# DEVELOPMENT OF A METHOD TO IMPOSE WATERLOGGING ON SUGARCANE GROWN IN POTS

By

B SALTER, E KOK
*Sugar Research Australia, Mackay*
BSalter@sugarresearch.com.au

**KEYWORDS: Weather, Climate, Tolerance, Anaerobic, Crop.**

**Abstract**

RECENT PRODUCTIVITY REVIEWS in the Herbert and Central regions identified strong negative correlations between excessive rainfall and productivity. Waterlogging has been estimated to reduce yield by 0.5 t/ha for every day the water-table is within 50 cm of the soil surface. Identification of varieties that perform better under waterlogged conditions is based on anecdotal observations from the field, after a variety is released. If a variety's tolerance was known closer to the time of release, growers could make informed decisions on whether particular varieties are best suited to their farm or blocks within their farm. In order for this to occur a simple and reliable method to assess waterlogging tolerance of varieties is required. Four experiments were conducted as part of the process to develop a method to assess waterlogging tolerance of sugarcane varieties growing in pots. During the development of the method pots were immersed in water with low dissolved oxygen concentration (DO). The low DO concentration was maintained by the addition of fibrated sugarcane stalk, in order to increased biological oxygen demand. In later experiments water level was maintained at the soil surface through the development of a system that incorporated a float valve. Sugarcane shoot and leaf growth was reduced in waterlogging treatments. Tillering was reduced in some experiments, which appeared to be related to crop age when treatments were imposed. Overall, the methods used allowed anaerobic conditions to be maintained within the pot and plant response was typical for waterlogging. This provides confidence that this method could be used to assess tolerance of sugarcane varieties.

## Introduction

Waterlogging is an abiotic stress that limits the potential productivity of sugarcane in a number of growing regions within Australia. This was highlighted in recent productivity reviews in the Herbert and Central regions, where strong negative correlations between excessive rainfall and productivity were found (Garside *et al.*, 2014; Salter and Schroeder, 2012). While other environmental conditions are also affected during periods of excessive rainfall, particularly solar radiation, and nitrogen use efficiency declines, waterlogging contributes significantly to the decline in yield potential. Previous work has shown that sugarcane lost 0.5 t/ha for every day the watertable was within 50 cm of the soil surface (Rudd and Chardon, 1977).

Growers can reduce the occurrence of waterlogging through management practices. These include:

- laser levelling blocks,
- improving drainage systems,
- planting on mounds, and
- planting earlier to avoid waterlogging when the crop is small (Reghenzani and Roth, 2006).

Planting varieties with waterlogging tolerance is beneficial, and in combination with management practices, offers the best approach to reduce the impact of waterlogging on

productivity. However, currently information on the waterlogging tolerance of Australian sugarcane varieties is gained from anecdotal evidence on farm after a variety is released or near release. This occurs on a regional basis and has resulted in some variability in ratings for some varieties across regions (Table 1). This variability is possibly associated with differences in waterlogging intensities experienced, timing of waterlogging events in relation to crop age, differences between waterlogging and flood tolerance, and other factors.

When a variety is first released in a region its tolerance to waterlogging is stated as 'unknown' (Table 1) or it is highlighted that the information is based on limited data. The actual data or observations required prior to a variety receiving a rating are subjective. In order for these ratings to be more reliable and available to growers at release, a more structured approach to rating varieties for waterlogging tolerance is required.

**Table 1**—Waterlogging tolerance ratings of sugarcane varieties in four regions (QCANESelect™). Blank cells indicate that the variety is not grown in that region.

| Variety | Region | | | |
|---|---|---|---|---|
| | Northern Coastal | Herbert (wet zone) | Burdekin | Central |
| Q247 | | Average | Poor | Unknown |
| Q242 | | Good | | Good |
| Q240 | Average | Good | Unknown | Average |
| MQ239 | | Good | | |
| Q238 | Poor | Average | Unknown | Poor |
| Q237 | Average | Average | | |
| Q232 | Average | Average | Unknown | Good |
| Q231 | Good | Good | | |
| Q230 | Poor | | | |
| KQ228 | Average | Poor | Average | Poor |
| Q226 | | Good | | Poor |
| Q219 | Good | | | |
| Q212 | | | | Average |
| Q209 | | | | Average |
| Q208 | Good | Good | Poor | Good |
| Q200 | Poor | Good | Average | Average |
| Q190 | | Average | | Good |
| Q183 | Poor | Good | Good | Poor |

Screening varieties for waterlogging tolerance in the field is difficult. It requires large plots to be artificially waterlogged and water tables maintained, often at different heights, for long periods of time (Gilbert *et al.,* 2007). Alternatively, blocks with natural differences in waterlogging propensity, based on position in the landscape, have been used (Roach and Mullins, 1988). However, waterlogging stress treatments are then reliant on specific seasonal conditions. Screening genotypes for waterlogging tolerance in pots has been explored, particularly during early stages of development (Burry *et al.,* 2004).

During natural waterlogging events, the dissolved oxygen (DO) concentration of water in the soil profile is reduced as consumption by biota exceeds diffusion into the profile. Low DO reduces the ability of the root system to function (Gomathi *et al.*, 2015). Burry *et al.,* (2004) reported DO concentrations below 2 mg/L in a waterlogged field in Ingham.

Fully aerated water is often in the range 6–8 mg/L. In pot experiments, it is important that the DO concentration of the water is reduced to levels similar to those found in waterlogged fields, as this is an important component of this abiotic stress.

This paper describes experiments that were conducted in order to develop a method to impose waterlogging on sugarcane grown in pots. A simple and reliable method would allow more accurate and timely waterlogging tolerance ratings to be provided to industry. This would assist growers to make informed decisions, based on more robust data, about variety selection on farm and lead to improved productivity.

## Materials and methods

Four pot experiments were conducted at the Sugar Research Australia experimental station at Mackay. All experiments were conducted in an area open to the environment. A brief summary of the experiments is shown in Table 2.

### Experiment 1

Single eye setts of KQ228$^{\phi}$ and Q208$^{\phi}$ were planted in pots on 18 August 2014. These varieties were chosen due to perceived difference in waterlogging tolerance (QCANESelect$^{TM}$). Pots size was 14 cm × 14 cm (diam. × height) and contained a mixture of 50% coarse sand and 50% Searles premium potting mix. On 9 October 2014, ten pots of each variety were submersed in water by placing them in a bucket. Water level was adjusted with tap water on a daily basis so that it was at or slightly above the soil surface. Ten pots of each variety were also maintained as controls. After one week in these waterlogged conditions no visible signs of stress were evident.

Fibrated sugarcane stalk (1 L) was added to half of the waterlogged pots (5 KQ228$^{\phi}$ and 5 Q208$^{\phi}$). This was similar to the method used in previous sugarcane studies (Roach and Mullins, 1985) in order to reduce DO concentration. DO concentration was monitored with an oxygen test kit (Merck). Addition of fibrated material resulted in plants showing visible symptoms of stress within five days. All pots were then removed from the waterlogging treatments. Plants were cut at the base, weighed and placed in a drying oven at 60 °C to determine dry biomass 72 DAP.

**Table 2**—Summary of experimental details of four pot experiments conducted at Mackay. FB–fibrated sugarcane stalk, recov–plants allowed to recover from waterlogging stress.

| Experiment | Variety | Setts planted | Treatments | Treatments initiated (DAP) | Harvested (DAP) |
|---|---|---|---|---|---|
| 1 | Q208$^{\phi}$, KQ228$^{\phi}$ | 18/08/2014 | Control<br>Waterlogged<br>Waterlogged+FB | 9/10/2014 (52)<br>9/10/14 + FB 16/10/14 (59) | 29/10/2014 (72) |
| 2 | KQ228$^{\phi}$ | 3/10/2014 | Control<br>Waterlogged<br>Waterlogged+FB | 25/11/2014 (53) | 18/12/2014 (76) |
| 3 | Q208$^{\phi}$, KQ228$^{\phi}$ | 3/10/2014 | Control<br>Waterlogged+FB<br>Waterlogged+FB+recov | 9/01/2015 (98) | 23/02/2015 (143) |
| 4 | Q208$^{\phi}$, KQ228$^{\phi}$ | 6/02/2015 | Control<br>Waterlogged+FB<br>Waterlogged+FB+recov | 18/03/2015 (40) | 15/05/2015 (98) |

### Experiment 2

KQ228$^{\phi}$ was planted in pots (20 cm × 19 cm) on 3 October 2014. A single-eye sett was placed in a mixture of 50% coarse sand and 50% Searles premium potting mix. Plants were fertilised with Osmocote (5 g every 4 weeks) and urea (1 g per fortnight). Waterlogging treatments were imposed on 25 November 2014.

Treatments were:

1. Control (sugarcane growing in a drained pot)
2. Waterlogged (sugarcane pot placed in bucket and water level maintained at soil surface)
3. Waterlogged + FB (As above with the addition of fibrated sugarcane stalk (15 g) to water to reduce DO concentration. Fibrated material added to pots on 28 November 2014, 2 December 2014 and 11 December 2014)

Leaf development (length, maximum breadth) on the primary shoot in each pot was monitored throughout the experiment. Leaves were numbered as they appeared, the first leaf with a lamina greater than 20 mm was labelled leaf 1. Shoot height was recorded on 1 December 2014, 12 December 2014 and 18 December 2014. The trial was harvested on 18 December 2014. Above ground biomass was weighed, placed in a paper bag and dried at 60 °C to determine moisture content. Shoot number was recorded. A section of the last fully expanded leaf from each pot was used to determine relative water content (RWC). This was performed by weighing segments of leaf following removal from the plant, after 24 hours in water and after drying at 60 °C. The root mass was removed from pots and divided into the upper and lower halves. Roots were washed from soil and dried at 60 °C. Measurements of DO concentration (Cyberscan DO 110 dissolved oxygen meter) were taken throughout the experiment. Water within the buckets that held the pot containing the sugarcane plant was used for the analysis. At final harvest, samples were also collected from the water that drained out of the pot (water within the root zone).

**Experiment 3**

Sugarcane (Q208$^{(\phi}$ and KQ228$^{(\phi)}$) was planted in pots on 3 October 2014. Pots (20 cm × 19 cm) contained a mixture of 50% coarse sand and 50% Searles premium potting mix. Plants were fertilised with Osmocote (15 g every 4 weeks) and Wuxal (150 ml of a 20 ml/L solution applied to soil within each pot per fortnight). A 30 cm section of 4 mm irrigation riser tubing, with 20 holes drilled through the bottom 10 cm and wrapped in geo-fabric, was buried within each pot. A BD Connecta$^{TM}$ was placed on the exposed end of the tube and a syringe was used to collect water samples from within the root zone throughout the experiment. These samples were analysed for DO concentration. The experiment was established on 9 January 2015 (98 DAP) and was arranged as a factorial design (variety, treatment) in randomised blocks with 5 replicates. Treatments were:

1. Control
2. Waterlogged (+Fibrated sugarcane stalk)
3. Waterlogged (+Fibrated sugarcane stalk) and allowed to recover (pots were removed from buckets on 28 January 2015)

Fibrated material (15 g) was added to pots on 12 January 2015, 20 January 2015, 4 February 2015, 9 February 2015 and 17 February 2015. On 23 February 2015 stalks in each pot were counted, weighed, and length recorded. A subsample of millable stalk, and leaf and cabbage, was placed in a paper bag, weighed, and dried at 60 °C to determine moisture content. These measurements allowed the calculation of total dry biomass, average stalk length, % dry matter and average stalk weight.

**Experiment 4**

Q208$^{(\phi}$ and KQ228$^{(\phi)}$ were planted in pots (and managed as described in Experiment 3) on 6 February 2015. Pots included tubing for the extraction of water samples from the root zone and analysis of DO concentration as described previously. A system was also developed to automatically control the water level within waterlogged pots. All pots in waterlogged treatments were connected to a 20 L container. Water level within the container (and all pots connected to it) was controlled with a float valve. The water source for the container was a 1000 L tank. Water in this tank was deoxygenated with the addition 1.5 kg fibrated cane stalk per 500 L water. Fibrated material was added to the tank on 17 March 2015, 30 March 2015 and 4 May 2015. The tank was also topped up prior to this.

Waterlogging treatments commenced on 18 March 2015. The experiment was arranged as a factorial design in randomised blocks (5 replicates). Treatments were:

1. Control
2. Waterlogged (with deoxygenated water and automatically controlled water height)
3. Waterlogged (as above) and allowed to recover

Pots in the waterlogged + recovery treatment were removed from waterlogging after 2 weeks (1 April 2015), allowed to recover for 2 weeks and returned to waterlogging conditions (15 April 2015). These pots were allowed to recover for a further 2 weeks commencing 1 May 2015.

Leaf development (length, width, area) was assessed with a Licor LI-3000C portable leaf area meter. Plants in all pots were harvested on 15 May 2015. Stalks in each pot were counted and weighed. A subsample was placed in a paper bag, weighed, and dried at 60$^{o}$C to determine moisture content. These measurements allowed the calculation of total dry biomass and % dry matter.

All data were analysed using ANOVA procedures in GenStat 16.2.

## Results and discussion

### Experiment 1

Despite the lack of a statistically significant difference, plants growing while submerged in water, without fibrated sugarcane stalk, had greater dry biomass than the controls (Table 3). This indicated that the irrigation frequency of controls was inadequate and was adjusted for other experiments. While also not statistically significant, addition of fibrated sugarcane stalk reduced shoot biomass. Given that it took five days for plants to show severe stress following the addition of fibrated cane stalk, there was not sufficient time for the non-stressed plants to grow sufficiently to produce a statistically significant difference. Plants were removed from the waterlogging treatments after five days as it was likely that they would not survive.

While DO was reduced (data not shown) with the addition of fibrated sugarcane stalk, the volume of material added was relatively large (approximately 1 L). There may have been other effects on plant growth, possibly the concentration of sugar may have induced osmotic stress. Therefore, the dramatic stress shown by the plants may not have been due to waterlogging. In future experiments reduced amounts of fibrated material were added in order to reduce DO. Given the uncertainty around the actual cause of the stress seen in this preliminary experiment, these results should be treated with caution.

**Table 3**—Dry biomass (g/pot) of shoots grown in drained pots and pots submerged in water with and without fibrated sugarcane stalk.

| Treatment | Fibrated stalk | Variety | |
|---|---|---|---|
| | | KQ228$^{(\diamond)}$ | Q208$^{(\diamond)}$ |
| Control | no | 9.8 | 8.4 |
| Waterlogging | no | 12.2 | 10.4 |
| | yes | 9.8 | 10.2 |
| | LSD(0.05) | ns | ns |

### Experiment 2

Submerging pots in water and water with added fibrated sugarcane stalk significantly reduced total biomass, both shoot and roots (Table 4). Sugarcane typically produces an adventitious root system at the soil surface in response to waterlogging (Gilbert *et al.,* 2007*;* Gomathi *et al.,* 2015*).* While this was observed in all experiments, the sampling process used was not able to show this difference. It is unlikely that a root system trait could be used to rate varieties due to difficulty in assessing sugarcane root systems. Total shoot number per pot appeared to decline with the waterlogging treatments but this was not statistically significant. No difference was found for plant

percent dry matter and differences in leaf relative water content were not statistically significant. Stalk height was similar among treatments at 59 DAP. At 70 and 76 DAP plants within the waterlogged + FB treatment were significantly shorter than those in the control and waterlogged treatments (Table 5).

**Table 4**—Harvest data for control, pots submersed in water and pots submersed in water with the addition of fibrated (FB) sugarcane stalk.

| Treatment | Fresh biomass (g/pot) | Dry biomass (g/pot) | % DM | Leaf rel. water content (%) | Shoot count (no./pot) | Root dry wt (g/pot) | |
|---|---|---|---|---|---|---|---|
| | | | | | | Upper | Lower |
| Control | 257.6 | 61.7 | 23.9 | 90.9 | 14.4 | 41.9 | 58.8 |
| Waterlogged | 193.3 | 47.1 | 24.3 | 88.0 | 10.6 | 21.6 | 21.0 |
| Waterlogged + FB | 137.1 | 33.6 | 24.5 | 86.5 | 9.0 | 17.5 | 19.6 |
| LSD(0.05) | 29.2 | 7.2 | ns | ns | ns | 14.7 | 3.3 |

**Table 5**—Stalk height (mm) at 59, 70 and 76 days after planting for control, pots submersed in water and pots submersed in water with the addition of fibrated (FB) sugarcane stalk.

| Days after planting | Treatments | | | Mean |
|---|---|---|---|---|
| | Control | Waterlogged | Waterlogged + FB | |
| 59 | 220a | 216a | 210a | 215.3 |
| 70 | 308b | 312b | 238a | 286.0 |
| 76 | 356b | 375b | 273a | 334.7 |

Means followed by the same letter are not significantly different (P > 0.05)

A significant leaf number by leaf lamina length interaction was found. Leaf length was similar across all treatments for leaves 1–3. The waterlogged + FB treatment reduced leaf length in relation to the control for leaves 4–6, but not at leaf 7 (Figure 1).

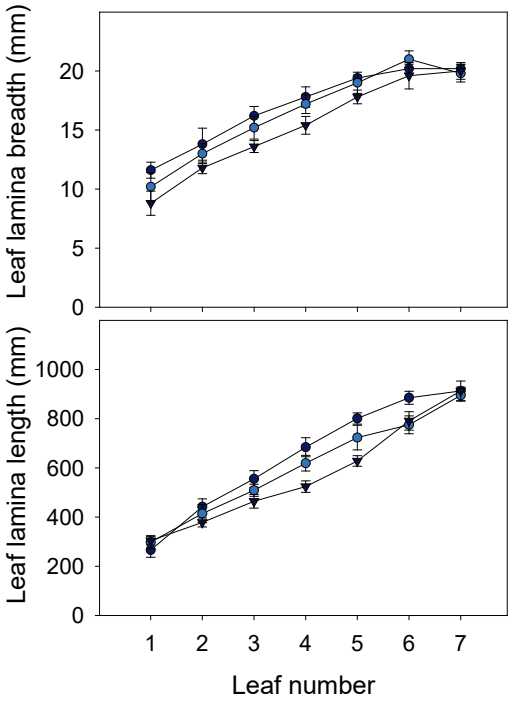


Fig. 1—Leaf lamina length and breadth for control (●), waterlogged (●) and waterlogged +fibrated sugarcane stalk (▼) treatments. Errors ± SEM.

While the initial lack of any difference was due to the treatments being implemented after establishment, the lack of any difference at the end of the experiment (leaf 7) cannot be explained. No statistically significant treatment effects were found for leaf lamina breadth.

Leaves were consistently narrower in the waterlogged + FB treatment in comparison to the control, however this may have been an inherent difference between plants used for each treatment as this difference was evident prior to treatments being imposed. Reduced shoot and leaf elongation is a typical waterlogging response (Gomathi *et al.*, 2015).

No difference in DO concentration between waterlogged and waterlogged + FB was found over the period of the experiment or at final harvest when water samples were collected from the root zone (Table 6). Dissolved oxygen concentrations were very low in both treatments, most likely due to the use of bore water and hot conditions during the experimental period.

Overall, there was a good indication that plant growth had been negatively affected by waterlogging treatments.

Stress was more severe where fibrated sugarcane stalk was added. Additional analyses of the water where fibrated stalk was added showed that pH and electrical conductivity were similar to water without fibrated material (data not shown) and suitable for plant growth.

Given that this approach had been used previously (Roach and Mullins, 1985), this treatment was pursued further.

**Table 6**—Dissolved oxygen concentration (mg/L) of water within buckets during experiment 2 and from the root zone at final harvest.

| Measurement location | DAP | Dissolved oxygen (mg/L) | | |
|---|---|---|---|---|
| | | Waterlogged | Waterlogged + FB | LSD(0.05) |
| Within bucket | 61 | 1.20 | 0.40 | ns |
| Within bucket | 70 | 0.25 | 0.28 | ns |
| Within bucket | 74 | 0.02 | 0.04 | ns |
| Within bucket | 75 | 0.26 | 0.38 | ns |
| Within bucket | 76 | 0.35 | 0.25 | ns |
| Root zone | 76 | 1.60 | 1.50 | ns |

## Experiment 3

Waterlogging treatments caused a reduction in fresh and dry biomass, and stalk length. Percent dry matter of leaf and cabbage increased in the waterlogged treatment, which is consistent with the inability of the root system to absorb water in anaerobic conditions. Stalk number and percent dry matter of millable stalk were not affected by waterlogging treatments (Table 7).

Q208$^{\Phi}$ had significantly higher fresh biomass than KQ228$^{\Phi}$, and greater stalk length. However, no statistically significant treatment by variety interactions were found. While the interaction term was not significant, Q208$^{\Phi}$ under waterlogged conditions showed a 25% reduction in fresh biomass relative to the control whereas, KQ228$^{\Phi}$ showed a 43% reduction.

This evidence supports current waterlogging ratings in QCANESelect$^{TM}$, where KQ228$^{\Phi}$'s performance is rated as poor. The use of a waterlogging tolerance coefficient, where performance is calculated relative to control plants was reported by Liu *et al.* (2010) in maize. This coefficient can be calculated for different plant traits (biomass, tillering, leaf length, etc.). The use of a waterlogging tolerance coefficient will be explored in future experiments to assess and rate sugarcane varieties.

Few statistically significant differences were found between waterlogged plants and those allowed to recover for 26 days prior to final sampling. However, plants that were allowed to recover

showed significantly lower percent dry matter of green leaf and cabbage compared to the waterlogged plants, and were similar to controls.

This is consistent with the recovery of the root system from waterlogging and the ability to supply water to the leaves.

No difference in DO concentration of water between waterlogging treatments or varieties was found (Figure 2). Dissolved oxygen concentrations were very low, possibly due to high temperatures. Values from 1.5–2.4 mg/L were recorded in waterlogged fields at a site near Ingham (Burry *et al.,* 2004).

**Table 7**—Crop traits of Q208$^{(\phi)}$ and KQ228$^{(\phi)}$ in control, waterlogged and waterlogged + recovery treatments from experiment 3.

| Trait | Treatment | Variety | | Mean (Treatment) |
|---|---|---|---|---|
| | | KQ228$^{(\phi)}$ | Q208$^{(\phi)}$ | |
| Fresh biomass per pot (kg) | Control | 1.06 | 1.16 | 1.11 |
| | Waterlogged + FB | 0.60 | 0.86 | 0.73 |
| | Waterlogged + FB + recov | 0.72 | 0.90 | 0.81 |
| | Mean (variety) | 0.79 | 0.97 | |
| | *LSD(0.05): Treat 0.13, Variety 0.11, Treat x Variety ns* | | | |
| Dry biomass per pot (kg) | Control | 0.28 | 0.30 | 0.29 |
| | Waterlogged + FB | 0.19 | 0.24 | 0.21 |
| | Waterlogged + FB + recov | 0.17 | 0.22 | 0.20 |
| | Mean (variety) | 0.21 | 0.25 | |
| | *LSD(0.05): Treat 0.05 , Variety ns , Treat x Variety ns* | | | |
| Stalks per pot | Control | 6.40 | 6.40 | 6.40 |
| | Waterlogged + FB | 6.60 | 6.80 | 6.70 |
| | Waterlogged + FB + recov | 7.20 | 6.20 | 6.70 |
| | Mean (variety) | 6.73 | 6.47 | |
| | *LSD(0.05): Treat ns, Variety ns, Treat x Variety ns* | | | |
| Stalk length (mm) | Control | 523.3 | 727.3 | 625.3 |
| | Waterlogged + FB | 429.1 | 592.8 | 510.9 |
| | Waterlogged + FB + recov | 395.4 | 583.7 | 489.5 |
| | Mean (variety) | 449.3 | 634.6 | |
| | *LSD(0.05): Treat 89.4, Variety 73.0, Treat x Variety ns* | | | |
| Millable stalk %DM | Control | 22.46 | 23.19 | 22.82 |
| | Waterlogged + FB | 23.52 | 23.30 | 23.41 |
| | Waterlogged + FB + recov | 21.36 | 20.50 | 20.93 |
| | Mean (variety) | 22.45 | 22.33 | |
| | *LSD(0.05): Treat ns , Variety ns , Treat x Variety ns* | | | |
| Leaf and cabbage %DM | Control | 35.83 | 33.83 | 34.83 |
| | Waterlogged + FB | 53.47 | 40.71 | 47.09 |
| | Waterlogged + FB + recov | 30.07 | 36.40 | 33.23 |
| | Mean (variety) | 39.79 | 36.98 | |
| | *LSD(0.05): Treat 11.1, Variety ns, Treat x Variety ns* | | | |

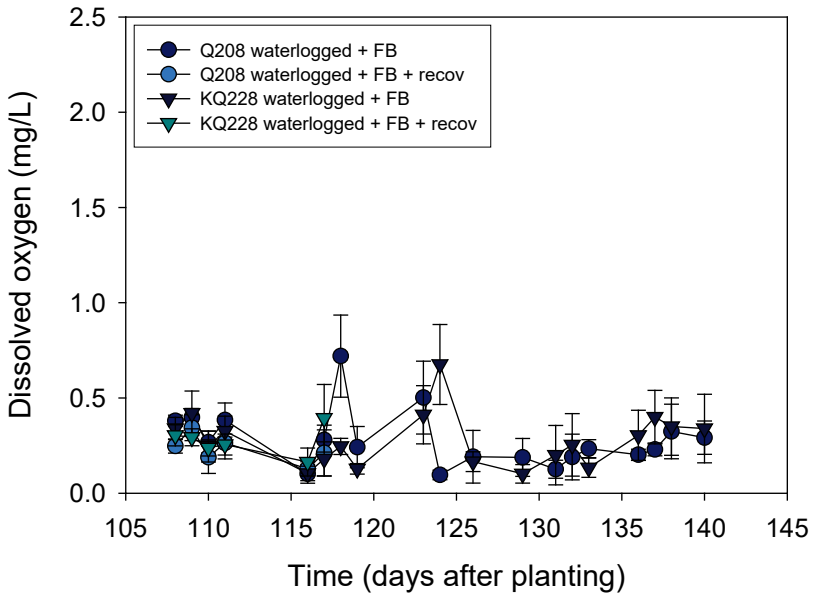


Fig. 2—Dissolved oxygen concentration of water in waterlogging treatments. Error bars ± SEM.

**Experiment 4**

As in earlier experiments, leaf expansion was affected by waterlogging treatments. Developing leaves had lower leaf area after the establishment of waterlogging treatments (Figure 3). Again, this result is a typical waterlogging response (Gomathi *et al.* 2015).

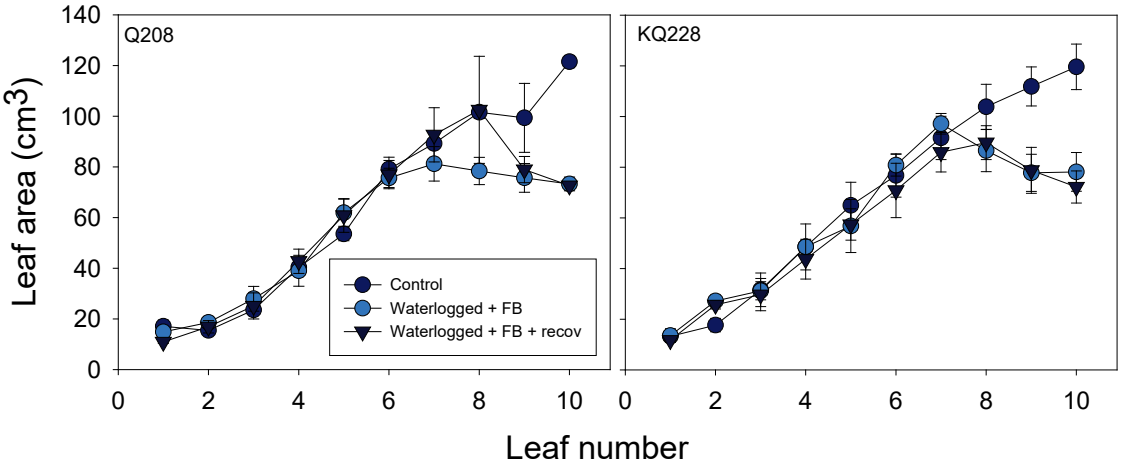


Fig. 3—Leaf area development for Q208$^{(\!)}$ and KQ228$^{(\!)}$ in control, waterlogged and waterlogged + recovery treatments. Error bars ± SEM.

At final harvest, both waterlogging treatments had a significant effect on plant growth. Fresh biomass, dry biomass and stalk number were all reduced due to waterlogging treatments (Table 8). There was a trend ($P < 0.10$) for a variety by treatment interaction for stalk number. This was associated with low stalk number in the waterlogged + FB + recov treatment for Q208$^{(\!)}$ but not KQ228$^{(\!)}$. The effect of waterlogging treatments on stalk number was also evident in experiment 2 but not experiment 3.

Treatments commenced 98 DAP in experiment 3, whereas plants were younger in other experiments. Potentially, the impact of waterlogging on tillering was reduced in experiment 3 due to a later stage of development when the treatments were applied, and tillering had already declined. Reduced tillering is a typical response of sugarcane to waterlogging (Gomathi *et al.,* 2015). Plants allowed to recover from waterlogging had significantly lower percent dry matter than controls, but

were similar to permanently waterlogged plants. The effect of waterlogging treatments on percent dry matter was not consistent across experiments.

The lack of any further significant interactions in these experiments may be associated with the use of only two varieties, and possibly only a small difference in response to waterlogging for Q208$^{\phi}$ and KQ228$^{\phi}$ (despite their ratings in QCANESelect$^{TM}$). Future work should try include varieties that are known to have either poor or good tolerance.

DO concentration within waterlogged pots (Figures 4 and 5) was similar to field observations in the Ingham region (Burry *et al*., 2004). The methodology was able to maintain low DO concentrations and simulate natural anaerobic conditions that occur during waterlogging events. This experiment demonstrated further that sugarcane growth was significantly reduced with the waterlogging treatments and the methodology could potentially be used to assess a wider range of varieties.

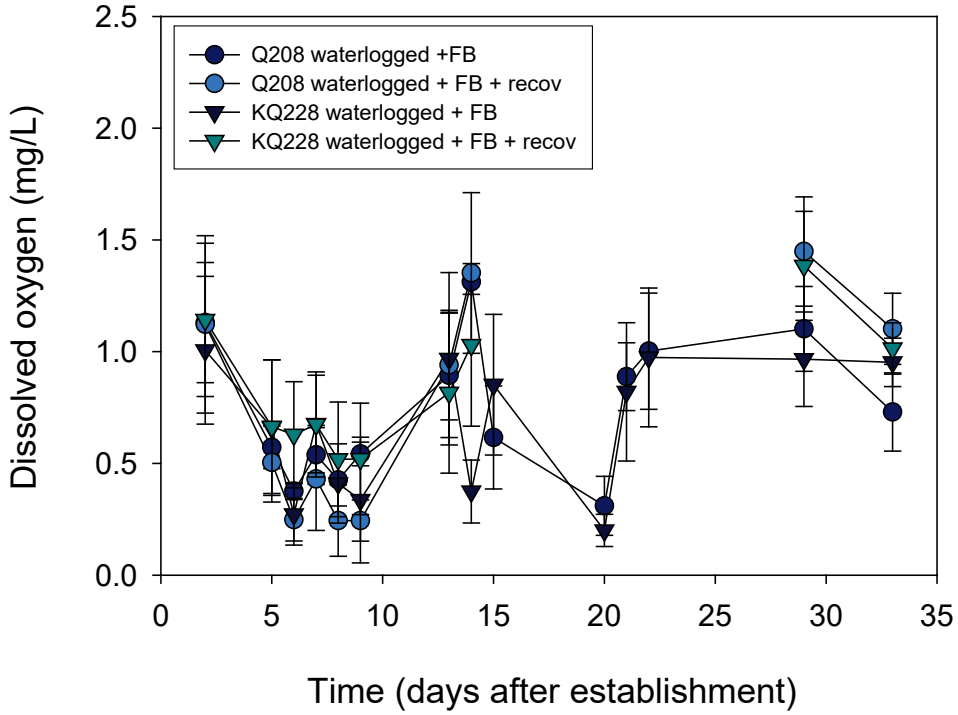


Fig. 4—Dissolved oxygen (mg/L) concentration of water collected from within the root zone of waterlogged pots. Error bars ± SEM.

Fig. 5—KQ228$^{\phi}$ in control (left) and waterlogged + FB (right) treatments.

**Table 8**—Plant traits following the waterlogging of two sugarcane varieties in pots in experiment 4.

| Trait | Treatment | Variety | | Mean (Treat) |
|---|---|---|---|---|
| | | KQ228(l) | Q208(l) | |
| Fresh wt (g/pot) | Control | 674.4 | 668.6 | 671.5 |
| | Waterlogged + FB | 474.0 | 582.4 | 528.2 |
| | Waterlogged + FB + recov | 395.6 | 483.8 | 439.7 |
| | *LSD(0.05): Treatment 90.2; Variety x Treat. ns* | | | |
| Stalks per pot | Control | 22.6 | 17.8 | 20.2 |
| | Waterlogged + FB | 13.8 | 16.4 | 15.1 |
| | Waterlogged + FB + recov | 16.8 | 12.2 | 14.5 |
| | *LSD(0.05): Treatment 3.5; Variety x Treat 5.0** | | | |
| %DM | Control | 22.9 | 21.8 | 22.4 |
| | Waterlogged + FB | 22.2 | 19.8 | 21.0 |
| | Waterlogged + FB + recov | 19.9 | 19.0 | 19.5 |
| | *LSD(0.05): Treatment 1.9; Variety x Treat. ns* | | | |
| Dry biomass (g/pot) | Control | 154.0 | 144.9 | 149.4 |
| | Waterlogged + FB | 107.4 | 115.2 | 111.3 |
| | Waterlogged + FB + recov | 79.0 | 91.7 | 85.4 |
| | *LSD(0.05): Treatment 22.3; Variety x Treat. ns* | | | |

*P = 0.066

## Conclusions

The four experiments outlined in this paper show the development of a method to impose waterlogging on sugarcane growing in pots. The method is likely to be used in future work to assess differences among varieties and provide growers with more robust and accurate information on waterlogging tolerance through QCANESelect$^{TM}$.

Waterlogging was established by immersing pots in water with low DO concentration. A low DO concentration was maintained by the addition of fibrated sugarcane stalk, which would have increased biological oxygen demand. It was possible to maintain the DO concentration at similar levels to those observed in waterlogged fields. The use of a more uniform substrate, such as sugar, should be investigated further. During the development of the methodology, tubes were designed that allowed the DO concentration of water within the root zone to be analysed. A system was also developed to maintain the water level at the soil surface automatically, reducing the need to replace evaporation manually each day.

The waterlogging treatments significantly reduced sugarcane shoot growth and leaf development. Stalk number was reduced in some experiments which may have been related to the age at which treatments commenced. Given this, assessing varieties prior to the commencement of tillering may be advantageous. Plant responses to treatments were consistent with those observed in other waterlogging studies, indicating the potential for pot experiments to be used to assess waterlogging tolerance.

## Acknowledgements

The authors wish to thank Bernard Schroeder (University of Southern Queensland), Glen Park (SRA), Brad Hussey (SRA) and Lawrence DiBella (Herbert Cane and Productivity Services Limited) for advice on setting up the pot experiments. Farm staff at SRA Mackay are thanked for assistance with experimental work. The work reported in this paper was funded by Sugar Research Australia project 2014046 ‘Too wet to forget: Reducing the impact of excessive rainfall on productivity’.

## REFERENCES

Burry RK, Bonnett GD, Holtum JAM (2004) Reassessing waterlogging: Novel method to compare the germination and early growth responses of sugarcane genotypes. *Proceedings of the Australian Society of Sugar Cane Technologists* **26**, (CD ROM) 11 pp.

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**, (electronic format) 11 pp.

Gilbert RA, Curtis RR, Dolen RM, Bennett AC (2007) Morphological responses of sugarcane to long-term flooding. *Agronomy Journal* **99**, 1622–1628.

Gomathi R, Gururaja Rao PN, Chandran K, Selvi A (2015) Adaptive responses of sugarcane to waterlogging stress: An over view. *Sugar Tech* **17**, 325–338.

Liu Y, Tang B, Zheng Y, Ma K, Xu S, Qiu F (2010) Screening methods for waterlogging tolerance in maize (*Zea mays* L.) seedling stage. *Agricultural Sciences in China* **9**, 362–369.

Reghenzani JR, Roth CH (2006) Best-practice surface drainage for low-lying sugarcane lands, Herbert district. BSES Technical publication TE06004.

Roach BT, Mullins RT (1985) Testing sugarcane for waterlogging tolerance. *Proceedings of the Australian Society of Sugar Cane Technologists* **7**, 95–102.

Rudd AV, Chardon CW (1977) The effect of drainage on cane yields as measured by watertable heights in the Macknade mill area. *Proceedings of the Queensland Society of Sugar Cane Technologists* **44**, 111–117.

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