illustrating an apparent yield plateau in more recent times (1969–1988) (Table 2).

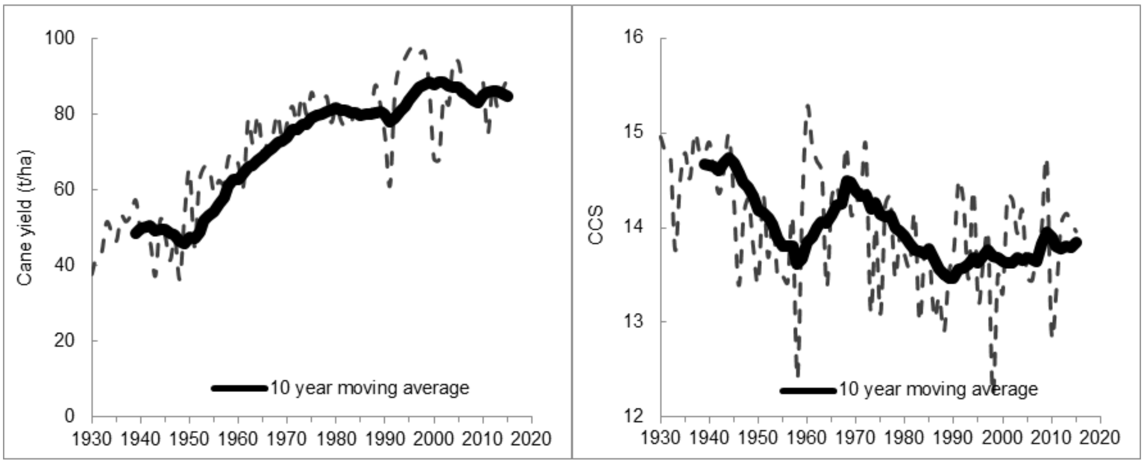

Fig. 1—The trends in Queensland cane yield per hectare and CCS from 1930 to 2015. Data from New South Wales were not included as cane is harvested as 1 or 2 year crops thereby skewing the data trends (Source: Australia Sugar Yearbook, Strand Publishing and Rural Press Qld; Sugar Research Australia, 2016).

Table 2—The annual change in Queensland cane yield and sugar yield between 1899 and 1988 (Smith, 1991).

Period of interest	Change in cane yield (tonnes cane/ha/year)	Change in sugar yield (tonnes sugar/ha/year)
1899–1919	0.6	0.09
1920–1940	0.7	0.15
1948–1970	0.9	0.15
1969–1988	0.01	0.00

Factors leading to yield improvement

A number of reviews were undertaken to help explain yield trends over time. However, most of these reviews neglected to look at the drivers for the increase in cane yield from the 1890s–1970s.

A review of the publications on the Australian Society of Sugarcane Technologists (ASSCT) website (https://www.assct.com.au/) identified that the three major areas of research from 1930–1970 were nutrition, pest and disease management, while soil health, irrigation and variety research also figured prominently (Table 3). This research was responsible for identifying new technologies critical in driving cane yield increases during the period, and included:

- Control of both pests and diseases:
  - Organochloride insecticide, BHC and Dieldrin, to control cane grubs and soldier fly.
  - Effective control methods for ratoon stunting disease.
  - Fungicides to control pineapple sett rot (Skinner, 1953; Egan, 2015).
- Development of resistant varieties to many of the known disease problems, including the eradication of gumming and downy mildew diseases (Egan, 2015).
- The introduction of new more productive varieties (Bieske, 1983; Smith, 1991; Cox and Hansen, 1995; Wilson and Leslie, 1997; Ellis *et al*., 2000).
- The introduction of better nutrient recommendations, fertiliser types and application methods (Schroeder *et al*., 2014).
- Increase in area under irrigation and improvements in irrigation management and scheduling (Moller and Chapman, 1975; Kingston and Chapman, 1975).

Table 3—The number of publications in ASSCT and QSSCT that address key productivity drivers in the Australian sugar industry from 1930 to 2016. The analysis was based on key words in the paper title.

Number of publication on productivity drivers	1930–1950	1950–1970	1970–1990	1990–2010	2010–2016	Total	% of total
Crop nutrition	17	16	32	129	50	244	23%
Disease management	19	16	48	93	52	228	21%
Water management	10	5	38	80	14	147	14%
Variety improvement	8	15	13	64	29	129	12%
Pest management	12	12	15	57	24	120	11%
Farming system/soil health	8	2	10	63	11	94	9%
Weed control	1	15	9	4	17	46	4%
Drainage	4	1	13	10	2	30	3%
Ameliorants	2	1	4	14	6	27	3%
Total publications	81	83	182	514	205	1065	
% of total	8%	8%	17%	48%	19%		

Interestingly, one technology that growers were relatively slow to adopt prior to the 1970s was the use of herbicides (Rehbein and Bates 1960); however research undertaken between 1950 and 1970 must have been sufficient to spur the adoption of this technology, as it is now common practice (Table 3).

Factors leading to decreased yield

Factors common to a number of reviews that were seen as limiting yield in the 1970–1990 period were:

- Increasing nitrogen fertiliser rates and increasing fibre content reduced CCS (Bieske, 1983);
- Ploughout replant and longer crop cycles contributed to yield decline (Smith, 1991; Wilson and Leslie, 1997);
- Increases in extraneous matter and suckers resulted in a reduction in CCS; and
- Weather variation resulted in large fluctuations in CCS; excessive rainfall was shown to reduce cane yield (Wilson and Leslie, 1997; Salter and Schroeder, 2012; Skocaj and Everingham, 2014).

Industry standards

There was an exponential increase in the quantity of research published on key productivity drivers in the 1930s to 2010 period (Table 3). The outputs and tools developed from this research have been used to produce a series of standards on sugarcane productivity, profitability and sustainability and incorporated into an industry-wide program called Smartcane BMP (https://www.smartcane.com.au/home.aspx).

These standards provide a strong foundation from which growers can identify issues that may be affecting their crops and then manage their land, water resources and other inputs accordingly.

However, increased yields associated with research outcomes over the last 35 years remain questionable (Fig. 1) and it has been suggested that technology adoption and appropriate timing would appear to be the major limitation to growers increasing their productivity (Stringer *et al.*, 2016; Stringer *et al.*, 2017).

So the key questions are ‘Why is sugar yield still flat lining and how does the industry kick-start improvement in sugar productivity?’.

Yield targets

Specific targets will assist the industry to improve productivity; they encourage the whole industry to work together towards a common goal. The most important question is, what target are we aiming for? What is the target yield for each region?

Industry yield measures

To discuss target yield, we need to define the yield to which we are referring. The Australian Centre for International Agricultural Research (ACIAR) defines seven different categories of crop yield (Fischer *et al*., 2014). Five of these are outlined below:

1. Farm Yield (FY): refers to the district average yield in kg/ha or tonnes/ha. In the Australian sugarcane industry we can use the district averages to derive this figure.
2. Potential Yield (PY): is the maximum yield achievable with the best adapted variety, optimised agronomic inputs and an environment that is free of manageable abiotic and biotic stresses.
3. Water-Limited Potential Yield (WLYP): is the yield obtained with no other manageable limitation to the crop apart from water supply. This yield is expressed as an index of yield against water supply (yield/ha/mm).
4. Theoretical Yield (TY): is the yield achieved when all crop requirements are optimised in a crop model such as APSIM.
5. Record and Contest-Winning Yield (RACWY): are exceptional yields and achieved under very favourable conditions with excellent management. Prize winning or not, this figure can be easily derived in the Australian sugar industry due to our detailed block recording systems.

We can easily benchmark the current performance of the industry and determine FY using the data compiled annually through mill productivity figures. This is the benchmark for each farm but what is the yield definition we should use to set a target for growers?

PY is difficult to derive and demonstrate. Firstly, the regular turnover of varieties and subjective assessment of the best environment for a variety results in uncertainty related to maximum variety performance.

Secondly, we lack the necessary knowledge to remove all the manageable abiotic and biotic stresses. For example, a low level of brown rust or Pachymetra is considered ‘non-yield limiting’, but is the compounded effect of a low level of each disease also ‘non-yield limiting’?

WLPY is also difficult to derive for the same reasons mentioned above. It is also a moving target, dependent on water availability, sourced from irrigation and/or rainfall. This may be even more difficult and variable in the future as a result of climate change. Additionally, if we use WLPY as a yield target, we send an extension message that increasing irrigation supply and efficiency is not a productivity improvement option.

The SRA Advisors Kit quotes the following theoretical (cane) yields calculated using a 14 month growing period, with a 1st August planting date; Tully 196 TCH, Ayr 213 TCH, Bundaberg 194 TCH and Harwood 164 TCH. Fischer *et al.* (2014) calculates a theoretical maximum as a remarkable 381 TCH and Muchow *et al.* (1997) have defined theoretical (sugar) yields for a range of Australian regions (Table 4).

It is unlikely that commercially-minded industry managers would accept a yield target based on theory due to the lack of agreement between different authors in the quantum of the TY and the reliance of this method on models.

RACWY is easily determined and reflects what is achievable in exceptional circumstances within each region/district and sub-district. We believe that exceptional is what our goal should be; mediocrity is unacceptable. Table 4 shows the RACWY for some Australian regions compared with the 20 year Farm Yield (region average) and the Theoretical (sugar) Yields determined by Muchow *et al.* (1997).

Table 4—A comparison of Record and Contest-Winning Yield (RACWY), Theoretical Sugar Yield (TSY) and Farm Yield (FY) measured in tonnes/ha for districts in the Australian sugar industry. The TSY was determined from Muchow *et al.* (1997). The (FY) were adapted from Sugar Research Australia statistics and the RACWY was a verifiable block yield obtained from consultation with local productivity services staff.

District	RACWY		TSY	FY		Reason for RACWY
	Cane	Sugar		Cane	Sugar	
Mossman			23.9	77.5	10.0	
Tablelands	206	22.8	26.7	94.7	13.1	Non-yield limiting nutrition program, efficient irrigation system
Mulgrave	158	20.2	23.9	86.2	11.0	Good drainage
South Johnstone	165	20.6	23.1	77.3	9.5	Good soil type
Tully	221	28.9	21.7	82.9	10.4	Good soil type, sound drainage, excellent climatic conditions. Minimal RSD/Pachymetra
Herbert	199	20.4	24.4	78.0	10.4	Uses improved farming system, good timing, good soil, progressive grower
Burdekin	262	30.1	27.4	114	16.7	Mill ash applied, good irrigation management, high solar radiation
Proserpine	134	17.8	24.6	82.2	11.5	Whole of farm data as mill data collected at farm and not paddock scale
Mackay	176	24.5	26.4	75.9	10.6	Improved Farming System, timely management, good irrigation management, average soil
Plane Creek	153	24.2	26.4	75.1	10.6	Good management and timely operations, grower involved in research activities, harvests own cane
Bundaberg	190	30.8	22.6	79.4	11.3	Good management and timely operations, good soil
ISIS	208	30.0	22.6	83.8	11.5	Highly fertile river soil
Maryborough	182	29.0	24.3	70.5	9.6	New land, good soil and management
Rocky Point	174	24.3		80.9	10.8	Good management
Condong	188	21	20.1	107	12.4	Timely operations, adequate N, fertile peat soil
Broadwater	188	21		128	14.7	
Harwood	188	21	17.6	121	14.0	

Table 4 demonstrates that RACWY is often more than double FY and generally less than the TY. The difference between RACWY and FY can be referred to as the 'Yield Gap' (YG). To bridge this YG, we suggest that RACWY be used to assess the factors limiting yield on each farm:

- The physical characteristics of the RACWY farm can be studied to identify key factors addressed in relation to the conditions prevailing on other farms.
- The management practices of the RACWY grower can be studied, replicated and used in an extension plan to increase productivity.
- RACWY grower inputs can be studied and replicated.

There are some factors driving productivity on RACWY farms that cannot be directly managed. For example, micro-climate, day length and certain soil characteristics cannot be altered and vary between sub-districts. Adjusted yield targets based on RACWY may be needed in each sub-district.

To determine an adjusted RACWY, we need to use the best available literature to determine the yield limiting effects of all the productivity drivers that cannot be better managed, increased or manipulated. These yield limiting effects would be used to apply a handicap on the RACWY to set a yield target for each sub-district. For example, in rain-fed districts there are sub-districts that receive less than the average district rainfall due to their geographical location.

If irrigation is unavailable then a water availability handicap would be placed on the yield target. If irrigation is available, then the sub-district would need to utilise this irrigation to move towards the yield target.

Identifying manageable productivity drivers

If delivered to the industry in a positive, well thought-out manner, a 'sub-district target yield' (SDTY) based on a district RACWY would be a way to mobilise extension and research resources towards an ambitious, yet achievable yield goal.

It is important ambitious targets are set for each SDTY. What productivity drivers are preventing us from reaching our SDTY and can these productivity drivers be better managed, increased or manipulated? We can use these productivity drivers to devise a plan to reach a SDTY.

We have outlined the status of each of these productivity yield drivers below:

<u>Crop nutrition –potentially limiting sugar productivity and can be better managed</u>

The sugar industry has a good understanding of the nutritional requirements of sugarcane and individual guidelines are available for most of the Australian sugarcane growing regions (Schroeder *et al.*, 2008).

However, management of sugarcane nutritional requirements is sometimes outside of growers control due to the cost and availability of some nutrient sources such as calcium and silicon and the impact of weather.

In recent times there has been an over-emphasis on nitrogen management; 103 publications on the ASSCT website since 1990 contain the word 'nitrogen' in the title, with little recognition that nitrogen is just one component in the sugarcane farming system. This research has been valuable in identifying loss pathways and recognising that the sugar industry is struggling with how to increase nitrogen use efficiency (NUE), particularly given the environmental concerns surrounding the loss of nitrogen to the Great Barrier Reef (Bell *et al*., 2014).

However, better management of nitrogen cannot occur without considering water x nitrogen interactions and, unless growers have the ability to predict rainfall in the short-term (less than 30 days) and mid-term (200 days), they will struggle to manage nitrogen effectively.

Conversely, if growers can improve water management through better utilisation of effective rainfall or irrigation as well as reduce negative impacts associated with poor drainage or low soil water-holding capacity, then water as a major limitation to crop productivity will be negligible and NUE will increase because yield will increase.

In short, crop nutrition should not be limiting sugar productivity; however, it could be better managed, in particular nitrogen, calcium and silicon in a whole farming system context and the interactions with water considered when determining nutrient management.

<u>Water management—major limitation to sugar productivity that can be better managed, manipulated and increased</u>

There is a good understanding of the water requirement of sugarcane to maximise productivity (Kingston and Chapman, 1975; Kingston, 1994; Inman-Bamber, 2007) and substantial evidence to suggest that climate, in particular rainfall, is the major factor influencing sugar productivity (Wilson and Leslie, 1997; Garside *et al.*, 2014; Everingham *et al.*, 2015).

The ability for sugarcane to access water is a function of the quantity and timing of rainfall or irrigation and the capacity of the soil to store water. The soil PAWC is affected by vehicle traffic and, an increase in soil compaction reduces water infiltration rate and soil porosity (Garside and Bell, 2006). Soil PAWC can be managed using controlled traffic and increased through the use and placement of ameliorants such as mill mud.

There is evidence that most growers who have access to irrigation water do not utilise irrigation scheduling tools and consequently their timing of water application is probably not optimised. Stringer *et al*. (2017) demonstrated that optimal timing of inputs to a cane crop is often the difference between high and low producing growers.

In addition, excess water has been identified as a major limitation to cane growth. However, there is ample information on how to improve drainage to minimise waterlogging (Kingston, 1982).

Growers have low certainty of accurately predicting the timing and quantity of rainfall events more than 5–7 days out. Future improvements in grower water management will be dependent on new technologies that improve the accuracy of rainfall forecasting and technology that can identify zones within paddocks that are subject to water stress. Some of these technologies are already available (Markley and Hughes, 2013; Webster *et al*., 2016); however, trained advisors who can interpret this information are limited.

Pest and disease management – limiting sugar productivity and could be better managed with integrated techniques

The major pest and diseases in the Australian sugar industry have been identified and strategies developed and implemented to reduce their impact on productivity (Magarey, 2005; Egan, 2015). In addition, strategies to identify and limit the impact of epidemics are well understood and in place in the industry (Magarey *et al*., 2011). It is apparent the sugar industry pathologists and plant breeders work in close consultation to identify varieties resistant to the major pests and diseases (Sugar Research Australia, 2013). However, grower variety planning is exposing the industry to the risk of epidemics (Stringer *et al.,* 2016).

Weed control – limiting sugar productivity primarily through timing of application which could be better managed

The negative impact of weeds on crop productivity is well known and it has been reported that weeds can reduce cane yields by as much as 30% (McMahon *et al*., 1989). All growers in the Australian sugar industry practise weed control to some degree. However, there is evidence that growers who have higher productivity undertake weed control at the optimum time while growers with lower productivity undertake weed control too late (Stringer *et al*., 2017).

Variety management—demonstrating continual improvement so keeping ahead of the game (maintains base line productivity, farm managers cannot control plant breeding)

The Australian sugar industry variety selection program has changed significantly over the last 25 years, which has resulted in a decrease in the time to release varieties, an increase in the rate of genetic gain for sugar yield to around 190 kg sugar/ha and an improvement in the disease rating of released varieties for most of the significant diseases (Cox *et al*., 2014).

Can the variety selection program in its current format and using the available genetic base take the industry to new levels and produce varieties with better WUE and NUE?

Farming systems and soil health—major limitation to sugar productivity can be better managed, increased and manipulated

The Australian sugar industry invested approximately $20M in the Sugar Yield Decline Joint Venture (SYDJV) between 1993 and 2005 and, 'given the assumptions made, the investment up to 2004–05 shows an expected net present value of $254m for a 5% discount rate, a benefit-cost ratio of 8.8 to 1 and an internal rate of return of 22%'. (Agtrans Research, 2006).

The outcome of the SYDJV was: 'Specific research has shown that the long-term monoculture, uncontrolled traffic from heavy machinery and excessive tillage, along with practices that deplete organic matter, all contribute to yield decline. It is argued that changes to the cropping system that will conserve organic matter, break the monoculture, control traffic and minimise tillage are the most appropriate ways to combat yield decline.' (Garside *et al*., 2005). The sugarcane harvester has increased in weight from 6 tonne gross weight in 1970s to more than 16 tonne gross weight in 2016, while haulouts have increased from 4 tonne in gross weight to greater than 15 tonne gross weight.

The technology developed in the SYDJV provides an excellent farming system foundation that will assist in improving sugar yields. However, adoption of this farming system has been less than expected, despite evidence that growers who adopt the improved farming system have higher sugar productivity (Stringer *et al*., 2016).

Research ideas and adoption strategies for the future

In this paper we discuss what the current omelette (Sugar Yield) looks like and how it was created. Next we have conducted market research and decided what sort of omelettes we can realistically create in order to optimise profit (sub-district Target Yields) and identified the ingredients for these omelettes (Productivity Drivers). The industries final task is to determine how much of each ingredient to add (Setting Priorities) and how to prepare the ingredients (Research and Development) (**Table 5**).

Setting priorities is all about determining what will produce the largest return on investment in the future. We will leave it to industry leaders to analyse the productivity drivers that can be better managed, increased or manipulated and allocate resources to those drivers that deliver the optimal triple bottom line – a good exercise in strategic thought. SDTY present researches and growers with a worthwhile goal to rally.

'When someone works towards a worthwhile well defined goal it is human nature that others feel compelled to help.'

Table 5—Future research and development strategies and technology adoption strategies required in the next 10 years to drive an increase in sugar productivity.

Productivity driver	Existing technology enablers	R&D and technology adoption strategies to be developed
Crop nutrition	Six easy steps Regional soil specific guidelines SCAMP and SAFEGUARD for Nutrients (Moody *et al.*, 2008) Spectral NDVI and GNDVI via satellite or drone Yield monitoring Soil electromagnetic surveying Spatial analysis tools for Precision Agriculture Rate controllers	Nitrogen R&D needs to focus on interaction with water management and the farming system Spectral sensors for nitrogen monitoring & calibration Spatial analysis for block nutrient planning
Water management	Irrigation scheduling Soil moisture monitoring probes GPS guided tractors and harvesting equipment Spectral NDVI and GNDVI via satellite or drone	Rainfall forecasting tools Controlled traffic Automated irrigation Sub-soil amelioration
Pest and disease	Pest detection labs Variety selection program Spectral NDVI and GNDVI via satellite or drone	Pest and pathogen sniffers Genetic markers
Weed control	Weedseeker Rate controllers Spectral NDVI and GNDVI via satellite or drone	Automatic weed identification
Variety management	Continual improvement through variety selection program	WUE and NUE Genetic markers Introgression of wild canes Local variety management programs
Farming system and soil health	GPS guided tractors and harvesting equipment Yield monitoring Soil electromagnetic surveying Spatial analysis tools for Precision Agriculture Amelioration of sub-soil constraints	Soil health kit Controlled traffic Sub-soil amelioration

Discussion

We believe that growers, industry service providers and researchers can use SDTY to increase sugar productivity and improve the profitability of the industry. It is anticipated some industry stakeholders will recoil with the introduction of this term. We need to be clear that SDTY is not intended to be used to set nitrogen fertiliser rates for districts as we believe this is covered adequately in the literature. SDTY is a target yield that is achievable if the productivity drivers of a paddock are conquered. SDTY's will vary enormously within a region and between regions however they should all be based on RACWY found in each region, as these are verifiable and readily observed by growers in the field.

In this paper, the status of the six productivity drivers limiting industry profitability have been discussed. It is not practical to prioritise these productivity drivers as the importance of any particular one will vary from paddock to paddock. However, it is arguable that the spatial analysis of spectral data from satellite or drones can be quickly used to identify and prioritise the productivity drivers that are preventing a grower achieving the SDTY. Unfortunately the lack of professional agronomists with the skills to do this type of analysis as well as assess the in-field situation will slow this process.

It is clear that one major impediment to the improvement of productivity in the Australian sugar industry is the lack of adoption of existing improved technology strategies. Table 4 demonstrates that FY is in general half that of RAWCY and, in the majority of these cases, the RAWCY growers simply do their operations at the best time to maximise their impact and minimise their cost, as well as practice components of the improved farming system. There is not a lack of knowledge.

It is also clear that some productivity drivers have had substantial research undertaken and are relatively well understood by industry stakeholders, namely nitrogen, although improvements in NUE still elude the industry, possibly due to nitrogen research not be undertaken with the entire farming system in mind. While other productivity drivers, soil compaction as an example, are understood but are insidious as they are not as visible to industry stakeholders. However, if these insidious productivity drivers could be easily identified we are confident that SDTY would be rapidly achieved and it behoves the industry R&D priority setters to provide growers with the tools to be able to see, feel and smell the insidious productivity drivers so that they find it easier to adopt the new technologies being thrust at them at a rate of over 200% compared to a quarter of a century ago.

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REFERENCES

ABS (2013) 7124.0 – Historical Selected Agriculture Commodities, by State (1861 to Present), 2010–11 (http://www.abs.gov.au/AUSSTATS/abs@.nsf/ProductsbyCatalogue/317C72EE05CF20AECA25709E003C52B0?OpenDocument).

Agtrans Research (2006) Assessment of investment by SRDC in selected projects. SRDC Internal Project Number – SRD007. pp. 90.

Bell MJ, Moody P, Salter B, Connellan J, Garside AL (2014) 3. Agronomy and physiology of nitrogen use in sugarcane crops. In 'A review of nitrogen use efficiency in sugarcane'. (Ed MJ Bell) pp. 89–124. (Sugar Research Australia: Brisbane).

Bieske GC (1983) Queensland regional CCS trends. *Proceedings of the Australian Society of Sugar Cane Technologists* **5**, 95–102.

Cox MC, Aitken FC, Wei X, Piperidis G, Parfitt RJ, Croft BJ, Stringer JK (2014) SRA plant breeding program—annual benchmarks. *Proceedings of the Australian Society of Sugar Cane Technologists* **36**, 271–279.

Cox MC, Hansen PB (1995) Productivity trends in southern and central regions and the impact of new varieties. *Proceedings of the Australian Society of Sugar Cane Technologists* **17**, 1–7.

Egan BT (2015) The history of cane pests and disease control boards in Queensland. (PUBLISHING Project Management Scribe Consulting: Brisbane).

Ellis RN, Basford KE, Cooper M, Leslie JK, Byth DE (2000) Analysis of sugarcane yield productivity trends in the wet tropics at a district level. *Proceedings of the Australian Society of Sugar Cane Technologists* **22**, 283–289.

Everingham Y, Sexton J, Robson A (2015) A statistical approach to identifying important climatic influences on sugarcane yields. *Proceedings of the Australian Society of Sugar Cane Technologists* **37**, 8–15.

Fischer RA, Byerlee D, Edmeades GO (2014) 'Crop yields and global food security: will yield increase continue to feed the world?' ACIAR Monograph No. 158. AUSTRALIAN CENTRE FOR INTERNATIONAL AGRICULTURAL RESEARCH: CANBERRA. xxii + 634 pp.

Garside AL, Bell MJ (2006) Final report – SRDC Project YDV002 Sugar Yield Decline Joint Venture Phase 2 (July 1999–June 2006). BSES Limited. SRDC Final Report SD06011.

Garside AL, Bell MJ, Robotham B., Magarey RC, Stirling GR (2005) Managing yield decline in sugarcane cropping systems. *International Sugar Journal* **107** (1273), 16–26.

Garside AL, Di Bella LP, Sefton M, Wood, AW (2014) Review of productivity trends in the Herbert sugarcane growing region. *Proceedings of the Australian Society of Sugar Cane Technologists* **36**, 1–11.

Inman-Bamber NG (2007) Economic impact of water stress on sugar production in Australia. *Proceedings of the Australian Society of Sugar Cane Technologists* **29**, electronic format pp 9.

Kingston G (1982) A review of drainage requirement of canelands in southern Queensland. *Proceedings of the Australian Society of Sugar Cane Technologists* **4**, 71–75.

Kingston G (1994) Benchmarking yield of sugarcane from estimates of crop water use. *Proceedings of the Australian Society of Sugar Cane Technologists* **16**, 201–209.

Kingston G, Chapman LS (1975) Water requirements and irrigation scheduling of sugarcane in Queensland II. Irrigation scheduling of sugarcane in Queensland. *Proceedings of the Queensland Society of Sugar Cane Technologists* **42**, 69–76.

Magarey RC (2005) The incidence of sugarcane diseases in Queensland. *Proceedings of the Australian Society of Sugar Cane Technologists* **27**, 252–265.

Magarey RC, Royal A, Williams DJ, Bull JI (2011) A brief history of disease epidemics in Queensland and of some economic outcomes. *Proceedings of the Australian Society of Sugar Cane Technologists* **33**, electronic format pp 12.

Markley J, Hughes J (2013) Understanding the barriers to the implementation of precision agriculture in the central region. *Proceedings of the Australian Society of Sugar Cane Technologists* **35**, electronic format pp 11.

McMahon GG, Williams RC, McGuire (1989) The effects of weed competition on ratoon sugarcane yield. *Proceedings of the Australian Society of Sugar Cane Technologists* **11**, 88–92.

Moller RB, Chapman LS (1975) Irrigation systems in the Queensland sugar industry. *Proceedings of the Queensland Society of Sugar Cane Technologists* **42**, 51–55.

Moody PW, Blogg D, Legrand J, Schroeder BL, Wood AW (2008) 'SCAMP' and SAFEGUARD FOR NUTRIENTS': two new decision support tools for minimising off-site movement of nutrients. *Proceedings of the Australian Society of Sugar Cane Technologists* **30**, 276–284.

Muchow RC, Robertson MJ, Keating BA (1997) Limits to the Australian sugar industry: climatic and biological factors. In 'Intensive Sugar Cane Production: Meeting the Challenges Beyond 2000.' (Eds BA Keating, JR Wilson) pp. 37–54 (CABI: Wallingford, UK).

Rehbein CA, Bates G (1960) A review of chemical weed control in north Queensland canefields. *Proceedings of the Queensland Society of Sugar Cane Technologists* **27**, 47–49.

Salter B, Schroeder BL (2012) Season rainfall and crop variability in the Mackay region. *Proceedings of the Australian Society of Sugar Cane Technologists* **34**, 1–12.

Schroeder BL, Salter B, Moody PW, Skocaj DM, Thorburn PJ (2014) 2. Evolving nature of nitrogen management in the Australian sugar industry. In 'A review of nitrogen use efficiency in sugarcane'. (Ed MJ Bell) pp. 15–88. (Sugar Research Australia: Brisbane).

Schroeder BL, Wood AW, Panitz JH, Salter B, Moody PW (2008) The 'SIX EASY STEPS' as a delivery mechanism for best practice nutrient management in the Australian sugar industry. Soils 2008 Conference, Massey University, Palmerston North, New Zealand. (Australian and New Zealand Societies of Soil Science).

Skinner SO (1953) A review of modern agricultural developments and the record 1952 crop in the Innisfail and Tully areas. *Proceedings of the Queensland Society of Sugar Cane Technologists* **20**, 119–121

Skocaj DM, Everingham YL (2014) Identifying climate variables having the greatest influence on sugarcane yields in the Tully mill area. *Proceedings of the Australian Society of Sugar Cane Technologists* **36**, 53–61.

Smith MA (1991) Recent production trends in the Queensland sugar industry. Bureau of Sugar Experiment Stations pp. 66

Stringer J, Croft B, Asamoah I, Di Bella L, Sefton M, Nielson R, Larsen P, De Lai R, Davies I (2017) Optimising productivity in the Herbert through analysis of mill data. *Proceedings of the* Australian Society of Sugar Cane Technologists **39**, in these proceedings

Stringer J, Croft B, Di Bella L, Sefton M, Nielson R, Larsen P, De Lai R, Davies I (2016) Optimising productivity and variety recommendations through analysis of mill data. *Proceedings of the Australian Society of Sugar Cane Technologists* **38**, 180–192.

Sugar Research Australia (2013) Strategic plan 2013/14 – 2017/18. http://www.sugarresearch.com.au/icms_docs/188322_Strategic_Plan_201314-201718.pdf.

Sugar Research Australia (2016) Mill Area Statistics 2015 Season. Sugar Research Publication ST16001.

Webster T, Panitz J, Jensen T, Bramley R (2016) Industry perspective on precision agriculture. *Proceedings of the Australian Society of Sugar Cane Technologists* **38**, 29–39.

Wilson GL, Leslie JK (1997) Productivity trends in sugarcane in the wet tropics. *Proceedings of the Australian Society of Sugar Cane Technologists* **19**, 21–29.