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Too wet to forget – reducing the impact of excessive rainfall on productivity

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ABSTRACT

Too wet to forget – reducing the impact of excessive rainfall on productivity, was established due to the large productivity losses associated with La-Nina events in the sugarcane industry. The effect of waterlogging on the crop has also been largely ignored for decades. The project had four main activities:

1. A field trial in Tully to investigate whether speed of establishment of varieties was an important trait in excessively wet environments;
2. A field trial in Ingham to investigate waterlogging tolerance of current varieties;
3. Development of a method to impose waterlogging on sugarcane grown in pots;
4. Screening of sugarcane varieties for waterlogging tolerance in pots.

Below average rainfall limited the field experiment in Tully, but varieties with differing growth traits performed in a similar manner irrespective of harvest time in the first ratoon crop. This suggested there is a relatively wide range of phenotypes associated with optimum crop performance in these environments. Differences in waterlogging tolerance of current varieties were found in the field experiment. Knowing which varieties have better waterlogging tolerance allows growers to select the best variety for blocks prone to waterlogging. It highlights the importance of having accurate information on waterlogging tolerance in QCANESelect^{TM}. The project developed a method to impose waterlogging on sugarcane growing in pots. The method was able to maintain anaerobic conditions within the root zone and resulted in typical waterlogging responses such as the development of adventitious roots at the soil surface. Pot experiments were then conducted to test current varieties for waterlogging tolerance. While differences were found between varieties, the reliability of this information is unclear and needs further development. It is suggested that future work include metabolomics approaches to determine differences among varieties.

EXECUTIVE SUMMARY

Poor crop yields over the past decade are a major concern to the Australian sugar industry. Recent productivity reviews have highlighted strong negative correlations between excessive rainfall and productivity. Cane yield in the wet tropics regions declines significantly in wet years. In Tully there was approximately a 50 % decline in production due to the 2011 La-Nina event. Similarly, waterlogging has been shown to reduce productivity by 0.5 t/ha for every day the watertable was within 50 cm of the soil surface (Rudd and Chardon 1977). This clearly shows the need to reduce the impact of this major productivity constraint.

The main objectives of the work were to commence research with longer term goals of: Improved establishment and proportion of the crop planted earlier in the season leading to an increase in cane yields in wet environments; Waterlogging tolerant varieties grown in wet blocks, leading to increased productivity and profitability; Identification of traits associated with waterlogging tolerance and potential incorporation of these into the plant breeding selection system; Increased mill supply security due to better crop performance in wet years; Better use of fertiliser inputs in wet years due to improved crop growth and nutrient uptake, reducing environmental impact

The project had four main activities

1. *A field trial in Tully to investigate whether speed of establishment of varieties was an important trait in excessively wet environments.*

The trial consisted of eight varieties with differing traits in terms of speed of establishment, reliability and waterlogging tolerance. Varieties were planted at two times, early and late, and ratooned at two times, early and late. The planting and ratooning time treatments were designed in order to establish two climatic scenarios. Sugarcane in the early planting/ratooning treatment would experience a relatively long period of time prior to the onset of the wet season, and would generally establish in optimum conditions. Under this scenario it was envisaged that early growth characteristics of each variety would have a low influence on overall performance. The late planting/ratooning treatment would experience a short period of time prior to the onset of the wet season, with crop establishment generally occurring in a period characterised by high rainfall and low solar radiation. This late treatment was designed in order to mimic conditions that generally occur during a season with very high rainfall. It was hypothesised that varieties with fast establishment and development would perform better in this climatic scenario. The results from this experiment were largely inconclusive. In the plant crop, it was likely that the difference between treatments in terms of establishing two climatic scenarios, was unsuccessful. Crop yields were very poor and no difference was found between planting times. This meant that it was not possible to assess whether any varieties, or particular growth patterns like fast establishment, were of any benefit in an excessively wet environment. The first ratoon crop showed a significant difference in crop yields due to ratooning time. This was consistent with previous research and indicated that the two climatic scenarios were likely to have been established, even in a below average rainfall season. However, a lack of any significant ratooning time.variety interactions for cane or sugar yield suggest that all varieties performed in a similar manner. This occurred despite some differences in the varieties phenotypic traits. The better performing varieties at the site (Q208$^{\Phi}$, Q232$^{\Phi}$ and Q200$^{\Phi}$) had variable combinations of stalk population, stalk weight, percent millable stalk and CCS.
This suggests that there is a relatively wide range of phenotypes associated with optimum crop performance, even when excessive rainfall is experienced relatively early in development. Given these results, there does not appear to be a link between fast crop establishment and crop performance in excessively wet environments.

Some factors that may have contributed to this outcome were: the trial was conducted during a period of below average rainfall; significant differences among variety in terms of establishment may not have been large enough or do not exist within commercial varieties.

2. Field trial in Ingham to investigate waterlogging tolerance of current varieties

The experiment consisted of three treatments (control, waterlogging early in development and waterlogging late in development). The waterlogging treatments were established in the field by bunding sections of the block and maintaining water level above the soil surface with irrigation. Eight sugarcane varieties with variable waterlogging tolerance ratings were tested and the trial was conducted over the plant and first ratoon crops. Significant treatment.variety interactions were found in both the plant and first ratoon crops and when cumulative yield over the two crops was analysed. All varieties showed a significant decline in cumulative cane and sugar yield in the early treatment, but this decline was more severe for Q208$^{\phi}$ and Q200$^{\phi}$, and to a lesser extent Q247$^{\phi}$. For the late treatment, MQ239$^{\phi}$, Q219$^{\phi}$ and Q247$^{\phi}$, showed no loss of cumulative cane or sugar yield whereas all other varieties showed a significant decline. While Q232$^{\phi}$'s cumulative cane and sugar yield declined significantly in both waterlogging treatments, it was still one of the top performers across all treatments. This highlighted an important issue, in some cases varieties that are tolerant to stress are not the best producers. Q219$^{\phi}$ in this experiment was a good example, as it appeared to have better waterlogging tolerance than other varieties, but performed poorly under control conditions. In terms of overall variety performance across all treatments, which could be looked at as performance across different seasons with varying climatic conditions, Q232$^{\phi}$ and MQ239$^{\phi}$ produced significantly more cane than other varieties. For cumulative sugar yield, the top varieties were Q232$^{\phi}$, KQ228$^{\phi}$ and MQ239$^{\phi}$. Given that the site was a heavy clay soil in a wet environment, soil moisture content in control plots was likely to have been saturated for some period in both seasons. With this in mind, Q232$^{\phi}$ appeared to withstand these conditions better than other varieties, indicating it does have some tolerance. Results from the experiment were not always consistent with tolerance ratings in QCANESelect$^{\text{TM}}$, although these ratings are often variable across regions. In particular, Q208$^{\phi}$ did not perform well in waterlogging treatments but is rated as having good tolerance in a number of regions. More generally, cumulative cane and sugar yield was significantly reduced by the early (36 % loss over the two crops) and late (12 % loss over the two crops) waterlogging treatments. As waterlogging had a larger effect on productivity when it was experienced early in development, management practices that allow crops to be planted and ratooned earlier in the season, particularly on soils susceptible to waterlogging, should be promoted. These include minimum tillage planting systems, and prioritising harvest times so that wet blocks are harvested earlier. If irrigation is available, its use early in development to promote the establishment and growth of the crop should be encouraged. This should result in crops being more advanced prior to the onset of the wet-season and the likelihood of waterlogging events.

3. Development of a method to impose waterlogging on sugarcane grown in pots

Four pot experiments were conducted in order to develop a method to impose waterlogging on sugarcane growing in pots. This work was published in the Proceedings of the Australian Society of Sugar Cane Technologists conference (Salter and Kok, 2016). Waterlogging was established by immersing pots in water with low dissolved oxygen (DO) concentration. A low DO concentration of the water used in the experiments 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. 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, leaf development and stalk numbers. 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.

4. Screening of sugarcane varieties for waterlogging tolerance in pots.

Four pot experiment were conducted where the tolerance of nine sugarcane varieties was assessed in waterlogging treatments and a control. The trials were established using the methodology developed earlier in the project. Two of the experiments included all varieties that were also tested in the field experiment in Ingham. This was done in order to test whether the pot and field experiments produced similar outcomes. The relative performance (to controls) of varieties in waterlogged treatments was compared, and a pooled analysis across experiments showed significant differences among varieties. In particular, the relative performance of Q208$^{\phi}$ in waterlogging treatments was poor. A comparison of the mean relative performance of varieties in the four pot experiments to waterlogging tolerance ratings in QCANESelect$^{\text{TM}}$ did not provide any validation of the pot experiment method. This is due to the variability of tolerance ratings in QCANESelect$^{\text{TM}}$. Where, a varieties rating isn’t variable in QCANESelect$^{\text{TM}}$, the pot experiments would generally support Q219$^{\phi}$’s “good” rating, but not the “good” rating of MQ239$^{\phi}$ or the “poor” rating of Q135. It is not clear which rating is more reliable, the pot experiments have been conducted using a rigorous experimental approach, but are also an artificial environment in comparison to field conditions. When comparing pot experiments to the field trial, MQ239$^{\phi}$ performed poorly in pot experiments but showed very high relative performance in the field. MQ239$^{\phi}$’s performance in the field was more consistent with its rating in QCANESelect$^{\text{TM}}$. Q200$^{\phi}$ performed well in pot experiments but poorly in the field, its rating in QCANESelect$^{\text{TM}}$ is variable depending on region. Q219$^{\phi}$, Q232$^{\phi}$ and Q247$^{\phi}$ performed well in both pot and field experiments. Q208$^{\phi}$ performed poorly in both pot and field experiments. Given that there are both consistent and inconsistent results between the two experiment types, the reliability of the pot method is unclear. It is therefore unlikely that this method could be used solely to rate varieties for waterlogging tolerance at this stage.

Communication with industry to date has included a CaneConnection article, an ASSCT paper, an ASSCT poster, project updates each year at the Mackay trial information day and a further ASSCT paper is currently being developed. The HCPSL board also visited the Ingham field site during the project.

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1 BACKGROUND

Poor crop yields over the past decade are a major concern to the Australian sugar industry. Recent productivity reviews in the Herbert and Central regions identified strong negative correlations between excessive rainfall and productivity (Garside *et al.*, 2014; Salter and Schroeder, 2012). Similar relationships exist in other mill areas, particularly the wet tropics. Cane yield in Tully declines significantly in wet years. Yield was reduced by 50% in 2011 due to a La-Nina event. This clearly shows the need for research to alleviate this major productivity constraint.

Rudd and Chardon (1977) showed that sugarcane lost 0.5 t/ha for every day the watertable was within 50 cm of the soil surface. Despite this work being conducted four decades ago recent work by Skocaj et al., (2013) highlighted difficulties in modelling sugarcane production in wet environments due to a limited physiological understanding of waterlogging. Traits such as the formation of aerenchyma in the stalk may be associated with waterlogging tolerance (Gilbert et al., 2007) but are not used in variety selection. *Saccharum spontaneum* has greater tolerance of waterlogging than *Saccharum officinarum* (Roach and Mullins, 1985; Burry et al., 2004). Similarly, high fibre/ low sucrose genotypes have greater waterlogging tolerance than commercial sugarcane clones (Viator et al., 2012). This suggests that further introgression between *S. officinarum* and *S. spontaneum* could improve waterlogging tolerance. However, addressing this issue through introgression is a longer term approach.

In the interim, a program to reduce the impact of excessive rainfall on productivity is required in order for the industry to remain profitable. There are known management practices that reduce the effect of waterlogging on sugarcane production. In particular, extension of laser levelling, improved drainage and planting into beds should reduce productivity losses in wet years (Reghenzani and Roth, 2006). However, other approaches to reduce the impact of excessive rainfall need to be explored. Varieties that germinate and form a canopy quickly may be able to tolerate excessive rainfall events better than those that emerge more slowly. An assessment of this trait and others could identify ideotypes that perform better in wet environments. Currently information on the waterlogging tolerance of varieties is gained from anecdotal evidence on farm after a variety is released. The development of a simple method to impose waterlogging on sugarcane in pots could allow for accurate information to be provided to growers at or soon after release. This information would allow growers to select the most appropriate variety for wet blocks, potentially reducing the impact of excessively wet conditions.

2 PROJECT OBJECTIVES

The main research objectives, as outlined in the project proposal, were to address the following questions:

1. Do varieties that emerge and develop quickly perform better in wet environments?
2. Can a simple method be developed to impose waterlogging in pots?
3. Can this method be used to screen varieties and provide accurate information on the waterlogging tolerance of varieties to growers?
4. Which crop traits are associated with waterlogging tolerance?

In order to address these issues, there was also a requirement to tests varieties waterlogging tolerance in the field, and compare this to outputs from pot experiments. This would allow an assessment of the pot methodology.

3 OUTPUTS, OUTCOMES AND IMPLICATIONS

3.1 Outputs

Project outputs as outlined in the research agreement were:

1. Understanding the role fast crop establishment has in reducing the impact of excessive rainfall in a wet environment

A field trial was established in order to assess this trait. The results from this experiment were largely inconclusive. In the plant crop, it was likely that the difference between treatments in terms of establishing two climatic scenarios, one of which experienced ideal growing conditions (early plant), and the other excessive rainfall early in development (late plant), was unsuccessful. Crop yields were very poor and no difference was found between planting times. This meant that it was not possible to assess whether any varieties, or particular growth patterns like fast establishment, were of any benefit in an excessively wet environment. The first ratoon crop showed a significant difference in crop yields due to ratooning time. This was consistent with previous research and indicated that the two climatic scenarios were likely to have been established, even in a below average rainfall season. However, a lack of any significant ratooning time.variety interactions for cane or sugar yield suggest that all varieties performed in a similar manner. This occurred despite some differences in the varieties phenotypic traits. The better performing varieties at the site (Q208$^{\phi}$, Q232$^{\phi}$ and Q200$^{\phi}$) had variable combinations of stalk population, stalk weight, percent millable stalk and CCS. This suggests that there is a relatively wide range of phenotypes associated with optimum crop performance, even when excessive rainfall is experienced relatively early in development. Given these results, there does not appear to be a link between fast crop establishment and crop performance in excessively wet environments.

Some factors that may have contributed to this outcome were: the trial was conducted during a period of below average rainfall; significant differences among variety in terms of establishment may not have been large enough or do not exist within commercial varieties.

2. Improved understanding of the crop response to waterlogging

The project has shown that waterlogging has a large detrimental effect on sugarcane production. While this was already known, previous data was dated. Waterlogging early in the development of a plant crop was shown to reduce yield by 1 tc/day while waterlogging was in place. In the first ratoon crop, 0.48 tc/day was lost while the waterlogging treatment was in place. Waterlogging early in development caused a 36% loss of cumulative yield over the plant and first ratoon crops. The magnitude of these losses highlights the need for further work to alleviate this stress.

Waterlogging had a larger effect on productivity when it was experienced early in development. Management practices that allow crops to be planted and ratooned earlier in the season, particularly on soils susceptible to waterlogging, should be promoted. These include minimum tillage planting systems, and prioritising harvest times so that wet blocks are harvested earlier. If irrigation is available, its use early in development to promote the establishment and growth of the crop should be encouraged. This should result in crops being more advanced prior to the onset of the wet-season and the likelihood of waterlogging events.

The field experiment showed a significant variety.waterlogging interaction, suggesting that variation in tolerance exists among current commercial varieties, and could be exploited. All varieties showed a significant decline in cumulative cane and sugar yield in an early waterlogging treatment, but this decline was more severe for Q208$^{\Phi}$ and Q200$^{\Phi}$, and to a lesser extent Q247$^{\Phi}$. For a late waterlogging treatment, MQ239$^{\Phi}$, Q219$^{\Phi}$ and Q247$^{\Phi}$, showed no loss of cumulative cane or sugar yield whereas all other varieties showed a significant decline. Q232$^{\Phi}$'s cumulative cane and sugar yield declined significantly in both waterlogging treatments, but it was still one of the top performers across all treatments. This highlighted an important issue, in some cases varieties that are tolerant to stress are not the best producers.

3. Information on waterlogging tolerance of current and soon to be realised varieties and delivery of this information to growers

During the project a method to impose waterlogging on sugarcane growing in pots was developed. This method allowed water height to be adjusted automatically. Water within the root zone of the pot was shown to contain less than 2 mg/L dissolved oxygen. This meant that anaerobic conditions were able to be maintained using this method. Sugarcane growing in pots that were waterlogged showed signs of stress consistent with waterlogging, including the development of adventitious roots at the soil surface.

Both field and pot experiments explored the waterlogging tolerance of current commercial varieties. Differences in waterlogging tolerance among varieties were found in pot experiments. For example, a pooled analysis of four pot experiments showed that Q232$^{\Phi}$ produced significantly higher relative fresh biomass than Q208$^{\Phi}$ in waterlogging treatments. However, the reliability of the pot experiments for rating varieties tolerance is unclear. In some cases, results from the pot experiments differed substantially from the field. Therefore, delivery and promotion of this information to growers would be unwise. Data from the field experiment in Ingham should be highlighted to the Herbert regional variety committee, as it may inform decisions regarding waterlogging tolerance ratings in that region as well as recommendations for poorly drained soils.

4. Better understanding of crop traits associated with waterlogging tolerance.

Waterlogging consistently reduced leaf length and tiller numbers. It was also noted in pot and field experiments that it resulted in prolific adventitious root formation on the soil surface. Given that individual pot experiments often showed no clear difference in tolerance among varieties, little exploration of traits associated with differing tolerance was undertaken.

3.2 Outcomes and Implications

Waterlogging was shown to have a major effect on productivity and highlights the need for continued research and extension to alleviate the effect of this stress on productivity. If not, the industry will continue to suffer substantial productivity declines during periods of excessive rainfall.

Differences in tolerance among commercial varieties exist, but further development of a method to screen varieties in pot experiments will be required before this method can be used reliably. Without this, advice in QCANESelect^{TM} will continue to be based on anecdotal evidence, which has resulted in variable ratings for the same variety across regions. The value of these ratings, currently, should be reviewed. The alternative to pot experiments, is the establishment of periodic field trials to assess recently released varieties for waterlogging tolerance. While this is a difficult task, if conducted, would most likely require a dedicated site on a research farm and a funding source.

Given the longer term nature of this research area, no immediate outcomes are likely at this stage. The outputs from the project should be used more to set future direction.

Differences in tolerance may reside more in metabolic and biochemical responses to anaerobic conditions within the soil profile. If these can be identified, screening of varieties could potentially be done using these metabolic traits. Future work on waterlogging tolerance should incorporate a metabolomics approach as a way of identifying differences among varieties.

4 INDUSTRY COMMUNICATION AND ENGAGEMENT

4.1 Industry engagement during course of project

Industry engagement activities included:

CaneConnection article

> Putting varieties to the test with waterlogging – CaneConnection Autumn 2017

Mackay Trial Information day

> Project trial activities and data was presented and discussed at this local meeting of industry advisors and productivity board staff, in 2015, 2016 and 2017.

HCPSL board members visited the Ingham field site (HCPSL activity)

ASSCT paper

> Salter B, Kok E (2016), *Development of a method to impose waterlogging on sugarcane grown in pots*. Proceedings of the Australian Society of Sugarcane Technologists (electronic format) 38, 200-211.

ASSCT poster

> Park G, Salter B (2017), *The effect of waterlogging on eight sugarcane varieties grown on a heavy clay soil in the Herbert River*. Proceedings of the Australian Society of Sugarcane Technologists (electronic format) 39, 229.

Likely future communication activities:

- Further CaneConnection article including Ingham field trial data
- ASSCT paper presenting data from the Ingham field experiment – prepared for 2018 conference.

4.2 Industry communication messages

The following key communication points have arisen from the project:

- A field trial was conducted to see whether varieties with fast establishment and development performed better in environments where excessive rainfall is experienced early in development. This was explored by testing eight varieties with an early and late planting or ratooning time in Tully. Unfortunately rainfall during the period the trial was conducted was below average, limiting the ability to draw conclusions from the results. However, in the first ratoon crop, late harvesting significantly reduce sugarcane production, but performance of varieties, with differing growth patterns (phenotypes), was similar for both harvest times. This suggests there is a relatively wide range of phenotypes associated with optimum crop performance in these environments.
- A field trial was established in Ingham to test the waterlogging tolerance of eight varieties. Waterlogging was imposed at two stages of development, early (Dec) and late (Feb). Yields were reduced substantially by waterlogging, particularly when the crop was very young. The trial also showed that tolerance among varieties differed. Q219$^{\phi}$, MQ239$^{\phi}$ and Q247$^{\phi}$ (particularly when waterlogged late) showed better tolerance. Q232$^{\phi}$ performed particularly well at the site across all treatments. Q208$^{\phi}$ performed poorly in waterlogging treatments. Knowing which varieties are waterlogging tolerant assist growers to select the best varieties for each block.
- A method to impose waterlogging on sugarcane growing in pots was developed. This was done as testing varieties for waterlogging tolerance in the field is difficult. Artificial waterlogging zones need to be established and maintained on a large scale.
- Pot experiments were conducted to test current varieties for waterlogging tolerance. While differences were found between varieties, the reliability of this information is unclear and needs further development

5 METHODOLOGY

The project consisted of four main activities. These included a speed of establishment trial in Tully, a field waterlogging experiment in Ingham, the development of a method to impose waterlogging on sugarcane grown in pots, and the screening of sugarcane varieties for waterlogging tolerance in pots.

5.1 Speed of establishment field experiment

Sugarcane is known to be more susceptible to waterlogging damage early in development. Furthermore, development of the crop canopy and stalk population prior to excessive rainfall events and associated low radiation periods of the wet season may be critical agronomic traits that are associated with productivity in excessively wet environments. The aim of this trial was to assess the link between the speed of crop establishment and final productivity in wet environments.

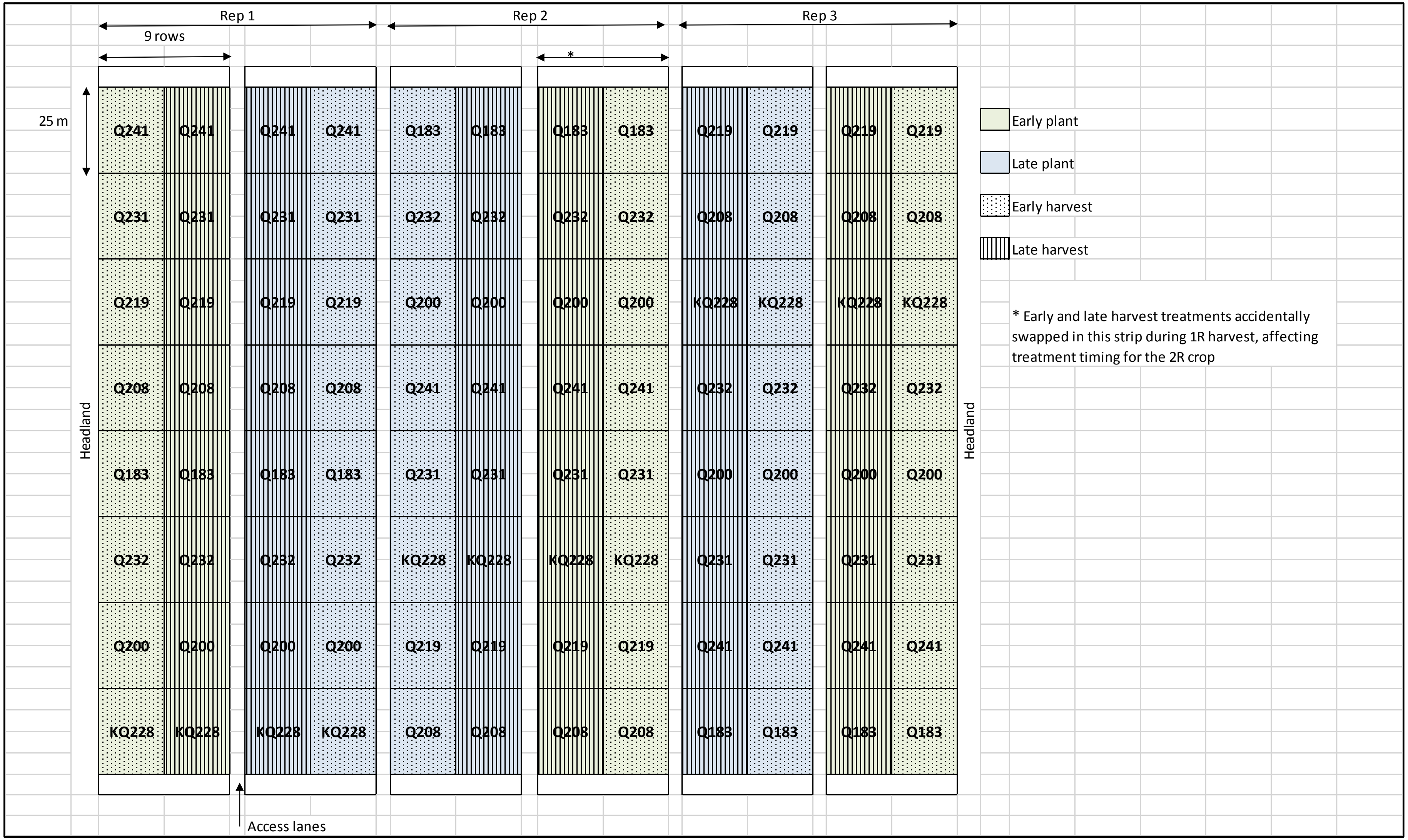
Varieties that germinate and form a canopy quickly may be able to tolerate excessive rainfall events better than those that emerge more slowly. An assessment of this trait and others could identify ideotypes that perform better in wet environments.

5.1.1 Trial design

An experiment was established at the SRA Tully experimental station (17° 58' 45.10" S; 145° 55' 22.95" E) to investigate the role crop establishment has in determining performance in a wet environment. The site was on a Bulgun series soil (poorly drained soil formed on alluvium). Permanent beds were previously established at the site on 1.85 m row spacing. These were maintained as a bare fallow prior to planting sugarcane in the trial.

The experiment included planting eight varieties with differing growth traits at two times in the season (early/ late). During the plant crop this was arranged as a split block design with planting time as the vertical factor and variety as the horizontal factor in each replicate. Each plot consisted of either eight or nine rows. Plots were split (four or five rows) at harvesting to include two harvest times, and the harvest time treatments were continued for the ratoon crops (Figure 5.1).
The experiment included three replicates.

The planting and ratooning time treatments were designed in order to establish two climatic scenarios. Sugarcane in the early planting/ ratooning treatment would experience a relatively long period of time prior to the onset of the wet season, and would generally establish in optimum conditions. Under this scenario it was envisaged that early growth characteristics of each variety would have a low influence on overall performance. The late planting/ ratooning treatment would experience a short period of time prior the onset of the wet season, with crop establishment generally occurring in a period characterised by high rainfall and low solar radiation. This late treatment was designed in order to mimic conditions that generally occur during a season with very high rainfall. It was hypothesised that varieties with fast establishment and development would perform better in this climatic scenario.



* Early and late harvest treatments accidentally swapped in this strip during 1R harvest, affecting treatment timing for the 2R crop

Figure 5.1 Experimental design to determine whether differences among varieties for early crop growth traits affected performance in wet environments.

The eight varieties included in the experiment were: Q241$^{\phi}$, Q232$^{\phi}$, Q231$^{\phi}$, KQ228$^{\phi}$, Q219$^{\phi}$, Q208$^{\phi}$, Q200$^{\phi}$, and Q183$^{\phi}$. This group of varieties has variability in waterlogging tolerance, speed of establishment and establishment reliability ratings (QCANESelect$^{\text{TM}}$ – Table 5.1). Q183$^{\phi}$, Q200$^{\phi}$, Q208$^{\phi}$ and KQ228$^{\phi}$ are also popular varieties across Queensland and are grown on a substantial proportion of the total land area. It should be noted that ratings for these traits in QCANESelect™ are based on anecdotal evidence.

Figure 5.2 Aerial image of the trial site on 1 May 2016. Dark green strips indicate location of early harvest.

5.1.2 Planting and harvesting dates

Planting treatments were established at the site on 6 August 2014 (early) and 6 November 2014 (late). The plant crop was harvested on 10 August 2015 (early) and 2 December 2015 (late). The 1st ratoon crop was harvested at the site on 11 September 2016 (early) and 9 November 2016 (late). All plots in the 2nd ratoon crop were sampled on 31 July 2017. Sugarcane was planted into beds with a single row double-disc opener planter. Planting material was obtained from a seed-plot managed by the Tully Productivity Services. The tops of the beds were tilled with a wavy disc renovator prior to planting.

Table 5.1 Reliability of germination, waterlogging tolerance and speed of germination ratings for eight varieties selected for the trial at Tully (information obtained from QCANESelect – Northern coastal variety information August 2014)

Reliability		Waterlogging tolerance			Speed of germination		
Good	Poor	Good	Average	Poor	Good	Average	Slow
Q241	Q232	Q231	Q232	Q241	KQ228	Q241	Q208
KQ228	Q231	Q219	KQ228	Q200	Q200	Q232	
Q208	Q219		Q208	Q183	Q183	Q231	
Q200						Q219	
Q183							

5.1.3 Crop management

The plant crop was fertilised immediately prior to planting with 200 kg/ha DAP. This was followed with 200 kg/ha muriate of potash and 186 kg/ha urea approximately two months after planting for both the early and late treatments. Overall the plant crop received 122 N, 40 P, 100 K, 3 S (kg/ha). The first ratoon crop received 121 N, 30 P, 112 K, 37 S (kg/ha) as urea, muriate of potash and super phosphate and 2 t/ha of Blend 3 (32 % Ca, 3 % Mg). The second ratoon crop received 118 N, 30 P, 100 K, 37 S (kg/ha) as urea, muriate of potash and super phosphate. The trial also received herbicide applications as required.

5.1.4 Biomass and yield

In the plant crop, sugarcane biomass was assessed 120, 245, 362 and 474 days after planting (DAP) the early planting treatment and 153, 270 and 382 DAP the late treatment. In the first ratoon crop, biomass was assessed 245 and 352 days after harvesting (DAH) the early treatment and 131, 238 and 331 DAH the late treatment. In the second ratoon crop, biomass was assessed 323 and 264 DAH the early and late treatments, respectively.

At each biomass sampling event stalks in a 15 m^2 sub-plot were counted, cut at the base, and weighed to ascertain total fresh biomass. A sub-sample of 15 stalks was taken from each plot and partitioned into two components: millable stalk, and green leaf and cabbage. This was done by removing the top of the stalk between the fifth and sixth dewlap or eighth and ninth dewlap of the stalk had flowered (counting flag leaves). Dead leaves were stripped from the millable stalk and discarded, green leaves were included with the green leaf and cabbage component.

Each component was weighed separately and used to calculate percent millable stalk. This percent was then applied to the total plot biomass to calculate sugarcane yield. A sub-sample of each of these components was mulched, weighed and placed in an oven set at 70°C until a constant dry weight was attained. This data was used to determine moisture content, and allowed the expression of biomass on a dry weight basis. A six-stalk sample was also collected for quality component analysis during the 12-month biomass sampling. Quality components were determined using the SpectraCane system at BSES Meringa (Berding et al., 2003) and a small mill at Ingham and Mackay.

5.1.5 Stalk population development

Stalks counts were conducted in 15 m^2 sub-plots during the development of the plant crop (2014-2015), between 111 and 233 days after planting the early treatment.

5.1.6 Canopy development

Canopy development was monitored using a SunScan canopy analysis system with an external BF5 sunshine sensor (Delta-T Devices). Measurements were taken on 3 December 2014,
23 December 2014, 3 February2015 and 23 April 2015.

Within each plot, the probe was placed perpendicular to the crop row and positioned from the middle of the interrow to the middle of the crop row. Four readings were taken per plot (two on each side of the crop row). The instrument estimates leaf area index, and an average for the plot was calculated.

5.1.7 Statistical analysis

Crop data were analysed using GenStat 16.2. During the plant crop, ANOVA was performed using a split-block model with planting time as the vertical factor and variety as the horizontal factor.
In ratoon crops, ANOVA was performed using a split-split-block model with ratooning time included in the model, or a split-block model with ratooning time as the vertical factor and variety as the horizontal factor if planting time was excluded from the analysis. For significant effects ($P<0.05$), means were compared using Fishers' least significant difference (LSD).

5.2 Field waterlogging experiment

5.2.1 Trial design

A field trial was established at a site near Ingham (18° 19' 19.35" S; 146° 09' 38.99" E) on a poorly drained clay soil (Hydrosol). The last ratoon of the previous crop cycle was disced out in 2014 and the block left as a bare fallow, which included two applications of Roundup. In order to prepare the block for planting, land was ripped, disced and rotary hoed after the application of 2.5 t/ha Ag lime. Sugarcane was planted with a single row double-disc opener planter on 18 August 2015. Beds were not formed in order to ensure waterlogging treatments were effective. Sugarcane was irrigated immediately after planting (19 August 2015) and again on 7 October 2015 due to dry conditions during the crop establishment period. Water was applied with a water truck directly to the planting furrow. The trial was conducted over two crops (plant and 1st ratoon), with the plant crop harvested on 8 September 2016 and the first ratoon crop on 5 August 2017. The crop (both plant and first ratoon crops) was fertilised with 120 kg N/ha using a 50:50 mixture of Urea and Agromaster Tropical (polymer coated urea). Both the plant and first ratoon crops also received 20 kg P/ha and 7 kg S/ha. The plant crop did not require potassium and the first ratoon crop received 50 kg K/ha. This was due to high exchangeable K (me%).

The trial included eight varieties and three waterlogging treatments, and was arranged as a split plot design with three replicates (Figure 5.3). Waterlogging treatments were main plots with varieties as sub-plots. Sub-plot size was 4 rows by 10 m.

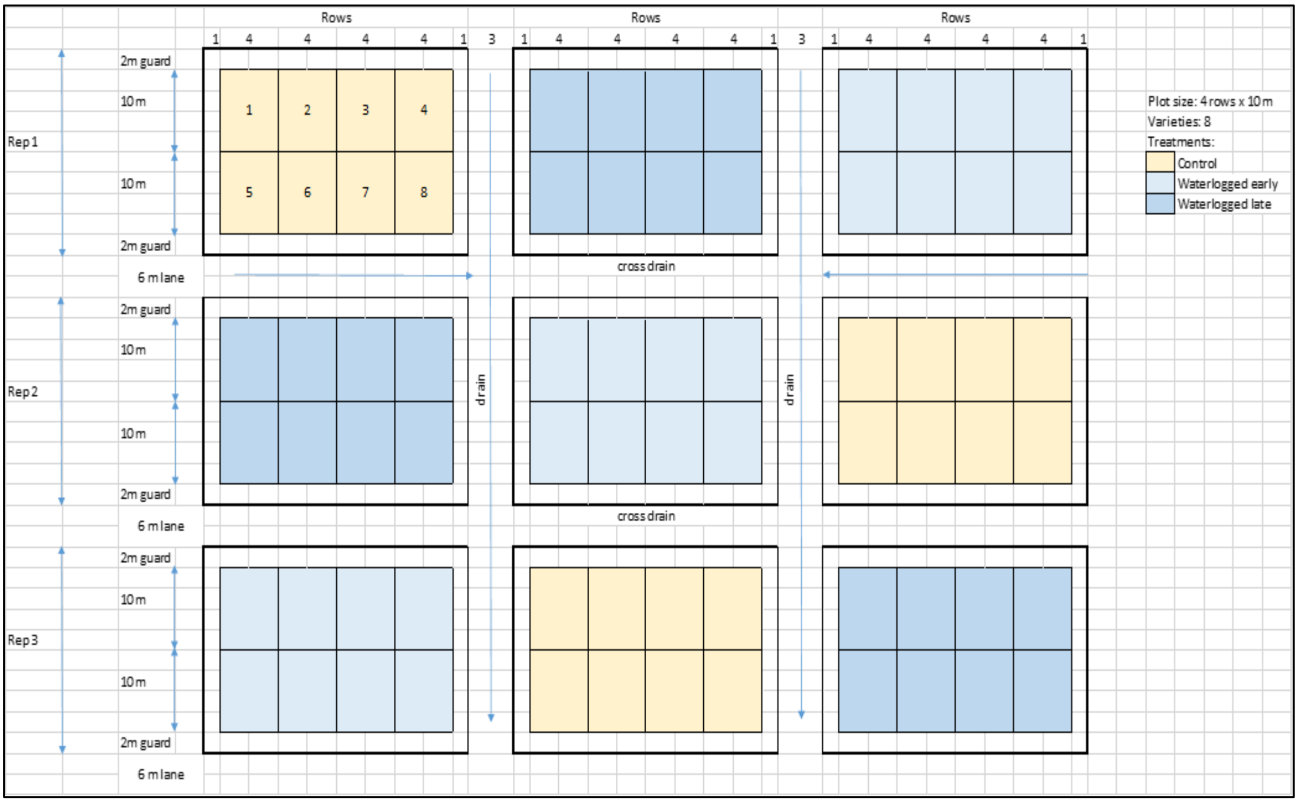


Figure 5.3 Field plan for the evaluation of waterlogging tolerance of eight sugarcane varieties

Varieties (Table 5.2) were selected following discussion with Lawrence DiBella (HCPSL), with the intention of including varieties with both poor and good tolerance, as well as newer varieties whose ratings were based on limited information or were unknown. Q238$^{\Phi}$ was not included in the trial as its poor rating is associated with susceptibility to chlorotic streak rather than physiological waterlogging tolerance.

Waterlogging treatments consisted of a control (no waterlogging) and waterlogging of the crop for 1 - 1.5 months at two crop stages (early and late) (Table 5.3). Waterlogging treatments were imposed by bunding the main plots (Figure 5.4) and applying irrigation until the soil profile was saturated and water remained above the soil surface (Figure 5.5). Irrigation was re-applied to maintain the plot in this waterlogged condition until it was drained.

Table 5.2 Waterlogging tolerance ratings for sugarcane varieties across regions. Varieties included in the experiment are highlighted (QCANESelect^{TM}).

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

Table 5.3 Timing of waterlogging treatments for the plant and first ratoon crops.

Waterlogging treatment	Plant crop		1st ratoon	
	Start	Drained	Start	Drained
Early	3-Dec-15	2-Jan-16	5-Dec-16	23-Jan-17
	107 DAP	137 DAP	88 DAH	137 DAH
Late	13-Jan-16	1-Feb-16	1-Feb-17	20-Mar-17
	148 DAP	167 DAP	146 DAH	193 DAH

5.2.2 Stalk population development

Stalks counts were conducted in 15 m^2 sub-plots on a regular basis during the development of the plant crop (2015-2016). A stalk count was also taken on 30 November 2016 during the development of the ratoon crop, prior to the commencement of waterlogging treatments.

Figure 5.4 Earthworks in order to bund plots for waterlogging treatments.

Figure 5.5 Waterlogged plot being drained

5.2.3 Biomass assessment

A within-season biomass assessment was conducted during the development of the plant crop on 18 April 2016, 244 days after planting (DAP). Stalks in a 15 m^2 quadrat were counted and ten stalks were randomly sampled and weighed. These stalks were partitioned into two components, millable stalk, and green leaf and cabbage, and each component weighed separately. Sub-samples of these components were also mulched and dried at 70^{o}C in order to calculate percent dry matter.

5.2.4 Relative water content

Relative water content of the first ratoon crop was assessed on 8 February 2017, 153 days after harvesting (DAH). This was whilst the late waterlogging treatment was in place, but followed the draining of the early treatment. A 10 cm segment from the middle portion of the last fully expanded leaf was collected. Eight leaf segments were collected per plot. Leaf segments were weighed at the time of sampling (fresh wt.), following 48 hours in a water bath at room temperature (wet wt.) and again after drying in an oven at 70 ^{o}C (dry wt.).

The following formula was used to calculate relative water content

RWC = (field wt.-dry wt.)/(wet wt.-dry wt.)

5.2.5 Aerial root assessment

The development of aerial roots is associated with waterlogging tolerance. Aerials roots were rated on 18 April 2017 in the first ratoon crop. The rating system was: 1 – no aerial roots; 2 – average aerial roots; 3 prolific aerial roots. The number of above ground nodes with aerial roots was also counted at this time.

5.2.6 Sugarcane yield

Sugarcane yield was assessed through manual harvesting. Stalks in a 15 m^2 sub-plot were counted, cut at the base, and weighed to ascertain total fresh biomass. A sub-sample of 15 stalks was taken from each plot and partitioned into two components: millable stalk, and green leaf and cabbage. This was done by removing the top of the stalk between the fifth and sixth dewlap or eighth and ninth dewlap if the stalk had flowered (counting flag leaves). Dead leaves were stripped from the millable stalk and discarded, green leaves were included with the green leaf and cabbage component. Each component was weighed separately and used to calculate percent millable stalk. This percentage was then applied to the total plot biomass to calculate sugarcane yield. A sub-sample of each of the components was mulched, weighed and placed in an oven set at 70°C until a constant dry weight was attained. This data was used to determine moisture content, and allowed the expression of biomass on a dry weight basis. A six-stalk sample was also collected for quality component analysis. Quality components were determined using the SpectraCane system (Berding et al., 2003).

5.2.7 Nitrogen content and Nitrogen use efficiency

At the harvest of the first ratoon crop, a subsample of the millable stalk and green leaf and cabbage components, that were used to determine crop moisture content, were ground in a plant mill (1 mm sieve plate) and analysed for nitrogen content (Dumas) at SRA's analytical laboratory in Brisbane. Plant percent N concentration of each component was used to calculate total crop N uptake and allowed the calculation of nitrogen utilisation efficiency (NuteE) (TCH/kg crop N).

5.2.8 Statistical analysis

Crop data were analysed using Genstat 16.2. ANOVA was performed using a split plot model. For significant effects ($P<0.05$), means were compared using Fishers' least significant difference (LSD).

5.3 Waterlogging pot experiments

5.3.1 Developing a method to impose waterlogging on sugarcane grown in pots

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 5.2). 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 5.2) 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 is 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.

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 section describes four pot experiments that were conducted at the SRA station at Mackay in order to develop a method to impose waterlogging on sugarcane grown in pots. All experiments were conducted in an area open to the environment. A brief summary of the experiments is shown in Table 5.4. 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.

5.3.1.1 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$^{\text{TM}}$). Pots size was 14 cm x 14 cm (diam. x 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 5.4 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	9/10/2014 (52) 9/10/14 + FB 16/10/14 (59)	29/10/2014 (72)
			Waterlogged		
			Waterlogged+FB		
2	KQ228$^{\Phi}$	3/10/2014	Control	25/11/2014 (53)	18/12/2014 (76)
			Waterlogged		
			Waterlogged+FB		
3	Q208$^{\Phi}$, KQ228$^{\Phi}$	3/10/2014	Control	9/01/2015 (98)	23/02/2015 (143)
			Waterlogged+FB		
			Waterlogged+FB+recov		
4	Q208$^{\Phi}$, KQ228$^{\Phi}$	6/02/2015	Control	18/03/2015 (40)	15/05/2015 (98)
			Waterlogged+FB		
			Waterlogged+FB+recov		

5.3.1.2 Experiment 2

KQ228$^{\Phi}$ was planted in pots (20 cm x 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 labeled 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$^{\mathrm{o}}$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$^{\mathrm{o}}$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$^{\mathrm{o}}$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).

5.3.1.3 Experiment 3

Sugarcane (Q208$^{\Phi}$ and KQ228$^{\Phi}$) was planted in pots on 3 October 2014. Pots (20 cm x 19 cm) contained a mixture of 50 % coarse sand and 50 % Searles premium potting mix. Plants were fertilised with Osmocote (15 g every four 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$^{\mathrm{TM}}$ 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 (Figure 5.6). 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)

Figure 5.6 Tubes with BD Connecta^{TM} and wrapped in geofabric for the collection of water from the root zone

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.

5.3.1.4 Experiment 4

Q208$^{(b)}$ and KQ228$^{(b)}$ 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 two 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°C to determine moisture content. These measurements allowed the calculation of total dry biomass and % dry matter.

5.3.1.5 Statistical analysis

All data were analysed using ANOVA procedures in GenStat 16.2. For significant effects ($P<0.05$), means were compared using Fishers' least significant difference (LSD).

5.3.2 Screening of sugarcane varieties for waterlogging tolerance in pots

Following the development of a method to impose waterlogging on sugarcane in pots, this methodology was used to assess genotypic differences among sugarcane varieties for waterlogging tolerance. This was conducted in order to determine whether this methodology could be used on a regular basis prior to variety release to provide more accurate information in QCANESelect™. The results from screening varieties using the pot methodology would also need to be consistent with data obtained from the waterlogging experiment conducted in the field. Four experiments were conducted where the waterlogging tolerance of nine sugarcane varieties was assessed.

5.3.2.1 Experiment 1

The experiment consisted of three waterlogging treatments (control, waterlogging, waterlogging + recovery), nine varieties (Table 5.5) and 5 replicates arranged in a randomised block design. One eye setts of each variety were planted on 29 May 2015, treatments implemented on 7 July 2015, with the recovery treatment on a ~2 week cycle of exposure to waterlogging. This was done to reflect conditions where waterlogging events occur periodically over time.

Table 5.5 Waterlogging ratings for nine varieties included in the pot trial

Rating	Varieties		
Good tolerance	Q208	Q232	SP80*
Average or unknown	Q252	Q240	Q247
Poor tolerance	KQ228	Q183	Q135

*rating based on anecdotes in the Central region

Within each replicate, pots (20 cm x 19 cm) were arranged approximately 10 cm apart. As was the case during method development, all pots in waterlogged treatments, within each replicate, were connected to a 20 L container (Figure 5.7). 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 of 1.5 kg fibrated cane stalk per 500 L water.

Prior to waterlogging treatments being imposed, pots were irrigated four times per day with a dripper system, with the duration of each event (3-5 minutes) being adjusted depending on environmental conditions.

Control plants were maintained with this irrigation system throughout the experiment. Plants that were exposed to waterlogging treatments did not receive irrigation whilst under waterlogging conditions. 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). The experiment was conducted at the SRA station at Mackay, in an enclosed area open to environmental conditions.

As described previously (5.3.1.3), a perforated tube wrapped in geo-fabric was buried within each pot. This allowed the collection of water samples from within the root zone. Dissolved oxygen content of the water was assessed with a Cyberscan DO 110 dissolved oxygen meter.

Stalks counts were conducted through the experimental period to assess the effect of waterlogging on tillering and shoot survival. Leaf lamina length, lamina maximum width, and stalk height to the dewlap of the last fully expanded leaf was measured for Q135, Q208$^{\Phi}$, Q240$^{\Phi}$, Q252$^{\Phi}$, KQ228$^{\Phi}$ and SP80.

The experiment was harvested on 30 September 2015. All stalk were cut at the base, counted, and weighed to determine total fresh biomass. A sub-sample of the above ground biomass was collected, weighed, dried at 70°C until reaching a constant weight. The sub-sample was reweighed and percent dry matter calculated. This also allowed the calculation of total dry biomass.

Figure 5.7 Arrangement of pots and the system to impose waterlogging at the SRA site at Mackay. The cream tank in the background supplied deoxygenated water to the 20 L containers (red lids). This was controlled by a float valve which maintained water level within the 20 L tank and all the pots connected to it. Plants were exposed to waterlogging by placing pots within the water-filled pots

5.3.2.2 Experiment 2

The design, set-up and management of this experiment was as described in experiment 1.
The sugarcane varieties in the experiment included all those that were tested in the field trial at Ingham (Q183$^{\Phi}$, Q200$^{\Phi}$, Q219$^{\Phi}$, KQ228$^{\Phi}$, Q232$^{\Phi}$, MQ228$^{\Phi}$ and Q247$^{\Phi}$). Q135 was included as an additional variety, and is thought to have poor waterlogging tolerance. Single-eye setts of each variety were planted on 15 October 2015. Treatments were: control; waterlogging of all varieties on 26 November 2015 (Waterlogging early); waterlogging at a later time when each individual plant reached leaf 8 (Waterlogging late). These two treatments were implemented to assess differences among varieties as well as try determine whether speed of development was influencing experimental results. The experiment was sampled in a similar manner as experiment 1. The final harvest was conducted on 25 February 2016.

5.3.2.3 Experiment 3

The design, set-up and management of this experiment was as described in experiment 1.
The sugarcane varieties in the experiment included Q253$^{\Phi}$, Q247$^{\Phi}$, Q240$^{\Phi}$, MQ239$^{\Phi}$, Q232$^{\Phi}$, Q208$^{\Phi}$, Q200$^{\Phi}$, Q135 and SP80. This list includes newer varieties that appear to be gaining popularity amongst growers (Q253$^{\Phi}$ and Q240$^{\Phi}$) as well as repeating those that were used in previous pot experiments and the Ingham field trial in order to assess consistency of response. Three treatments were imposed: control; waterlogging when the first plant of any variety reached leaf 5 (WL early); waterlogging as each plant reached leaf 5 (WL at Leaf5). In the first waterlogging treatment, a difference in stage of development existed based on the speed of each variety to produce leaves. In the second waterlogging treatment each plant had produced the same number of leaves, and there should not have been any (or less) advantage to those varieties that established more quickly. Single-eye setts of each variety were planted on 12 April 2016. The experiment was sampled in a similar manner as experiment 1. The final harvest was conducted on 18 and 19 August 2016.

5.3.2.4 Experiment 4

The final pot experiment commenced on 10 April 2017 with the planting of single-eye setts of Q183$^{\Phi}$, Q200$^{\Phi}$, Q219$^{\Phi}$, KQ228$^{\Phi}$, Q232$^{\Phi}$, MQ228$^{\Phi}$, Q247$^{\Phi}$ and Q135. This followed a failed pot experiment that was damaged by Tropical cyclone Debbie and the lack of power to the site for the week following the cyclone (Figure 5.8).

Figure 5.8 Damage to a pot experiment caused by Cyclone Debbie

The varieties included in the final experiment were a repeat of Experiment 2, and matched the field trial at Ingham. This was done due to the presence of a statistically significant variety.waterlogging interaction at the field site. Consistency of response in both the field and pot experiments would provide confidence that the pot experiment method could be used in the future to screen sugarcane varieties. The design, set-up and management of the experiment was as described in Experiment 1. Treatments included: control; waterlogged early (11 July 2017); waterlogged late (9 August 2017). The trial was sampled in a similar manner as the other experiments and final harvest was conducted on 15 September 2017.

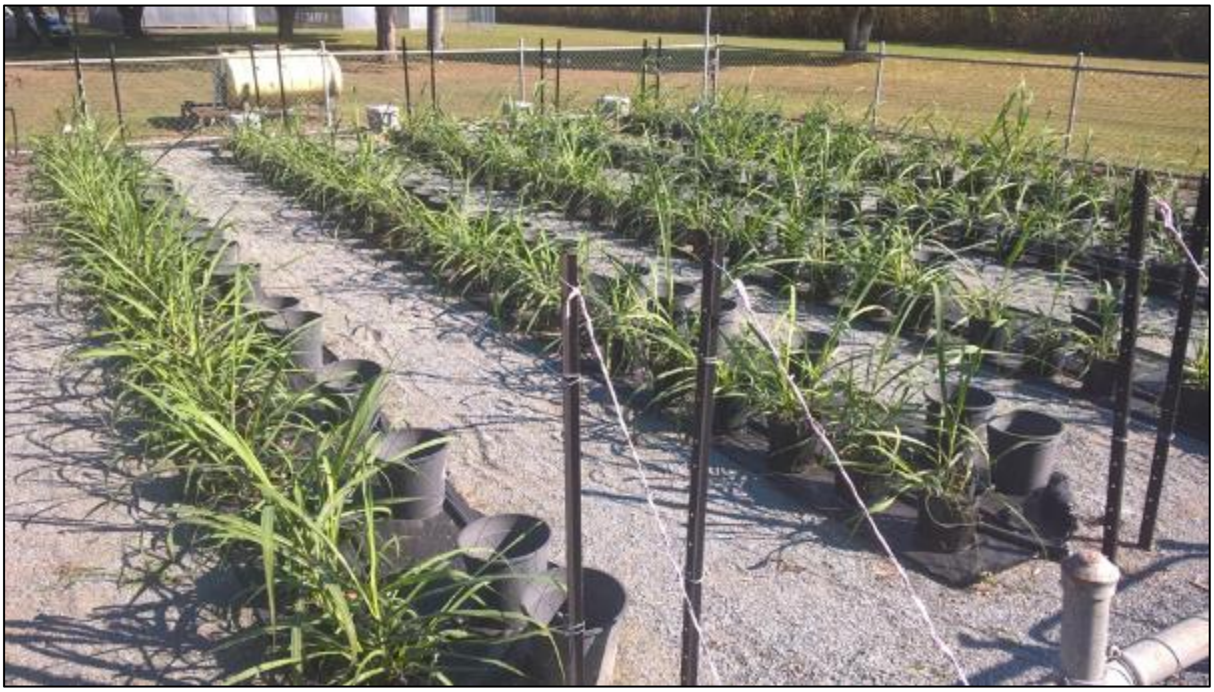


Figure 5.9 Young sugarcane prior to the commencement of waterlogging treatments

5.3.2.5 Statistical analyses

All statistical analyses were performed with GenStat 16.2. ANOVA procedures were performed using a completely randomised model with blocks (replicates). Where data was collected over time or from successive leaves from the same plant, repeated measures ANOVA was used. For significant effects (P<0.05), means were compared using Fishers' least significant difference (LSD).

6 RESULTS AND DISCUSSION

6.1 Speed of establishment field experiment

6.1.1 Environmental conditions

Rainfall during the trial period (Figure 6.1) was generally below average for the Tully region. Seasonal rainfall (July - June) for 2014 - 2015, 2015 - 2016 and 2016 - 2017 seasons was 2635, 3276 and 3530 mm, respectively. This can be compared with a seasonal average of 3943 mm and a median of 3842 mm. During the plant crop, there was a prolonged period (Sept - Dec 2014) following the early planting treatment where rainfall was below average. This resulted in poor growth of sugarcane in the early treatment. Cane was also planted into permanent raised beds which most likely resulted in lower soil moisture than if it has been planted conventionally. Usually, raised beds are recommended in a wet environment. The late onset of the wet season in 2014 - 2015 combined with lower total rainfall, meant that stress associated with late planting was limited.

This was also the case in 2015 - 2016, with three months following the late harvest treatment prior to a significant rainfall event in the region. In 2016 - 2017, the first significant rainfall event was two months following the late harvest treatment. These unusually dry conditions and late onset of the wet season, are likely to have affected the outcome of this experiment, where the harvest time treatments were used to create two climatic scenarios, one with optimum growing conditions and a long period prior to any excessive rainfall, and the second where excessive rainfall was received very early in crop development.

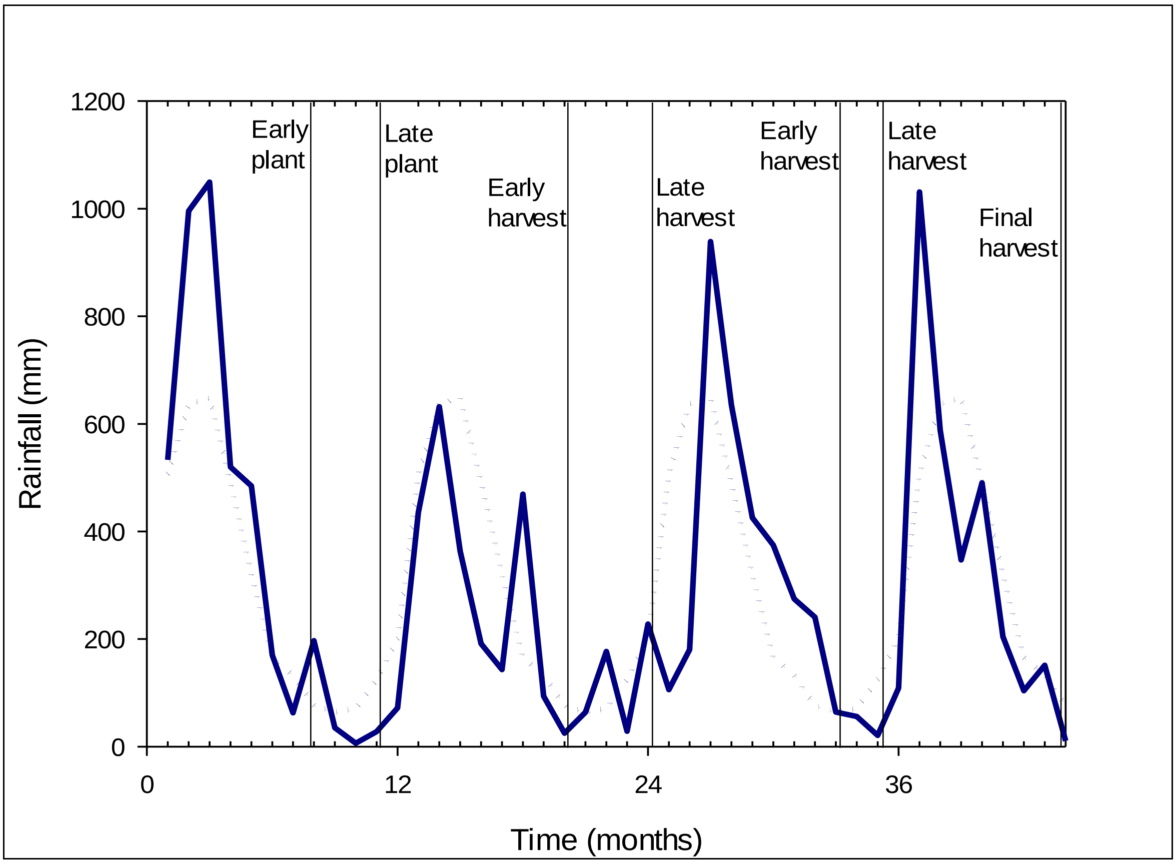


Figure 6.1 Rainfall at Tully mill and long-term median for the period during which the experiment was conducted. Tully mill - Solid blue line; Long term monthly median – dotted blue line

6.1.2 Stalk population development – plant crop

Significant differences in stalk population development were found among varieties for both early and late planting times (Figure 6.2). In general, Q231$^{\text{ⓓ}}$ and Q241$^{\text{ⓓ}}$ had the highest stalk population. Q183$^{\text{ⓓ}}$ tended to produce shoots earlier than other varieties but was overtaken later in crop development. Stalk numbers for Q208$^{\text{ⓓ}}$, Q219$^{\text{ⓓ}}$ and Q232$^{\text{ⓓ}}$ were consistently lower than other varieties. Stalk populations for all varieties were low, reflecting the very dry spring period experienced in 2014.

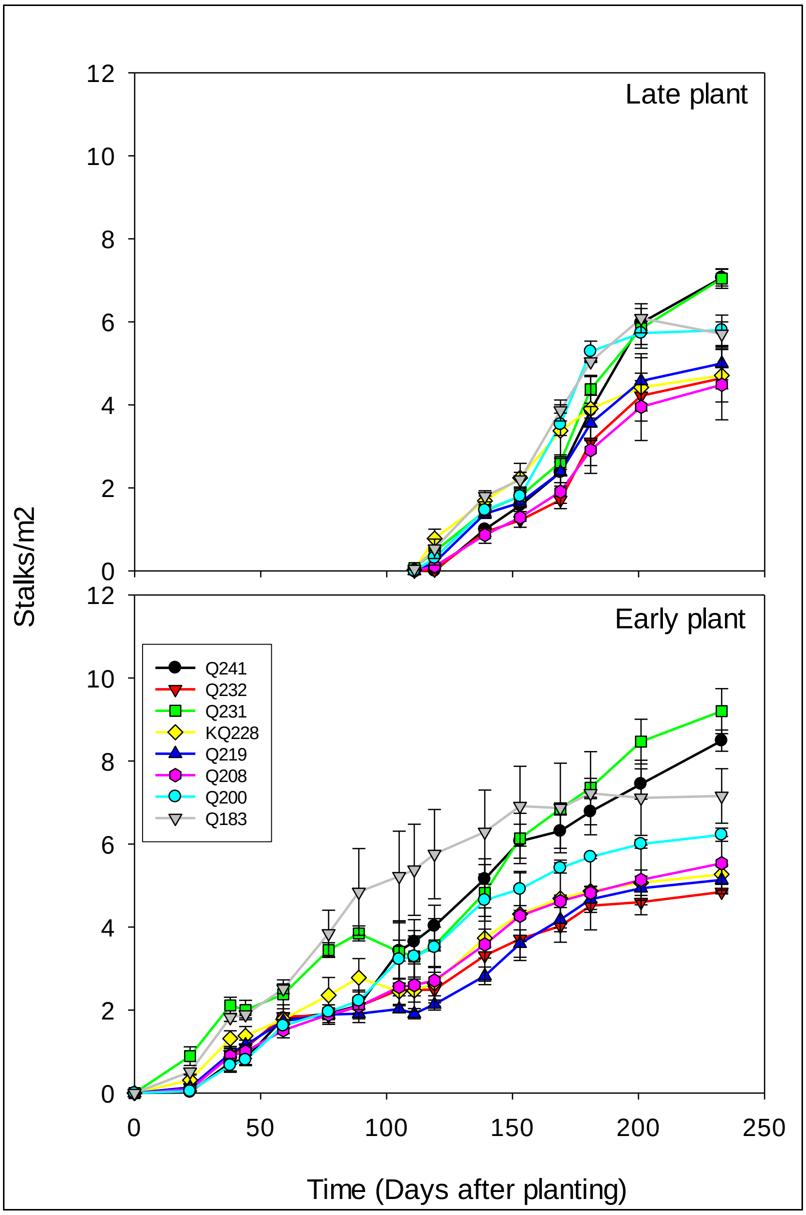


Figure 6.2 Stalk population development for Q241, Q232, Q231, KQ228, Q219, Q208, Q200 and Q183 planted early (August 2014) or late (November 2014). Error bars + SEM

6.1.3 Canopy development- plant crop

Crop light interception and leaf area index were very low on 3 December 2014 and 23 December 2014 due to slow growth following dry conditions. On 3 February 2015, leaf area index (LAI) and fractional light interception (FI) were significantly higher in the early planting treatment, reflecting more advanced development associated with planting time (Table 6.1). Q183$^{\Phi}$ and Q232$^{\Phi}$ had the highest LAI, whereas Q219$^{\Phi}$, KQ228$^{\Phi}$ and Q241$^{\Phi}$ were low. On 23 April 2015 differences in LAI and FI due to planting time were no longer statistically significant. Given the different crop ages, this indicates that the late planted crop developed LAI at a faster rate than the early planted crop. Q183$^{\Phi}$ and Q232$^{\Phi}$ had significantly higher LAI than Q208$^{\Phi}$. Planting time.variety interaction was not significant on either date. The low LAI of Q208$^{\Phi}$ relative to other varieties supports grower observations that this variety remains upright and is slow to fill in the interspace. It is interesting to note that LAI and stalk number are not always linked. Q232$^{\Phi}$ had low stalk numbers but high LAI whereas Q183$^{\Phi}$ had high stalk numbers and high LAI.

In general, leaf area index was low in comparison to other studies (Muchow et al., 1994, Sandhu et al., 2012). This most likely reflects the poor growing conditions experienced by this crop due to dry spring conditions and the use of pre-formed beds which shed water.

Table 6.1 Leaf area index and fractional light interception on 3 February 2015 for eight sugarcane varieties planted in August (early) and November (late) 2014 at Tully

Sampling date	Trait	Planting time	Variety								Mean
			Q241	Q232	Q231	KQ228	Q219	Q208	Q200	Q183	
3-Feb-15	Leaf area index	Early	0.42	0.63	0.53	0.29	0.28	0.48	0.52	0.64	0.47
		Late	0.08	0.25	0.08	0.11	0.09	0.19	0.13	0.26	0.15
		Mean	0.25	0.44	0.30	0.20	0.18	0.34	0.33	0.45	0.31
	$LSD^{(0.05)}$: Variety 0.15; Planting time 0.19; Variety.Plantign time ns										
	Fractional light interception	Early	0.20	0.28	0.25	0.15	0.14	0.21	0.24	0.26	0.22
		Late	0.05	0.12	0.05	0.05	0.05	0.10	0.08	0.13	0.08
		Mean	0.13	0.20	0.15	0.10	0.10	0.16	0.16	0.20	0.15
	$LSD^{(0.05)}$: Variety 0.06; Planting time 0.10; Variety.Plantign time ns										
23-Apr-15	Leaf area index	Early	1.52	1.76	1.89	1.10	1.48	1.15	1.33	2.28	1.56
		Late	1.31	1.48	1.56	1.43	1.04	1.07	1.48	1.38	1.34
		Mean	1.41	1.62	1.73	1.27	1.26	1.11	1.40	1.83	1.45
	$LSD^{(0.05)}$: Variety 0.46; Planting time ns; Variety.Planting time ns										
	Fractional light interception	Early	0.50	0.61	0.63	0.45	0.54	0.45	0.52	0.68	0.55
		Late	0.49	0.54	0.54	0.52	0.43	0.45	0.53	0.53	0.50
		Mean	0.49	0.58	0.58	0.49	0.48	0.45	0.52	0.60	0.52
	$LSD^{(0.05)}$: Variety ns; Planting time ns; Variety.Planting time ns										

The relationship between early canopy development and final crop biomass 362 days after planting the early treatment and 382 days after planting the late treatment was assessed (Figure 6.3). There did not appear to be a strong relationship between these two factors. A trend was apparent between LAI in April and final biomass. However, it is likely that LAI and biomass are correlated and therefore this may just reflect that plots that developed well during the early stages of development were the plots that achieved the highest final biomass.

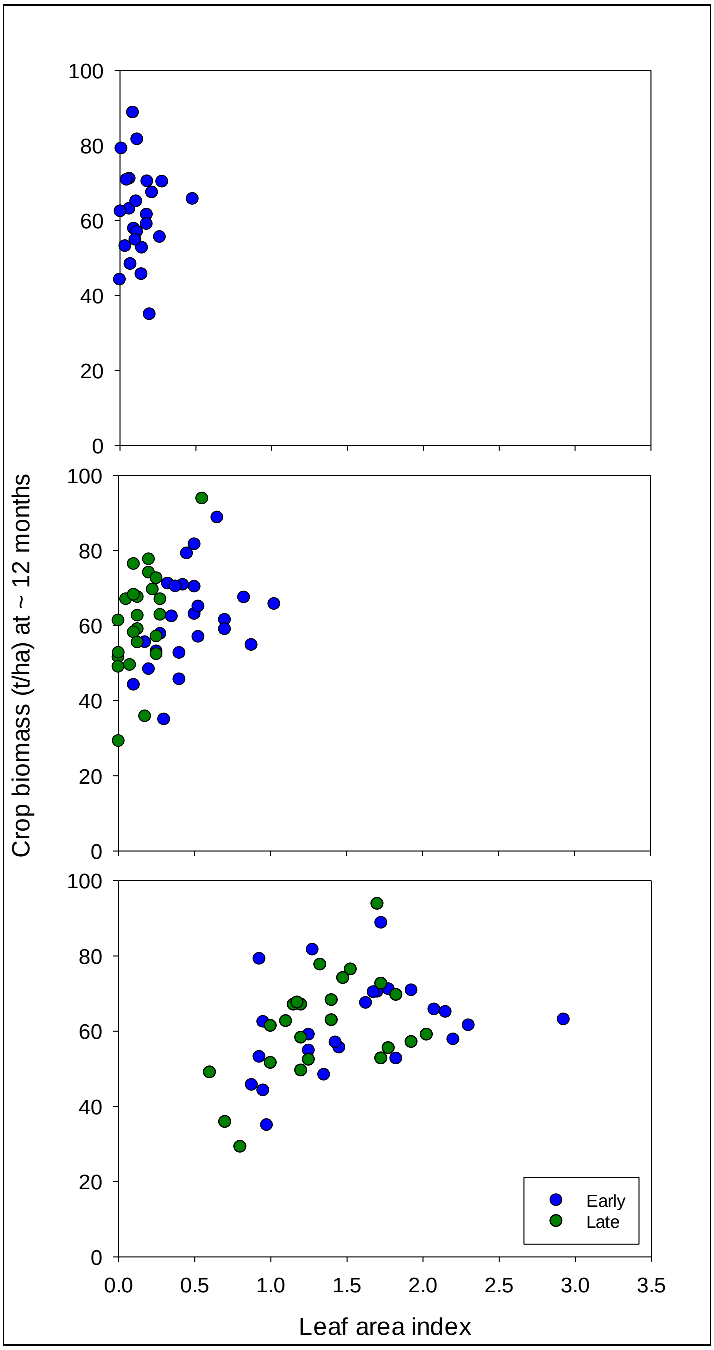


Figure 6.3 Relationship between canopy development (leaf area index) in December (top), February (middle) and April (bottom) and final crop biomass

The lack of significant rainfall during development of the late planted crop meant that the hypothesis that early canopy development would be strongly related to final performance under these environmental conditions was largely untested. If anything, the data suggests that without any significant excessive rainfall events, initial canopy development may not be a significant factor and high final biomass can be achieved through a number of growth pathways.

6.1.4 Biomass development – plant crop

The crop planted early and late developed differently over time (Table 6.2). The early planted crop showed slow growth in the first 4 months whereas the late planted crop achieved significant growth in this period. This reflects the differing environmental conditions in terms of thermal time and soil moisture availability during these two development periods. These differences were also present at 8 months after planting with the late planted crop having produced greater biomass. There was no difference in biomass production at 12 months after planting. Previous experiments in South Africa showed that crops starting in December (summer) grew into high temperatures and had more rapid canopy development than crops starting in April (early winter) (Inman-Bamber 1991). The planting time.variety.age interaction was not statistically significant which indicates that all varieties followed a similar pattern of development at the two planting times (Figure 6.4).

Table 6.2 Crop fresh and dry biomass development at 4, 8 and 12 months after planting either early (August) or late (November)

Trait	Variety	Early				Late				Mean (V)
		4	8	12	Mean	4	8	12	Mean	
Fresh biomass (t/ha)	Q241	1.6	34.4	64.6	33.5	23.7	58.9	56.6	46.4	44.2
	Q232	1.3	56.1	75.7	44.4	39.5	61.8	76.1	59.2	55.3
	Q231	2.0	41.2	67.4	36.9	19.7	47.1	58.6	41.8	44.3
	KQ228	1.5	33.0	45.4	26.7	31.8	44.2	54.1	43.4	36.6
	Q219	1.1	24.5	52.6	26.1	20.3	48.3	58.7	42.4	37.0
	Q208	2.2	35.7	64.6	34.2	30.3	63.1	53.8	49.1	44.1
	Q200	0.8	36.0	62.8	33.2	32.6	55.4	68.3	52.1	44.9
	Q183	3.0	42.3	60.5	35.3	37.8	55.3	64.0	52.4	47.9
	Mean (Age)	1.7	37.9	61.7	33.8	29.5	54.3	61.3	48.3	44.3
	LSD$^{(0.05)}$: Planting time (PT) ns; Variety (V) 8.5; PT.V ns; Age 3.2; PT.Age 13.8; V.Age ns ; PT.V.Age ns									
Dry biomass (t/ha)	Q241	0.4	7.6	18.5	8.9	4.9	16.0	18.1	13.0	12.6
	Q232	0.4	13.8	21.3	11.8	8.6	17.3	24.8	16.9	16.0
	Q231	0.6	10.4	19.0	10.0	4.5	12.9	19.2	12.2	12.9
	KQ228	0.4	7.9	14.2	7.5	7.4	13.1	18.1	12.8	11.0
	Q219	0.3	6.4	15.1	7.3	4.2	12.6	20.4	12.4	11.1
	Q208	0.6	9.8	18.1	9.5	7.6	17.5	17.3	14.1	13.0
	Q200	0.2	7.9	18.3	8.8	6.5	15.9	23.8	15.4	13.3
	Q183	0.9	10.8	17.3	9.6	8.3	14.3	20.8	14.5	13.7
	Mean (Age)	0.5	9.3	17.7	9.2	6.5	15.0	20.3	13.9	13.0
	LSD$^{(0.05)}$: Planting time (PT) 4.5; Variety (V) 2.2; PT.V ns; Age 0.9; PT.Age 3.6; V.Age ns; PT.V.Age ns									

It should be noted that the significantly lower average dry biomass with an early planting time (Table 6.2), is confounded by the inclusion of biomass data at 4 and 8 months after planting. At final harvest, there was no difference between the two planting times. The low total biomass at 12 months reflects poor growing conditions associated with low spring rainfall and low soil moisture.

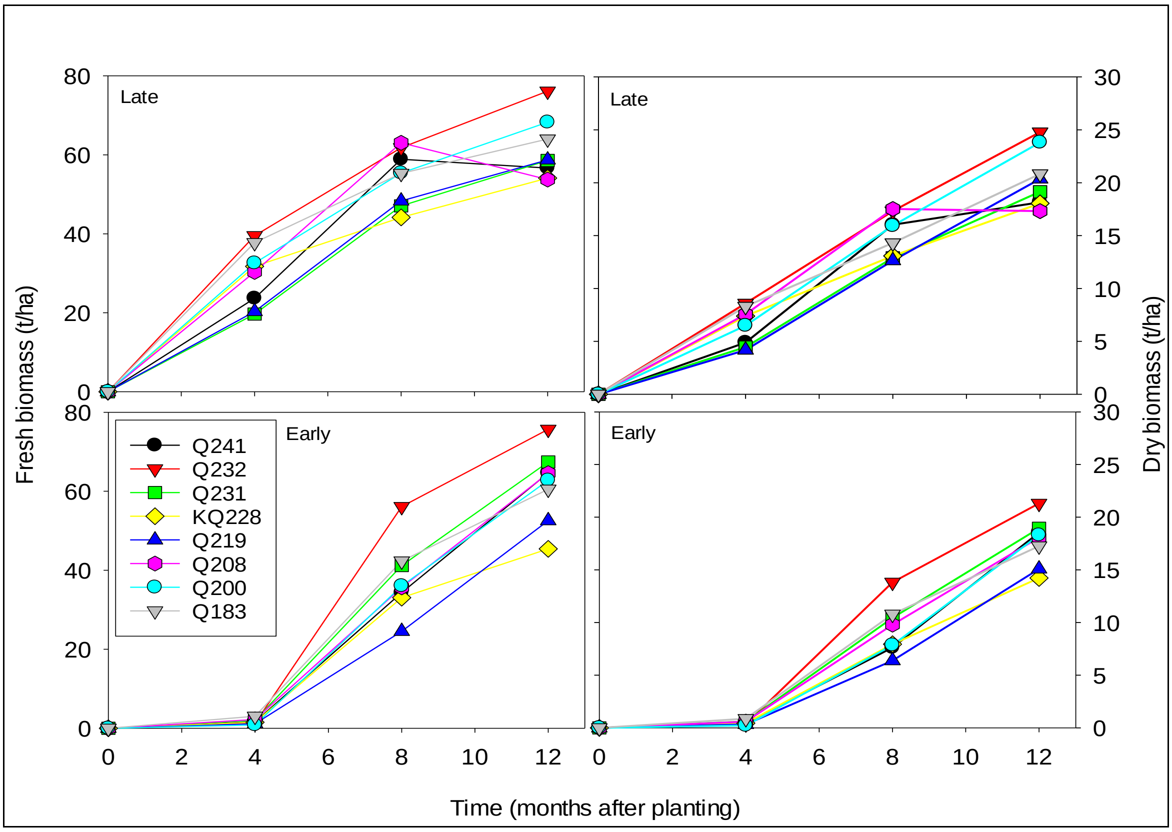


Figure 6.4 Plant crop biomass development for eight sugarcane varieties planted early (August) or late (December)

6.1.5 Plant crop yield

Cane yield, CCS and sugar yield for the early and late planted crops were compared at similar crop age (~12 months) (Table 6.3). Additional data was also obtained for the early planted crop at 15 months crop age, which coincided with the 12 month harvest of the late planting treatment (Table 6.3). At 12 months crop age, there was no difference in cane and sugar yield produced from crops planted early or late. There was also no difference among varieties or a planting time.variety interaction for cane or sugar yield. Cane that was planted late had significantly higher CCS than cane planted early when both crops were 12 months old. This is most likely associated with the late planted cane experiencing a drying off period late in development (spring) in comparison to the early planted treatment. Biomass development also showed that the early planted cane developed more slowly and was possibly still in a vegetative phase of growth at 12 months. The late planted crop developed biomass earlier and a slowing down of growth late in its development would also have contributed to higher CCS.

The lack of any yield difference between early and late planted cane is an unusual result given previous research on this topic (Lawes *et al*.., 2002; DiBella *et al., 2008, McDonald et al.*, 1999). This was attributed to the slow establishment of the early planted cane due to dry conditions and low soil moisture with pre-formed beds. As outlined previously, the lack of any significant rainfall events during the early development of the late planted crop also allowed this crop to develop without the constraints that are usually present in Tully. The low yields at the site, due to these issues, also limits our ability to assess any effects. Unfortunately the hypothesis that varieties with quick development in excessively wet environment outperform others was largely untested during the plant crop.

Table 6.3 Cane yield, CCS and sugar yield of eight varieties planted early or late at 12 months after planting. Additional data was also collected for the early planting time at 15 months after planting. LSD values for comparison of 12 month crop data only

Variety	Early at 12 months			Late at 12 months			Early at 15 months		
	TCH	CCS	TSH	TCH	CCS	TSH	TCH	CCS	TSH
Q241	45.9	12.9	5.9	43.3	14.8	6.4	53.6	15.5	8.3
Q232	55.4	12.9	7.2	60.3	15.8	9.5	61.0	16.0	9.8
Q231	47.0	12.5	5.9	43.7	14.8	6.5	56.8	15.5	8.8
KQ228	34.7	14.3	5.0	42.5	16.5	7.0	36.4	16.8	6.1
Q219	39.2	11.2	4.4	49.6	14.3	7.0	45.7	15.2	6.9
Q208	50.5	13.5	6.9	46.3	15.6	7.2	51.3	15.9	8.2
Q200	46.0	12.9	6.0	57.5	15.3	8.8	47.5	16.5	7.9
Q183	44.6	13.0	5.8	51.4	15.7	8.0	57.6	15.8	9.1
Mean	45.4	12.9	5.9	49.3	15.4	7.6	51.2	15.9	8.1
TCH LSD(0.05): Planting time ns; Variety ns; Planting time.Variety ns									
CCS LSD(0.05): Planting time 1.2; Variety 0.6; Planting time.Variety ns									
TSH LSD(0.05): Planting time ns; Variety ns; Planting time.Variety ns									

6.1.6 First ratoon crop

6.1.6.1 Within-season biomass

The trial was sampled on 11 April 2016 when the early harvest treatment was ~ 8 months and the late harvest treatment was ~4 months crop age. Analysis of this data showed highly significant ratoon time and variety effects, significant plant time.ratoon time.variety interactions, and a number of trends (P<0.1) (Table 6.4 and 6.5).

Ratoon time effects were associated with greater biomass and higher percent dry matter for the August (Early) ratooning time. This was not unexpected given the differences in crop age, but differs from the plant crop where planting time had little effect due to unusually dry conditions following the early planting time. Differences among varieties were mostly associated with the poor performance of KQ228$^{\Phi}$ and Q219$^{\Phi}$ and better performance of Q232$^{\Phi}$ and Q200$^{\Phi}$.

The significant plant time.ratoon time.variety interactions for both fresh biomass (Figure 6.5) and cane yield are associated with: Q232$^{\Phi}$ and Q200$^{\Phi}$ performing better than other varieties, particularly when ratooned late; Q231$^{\Phi}$ performed well with early ratooning and poorly with late ratooning; KQ228$^{\Phi}$ performed well in the late plant, early ratoon treatment only.

Table 6.4 Crop traits of eight varieties on 11 April 2016 following two planting (Aug and Nov) and ratooning times (Aug and Dec)

Plant Time	Ratoon time	Variety	Fresh biomass (t/ha)	Dry biomass (t/ha)	Cane yield (t/ha)	Crop %DM	Stalks/m^2
Early	Early	Q241	100.2	22.5	70.4	22.4	9.5
		Q232	113.1	24.6	80.2	21.7	8.2
		Q231	116.4	29.8	82.9	25.8	10.6
		KQ228	71.8	17.0	48.6	23.5	6.8
		Q219	89.2	20.2	64.1	22.5	8.1
		Q208	111.2	22.0	85.0	19.8	8.4
		Q200	96.6	20.7	68.9	21.5	9.3
		Q183	90.9	21.3	67.2	23.0	6.4
		Mean	98.7	22.2	70.9	22.5	8.4
	Late	Q241	53.8	10.6	30.8	19.9	10.6
		Q232	81.4	15.5	51.6	19.0	9.5
		Q231	40.8	8.8	23.0	20.8	8.7
		KQ228	48.1	9.2	28.0	19.2	7.2
		Q219	43.1	8.5	26.5	19.6	7.5
		Q208	56.9	11.1	36.2	19.5	8.6
		Q200	73.3	12.8	45.9	17.2	9.7
		Q183	55.8	10.9	34.9	19.6	7.5
		Mean	56.7	10.9	34.6	19.4	8.7
	Early plant mean		77.7	16.6	52.8	20.9	8.5
Late	Early	Q241	74.3	16.5	53.0	22.2	7.7
		Q232	98.0	20.1	68.5	20.6	7.2
		Q231	84.9	21.3	56.9	25.0	10.1
		KQ228	99.0	22.5	70.6	22.6	6.9
		Q219	65.7	14.3	46.1	22.0	7.2
		Q208	84.8	18.9	63.6	22.4	7.7
		Q200	98.6	22.1	69.9	22.5	8.7
		Q183	82.5	17.3	61.7	21.0	6.1
		Mean	86.0	19.1	61.3	22.3	7.7
	Late	Q241	39.9	7.7	22.6	19.2	8.4
		Q232	76.8	14.6	49.2	19.1	8.0
		Q231	43.8	9.0	25.4	20.8	9.1
		KQ228	41.1	8.6	23.6	21.0	5.9
		Q219	46.7	8.5	29.8	18.7	6.9
		Q208	58.0	11.8	37.4	20.5	8.0
		Q200	64.0	9.8	39.3	15.4	8.9
		Q183	49.9	9.7	31.5	19.7	6.9
		Mean	52.5	10.0	32.3	19.3	7.8
	Late plant mean		69.3	14.5	46.8	20.8	7.7

Table 6.5 P values following the analysis of crop traits from a biomass sample conducted on 11 April 2016

Effects	Fresh biomass (t/ha)	Dry biomass (t/ha)	Cane (t/ha)	Crop % DM	Stalks/m2
Plant time	**0.096**	0.122	0.181	0.691	**0.083**
Ratoon time	**<0.001**	**<0.001**	**<0.001**	**0.003**	0.635
Plant time.Ratoon time	0.156	0.117	0.195	0.857	0.747
Variety	**<0.001**	**0.005**	**0.002**	**<0.001**	**<0.001**
Plant time.Variety	0.503	0.268	0.457	0.556	0.614
Ratoon time.Variety	**0.081**	**0.056**	0.137	0.454	**0.092**
Plant time.Ratoon time.Variety	**0.028**	0.125	**0.021**	0.887	0.949

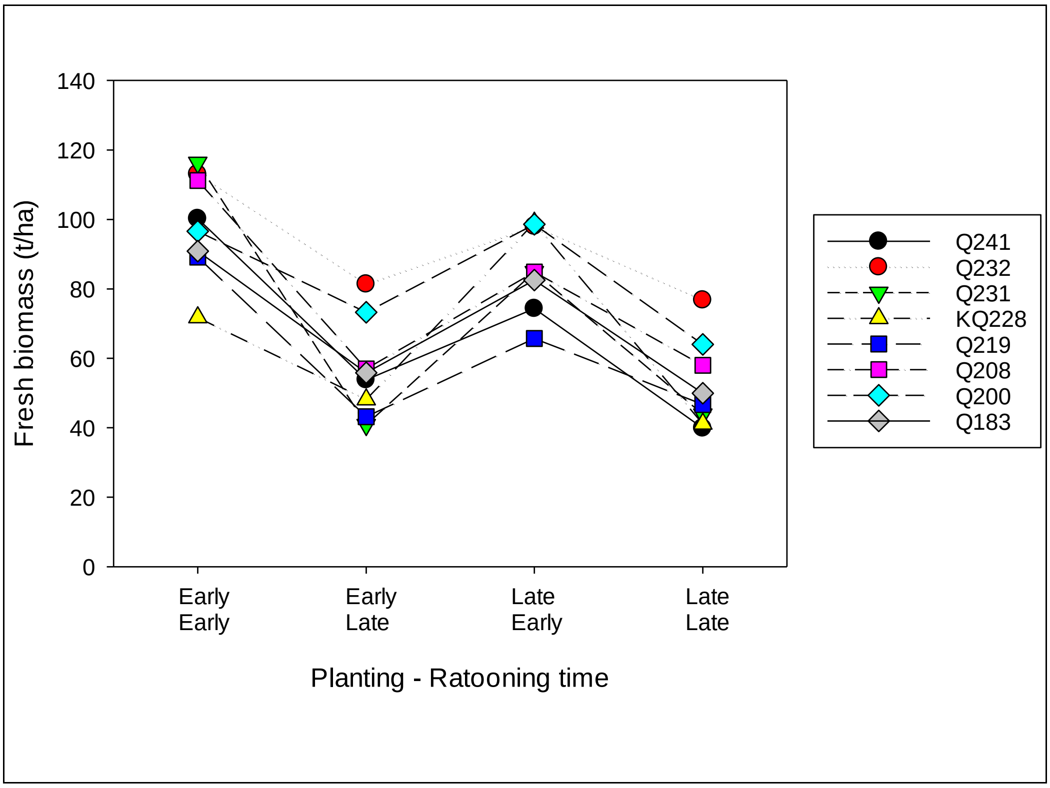


Figure 6.5 Fresh biomass of eight sugarcane varieties on 11 April 2016 following early (Aug) and late (Nov) planting followed by early (Aug) and late (Dec) ratooning in Tully

6.1.6.2 Crop harvest

The early treatment was harvested on 27 July 2016 (352 DAH) and the late treatment was harvested on 28 October 2016 (331DAH). While crop data from all plots was collected on 27 July 2016, only the early harvest plots were ~12 months of age. Data from these plots was explored to determine whether there was any historical influence of planting time (Table 6.6). For most crops traits, planting time and the interaction of planting and variety were not significant. This indicated that there were few carry-over effects from the plant crop treatments to the first ratoon crop. Curiously, crops that were planted late and harvested early had significantly higher CCS (13. 7) than crops that were planted early and harvested early (13.3). Significant variety effects were found for most traits.

On 28 October 2016 only the late harvest plots remained. This data was also explored to identify whether there was any historical influence of planting time on crop traits (Table 6.7). Again, there were few significant planting time or planting time.variety interactions on first ratoon crop performance. A significant planting time effect was found for percent millable stalk (%MS). However, the magnitude of this difference was small (1%). The effect of planting time on CCS was near statistical significance (P= 0.052). However, CCS for early planted cane that was harvested late was 16.3 whereas the CCS for late planted cane that was harvested late was 16.2. Significant variety effects were found for most traits.

Table 6.6 Crop traits at the harvest of the early harvest treatment when cane was ~ 12 months of age (27 July 2016)

Yield trait	Planting time	Variety								Mean
		Q241	Q232	Q231	KQ228	Q219	Q208	Q200	Q183	
Stalks/m^2	Early	9.5	9.3	10.8	7.8	8.8	8.8	10.1	6.3	8.9
	Late	8.5	8.2	9.8	8.4	8.1	8.6	9.0	6.4	8.4
	Mean	9.0	8.7	10.3	8.1	8.5	8.7	9.6	6.3	8.6
	LSD$^{(0.05)}$ *: Planting time ns; Variety 1.0; Planting time.Variety ns*									
Stalk wt (kg)	Early	1.2	1.6	1.2	1.2	1.4	1.4	1.3	1.5	1.3
	Late	1.4	1.4	1.2	1.5	1.3	1.5	1.3	1.4	1.4
	Mean	1.3	1.5	1.2	1.4	1.3	1.4	1.3	1.5	1.4
	LSD$^{(0.05)}$ *: Planting time ns; Variety 0.2; Planting time.Variety ns*									
%MS	Early	87.4	87.3	86.3	86.4	88.3	89.0	84.9	85.1	86.8
	Late	84.7	88.2	83.9	87.6	85.0	87.1	83.5	84.9	85.6
	Mean	86.1	87.8	85.1	87.0	86.6	88.1	84.2	85.0	86.2
	LSD$^{(0.05)}$ *: Planting time ns; Variety ns; Planting time.Variety ns*									
Crop % DM	Early	25.6	28.5	26.2	28.1	27.5	27.0	28.5	24.7	27.0
	Late	25.9	28.3	26.7	27.3	25.2	26.2	27.9	23.1	26.3
	Mean	25.8	28.4	26.4	27.7	26.4	26.6	28.2	23.9	26.7
	LSD$^{(0.05)}$ *: Planting time ns; Variety 1.8; Planting time.Variety ns*									

Table 6.7 Crop traits at the harvest of the late harvest treatments when cane was ~ 12 months of age (28 October 2016)

Yield trait	Planting time	Variety								Mean
		Q241	Q232	Q231	KQ228	Q219	Q208	Q200	Q183	
Stalks/m^2	Early	9.8	6.9	9.9	5.9	8.1	9.1	8.5	6.6	8.1
	Late	9.2	7.0	8.8	5.5	6.8	8.4	8.9	6.7	7.7
	Mean	9.4	7.0	9.2	5.7	7.3	8.7	8.7	6.6	7.8
	LSD$^{(0.05)}$ *: Planting time ns; Variety 1.9; Planting time.Variety ns*									
Stalk wt. (kg)	Early	1.0	1.5	0.9	1.2	1.2	1.3	1.0	1.3	1.2
	Late	0.9	1.6	1.1	1.4	1.4	1.2	1.2	1.2	1.2
	Mean	0.9	1.5	1.0	1.3	1.3	1.2	1.1	1.2	1.2
	LSD$^{(0.05)}$ *: Planting time ns; Variety 0.2; Planting time.Variety ns*									
%MS	Early	85.5	83.8	80.6	85.5	85.7	86.6	84.7	82.2	84.3
	Late	81.7	83.2	80.6	86.5	86.3	84.7	83.7	79.9	83.3
	Mean	83.2	83.5	80.6	86.1	86.1	85.5	84.1	80.8	83.7
	LSD$^{(0.05)}$ *: Planting time 0.05; Variety 0.33; Planting time.Variety ns*									
Crop % DM	Early	29.3	32.2	28.4	33.6	31.3	31.0	31.8	30.5	31.0
	Late	31.0	33.3	27.2	31.7	31.2	31.1	30.7	29.9	30.8
	Mean	30.3	32.8	27.7	32.5	31.2	31.1	31.1	30.2	30.9
	LSD$^{(0.05)}$ *: Planting time ns; Variety 1.8; Planting time.Variety ns*									

As planting time only had a limited effect on plant crop performance, and its historical influence on the performance of the first ratoon crop was not significant, the planting time effect was excluded from further analyses. Data from the harvest on 27 July 2016 and 28 October 2016 was combined in order to allow a comparison of crops that were of similar age (12 months) but developed over different time periods (Aug-July and Dec-Nov). While these crops were both located at the same site, they experienced the environmental conditions at different stages of development (Figure 6.1).

Overall, a first ratoon crop that was ratooned early and harvested early had similar stalk population, stalk weight and percent millable stalk as a first ratoon crop that was ratooned late and harvested late (Table 6.8).

The early crop had significantly lower crop % dry matter at harvest than the late crop, most likely due to the crop not drying out as much through the autumn period compared to a crop that experienced a dry spring period. The variety effect was significant for all crop traits. Q231$^{\phi}$ had a high stalk population whereas Q183$^{\phi}$ and KQ228$^{\phi}$ were low. As is often found in sugarcane, stalk weight was negatively correlated with stalk population (Bell and Garside 2005), and Q231$^{\phi}$ had low stalk weights whereas Q232$^{\phi}$, Q183$^{\phi}$, Q208$^{\phi}$, Q219$^{\phi}$ and KQ228$^{\phi}$ were high. Q183$^{\phi}$ and Q231 had low percent millable stalk whereas Q208$^{\phi}$, KQ228$^{\phi}$ and Q219$^{\phi}$ were high. Q232$^{\phi}$ had high crop percent dry matter in comparison to many of the other varieties. The ratooning time.variety interaction was significant for both stalk weight and crop percent dry matter. This was due to Q241$^{\phi}$ and Q183$^{\phi}$ having significantly lower stalk weight in the late ratooning treatment whereas other varieties maintained similar stalk weights in the ratoon time treatments, and, Q231$^{\phi}$ had similar crop percent dry matter in the ratoon time treatments whereas other varieties had higher crop percent dry matter in the late ratoon treatment. This difference was also particularly evident for Q183$^{\phi}$.

Table 6.8 Traits for a first ratoon crop ratooned early or late at ~12 months after harvesting

Yield trait	Ratooning time	Variety								Mean
		Q241	Q232	Q231	KQ228	Q219	Q208	Q200	Q183	
Stalks/m^2	Early	9.0	8.7	10.3	8.1	8.5	8.7	9.6	6.3	8.6
	Late	9.4	7.0	9.2	5.7	7.3	8.7	8.7	6.6	7.8
	Mean	9.2	7.9	9.8	7.0	8.0	8.7	9.2	6.5	8.3
	LSD$^{(0.05)}$: Ratooning time ns; Variety 1.0; Ratooning time.Variety ns									
Stalk wt (kg)	Early	1.29	1.48	1.17	1.35	1.35	1.44	1.28	1.49	1.36
	Late	0.94	1.54	1.00	1.28	1.33	1.21	1.09	1.22	1.20
	Mean	1.13	1.51	1.10	1.32	1.34	1.34	1.19	1.37	1.29
	LSD$^{(0.05)}$: Ratooning time ns; Variety 0.17; Ratooning time.Variety 0.25									
%MS	Early	86.1	87.8	85.1	87.0	86.6	88.1	84.2	85.0	86.2
	Late	83.2	83.5	80.6	86.1	86.1	85.5	84.1	80.8	83.7
	Mean	84.8	85.8	83.0	86.6	86.4	86.9	84.2	83.1	85.1
	LSD$^{(0.05)}$: Ratooning time ns; Variety 2.0; Ratooning time.Variety ns									
Crop % DM	Early	25.8	28.4	26.4	27.7	26.4	26.6	28.2	23.9	26.7
	Late	30.3	32.8	27.7	32.5	31.2	31.1	31.1	30.2	30.9
	Mean	27.8	30.4	27.0	29.9	28.6	28.6	29.5	26.7	28.6
	LSD$^{(0.05)}$: Ratooning time 2.0; Variety 1.4; Ratooning time.Variety 2.0									

Crop dry biomass, cane yield, CCS and sugar yield were significantly affected by the different crop ratooning times. Significantly more biomass, cane yield and sugar yield was produced by the first ratoon crop that was ratooned early. In contrast, the crop that was ratooned late had significantly higher CCS despite similar crop age. This is associated with drying off like conditions that this crop experienced through spring and is also reflected in higher crop percent dry matter (Table 6.9). This result is similar to the plant crop. Lower crop yields for crops that commence later in the year are consistent with the findings of others (Lawes *et al.*., 2002; DiBella *et al., 2008, McDonald et al.*, 1999). It is most likely associated with rainfall leading to excessive soil wetness and low solar radiation during critical growth phases. Nutrient losses due to application later in the season may also play a role.

Significant variety effects were evident for crop dry biomass, cane yield, CCS and sugar yield. However, the ratooning time.variety interaction was not significant for any of these traits.
This suggest that poor crop performance associated with late ratooning, which is linked to adverse environmental conditions during early development, affected all varieties (present in this experiment) in a similar manner and any differences in their growth (stalk population development, speed of development, other), were either not large enough to effect the result or are not traits linked to better performance under these conditions.

In terms of sugar yield in the first ratoon crop, Q208$^{\phi}$, Q232$^{\phi}$ and Q200$^{\phi}$ were the better performers. Q232$^{\phi}$ achieved high sugar yield mainly through high cane yield as it had relatively low CCS. Its yield was associated with a smaller number of heavy stalks. Q200$^{\phi}$ achieved high sugar yield through relatively high cane yield and relatively high CCS. It produced a large number of light stalks. Q208$^{\phi}$ was between Q232$^{\phi}$ and Q200$^{\phi}$ for nearly all traits, and had the highest sugar yield at this site. This data highlights that different phenotypic pathways, that exist among current varieties, can all potentially lead to optimum production.

The presence of a time of ratooning effect in the first ratoon crop, that was consistent with previous research, suggest that the two climatic scenarios outlined previously were likely to have been experienced by the developing crops. However, the lack of any significant ratooning time.variety interaction suggests the hypothesis that varieties with quick development in excessively wet environment outperform others is false, or the variation among varieties in this experiment for this trait was not large enough for this effect to be shown, or the conditions experience by the late ratooning crop were not sufficiently severe.

Table 6.9 Biomass and yield for a first ratoon crop ratooned early or late at ~12 months after harvesting

Yield trait	Ratooning time	Variety								Mean
		Q241	Q232	Q231	KQ228	Q219	Q208	Q200	Q183	
Dry biomass (t/ha)	Early	28.0	36.0	29.3	29.1	31.7	32.1	34.3	23.6	30.5
	Late	26.4	34.3	24.7	22.3	26.4	29.9	28.7	23.4	27.0
	Mean	27.3	35.2	27.2	26.0	29.3	31.1	31.7	23.5	28.9
	LSD$^{(0.05)}$ *: Ratooning time 3.4; Variety 3.7; Ratooning time.Variety ns*									
TCH	Early	93.65	111.46	94.08	91.39	103.72	106.25	102.33	84.02	98.36
	Late	67.06	82.72	67.32	53.79	69.13	80.33	74.65	58.52	69.19
	Mean	81.57	98.40	81.91	74.30	88.00	94.47	89.75	72.43	85.10
	LSD$^{(0.05)}$ *: Ratooning time 11.3; Variety 9.1; Ratooning time.Variety ns*									
CCS	Early	13.6	12.7	13.6	14.5	12.3	13.7	14.1	13.4	13.5
	Late	15.4	15.3	16.5	17.5	16.1	16.6	16.1	16.4	16.2
	Mean	14.4	13.9	14.9	15.9	14.0	15.0	15.0	14.8	14.7
	LSD$^{(0.05)}$ *: Ratooning time 0.2; Variety 0.5; Ratooning time.Variety ns*									
TSH	Early	12.7	14.2	12.8	13.3	12.7	14.6	14.4	11.3	13.2
	Late	10.3	12.6	11.2	9.5	11.1	13.3	12.0	9.6	11.2
	Mean	11.6	13.5	12.0	11.6	12.0	14.0	13.3	10.5	12.3
	LSD$^{(0.05)}$ *: Ratooning time 1.4; Variety 1.7; Ratooning time.Variety ns*									

6.1.7 Second ratoon crop

The second ratoon crop was harvested on 31 July 2017 when the crop in early ratooning treatment was 323 DAH and the crop in the late treatment was 264 DAH. This was done to allow completion of the project. However, it confounds the comparison of harvest times due to a difference in crop age. This should be considered when assessing the following effects. Q200$^{\phi}$ and Q208$^{\phi}$ had significantly higher stalk population at harvest in comparison to other varieties particularly KQ228$^{\phi}$ which was low (Table 6.10). There was no ratooning time effect on stalk population, including the ratooning time.variety interaction. Stalk weight was significantly heavier for the early ratoon time, and significant differences were also evident among varieties. Q183$^{\phi}$ and Q232$^{\phi}$ produced heavier stalks than Q241$^{\phi}$, Q208$^{\phi}$ and Q200$^{\phi}$. Variety effects and a ratooning time.variety interaction were found for percent millable stalk. All varieties, except Q241$^{\phi}$, Q231$^{\phi}$, Q219$^{\phi}$ and Q200$^{\phi}$, had significantly higher percent millable stalk in the early ratooning treatment. Q232$^{\phi}$ and Q200$^{\phi}$ had high crop percent dry matter, particularly in comparison to Q183$^{\phi}$ and Q219$^{\phi}$.

Overall, ratooning time did not have a statistically significant effect on dry biomass, cane or sugar yield but CCS was higher in the early ratooning treatment than the late treatment (Table 6.11).

The difference in crop age may explain why this result differs from the observations in the plant and first ratoon crops, which were made when the crops were of similar age (~12 months).

Table 6.10 Traits for a second ratoon crop ratooned early or late

Yield trait	Ratooning time	Variety								Mean
		Q241	Q232	Q231	KQ228	Q219	Q208	Q200	Q183	
Stalks/m^2	Early	9.6	9.2	8.4	7.7	8.6	9.3	9.5	7.2	8.7
	Late	10.2	8.9	10.0	7.5	9.0	10.6	10.6	7.7	9.3
	Mean	9.9	9.1	9.2	7.6	8.8	9.9	10.1	7.5	9.0
	LSD$^{(0.05)}$: Ratooning time ns; Variety 0.8; Ratooning time.Variety ns									
Stalk wt (kg)	Early	1.11	1.46	1.03	1.33	1.38	1.29	1.29	1.56	1.30
	Late	0.83	1.12	0.93	1.02	1.14	0.94	0.97	1.22	1.02
	Mean	0.97	1.29	0.98	1.18	1.26	1.11	1.13	1.39	1.16
	LSD$^{(0.05)}$: Ratooning time 0.15; Variety 0.13; Ratooning time.Variety ns									
%MS	Early	87.3	91.7	83.1	88.3	85.8	89.6	86.8	87.4	87.5
	Late	84.7	86.4	83.2	85.3	84.9	85.1	82.7	85.8	84.8
	Mean	86.0	89.0	83.2	86.8	85.3	87.3	84.8	86.6	86.1
	LSD$^{(0.05)}$: Ratooning time ns; Variety 1.6; Ratooning time.Variety 2.9									
Crop % DM	Early	28.5	30.7	29.2	29.7	27.3	29.3	30.4	26.9	29.0
	Late	27.6	29.2	28.5	29.1	27.0	28.0	27.8	26.2	27.9
	Mean	28.1	30.0	28.9	29.4	27.2	28.7	29.1	26.5	28.5
	LSD$^{(0.05)}$: Ratooning time ns; Variety 1.7; Ratooning time.Variety ns									

Significant variety effects were found for all yield traits. Q232$^{\phi}$ and Q208$^{\phi}$ produced the highest biomass, cane and sugar yield, followed by Q200$^{\phi}$ and Q183$^{\phi}$. The ratooning time.variety interaction was significant for all yield traits. This differs from the plant and first ratoon crops, and may therefore be associated with the confounding factor of two different crop ages being compared. For dry biomass, the interaction effect was due to Q241$^{\phi}$, Q232$^{\phi}$ and Q200$^{\phi}$ having higher biomass in the early ratooning treatment than the late treatment, whereas biomass was similar in the two treatments for all other varieties. For cane yield, the interaction effect was due Q241$^{\phi}$ and Q232$^{\phi}$ having higher cane yield in the early than late treatment, whereas cane yield was similar in the two treatments for all other varieties. For CCS, the interaction effect was due to Q241$^{\phi}$ and Q219$^{\phi}$ having similar CCS in both ratooning treatments, whereas CCS has higher in the early treatment for all other varieties. Finally, for sugar yield, the interaction effect was due to Q232$^{\phi}$, Q208$^{\phi}$ and Q200$^{\phi}$ having significantly higher sugar yield in the early treatment, whereas sugar yield was similar in the two treatments for all other varieties.

The results from this experiment are largely inconclusive. In the plant crop, it is likely that the difference between treatments in terms of establishing two climatic scenarios, one of which experienced ideal growing conditions (early plant), and the other excessive rainfall early in development (late plant), was unsuccessful. Crop yields were very poor and no difference was found between planting times. This meant that it was not possible to assess whether any varieties, or particular growth patterns like fast establishment, were of any benefit in an excessively wet environment. The first ratoon crop showed a significant difference in crop yields due to ratooning time. This was consistent with previous research and indicated that the two climatic scenarios were likely to have been established, even in a below average rainfall season. However, a lack of any significant ratooning time.variety interactions for cane or sugar yield suggest that all varieties performed in a similar manner. This occurred despite some differences in varieties phenotypic traits. The better performing varieties at the site (Q208$^{\phi}$, Q232$^{\phi}$ and Q200$^{\phi}$) had variable combinations of stalk population, stalk weight, percent millable stalk and CCS. This suggests that there is a relatively wide range of phenotypes associated with optimum crop performance, even when excessive rainfall is experienced relatively early in development.

The second ratoon crop data was confounded with crop age. If anything, the ratooning time.variety interactions in the second ratoon crop show the better performing varieties achieving significantly higher yields in the early treatment than the late treatment, rather than any variety showing significantly better performance in the late treatment. Given these results, we can't conclude that there is a link between fast crop establishment and crop performance in excessively wet environments. Some factors that may have contributed to this outcome were: the trial was conducted during a period of below average rainfall seasons and not experience an above average rainfall season; while the varieties showed variable growth patterns this variability may not have been large enough or does not exist within commercially viable sugarcane varieties.

Table 6.11 Biomass and yield for a second ratoon crop ratooned early or late

Yield trait	Ratooning time	Variety								Mean
		Q241	Q232	Q231	KQ228	Q219	Q208	Q200	Q183	
Dry biomass (t/ha)	Early	30.9	38.0	25.7	27.4	29.2	32.9	32.3	29.1	30.7
	Late	22.7	27.6	26.4	22.3	23.8	27.7	25.0	24.7	25.0
	Mean	26.8	32.8	26.0	24.9	26.5	30.3	28.7	26.9	27.9
	$LSD^{(0.05)}$: Ratooning time ns; Variety 3.2; Ratooning time.Variety 6.6									
TCH	Early	83.8	101.9	65.1	73.2	87.5	94.0	86.4	84.4	84.5
	Late	63.0	72.3	70.3	58.6	70.2	78.0	67.0	72.4	69.0
	Mean	73.4	87.1	67.7	65.9	78.8	86.0	76.7	78.4	76.7
	$LSD^{(0.05)}$: Ratooning time ns; Variety 8.5; Ratooning time.Variety 20.0									
CCS	Early	11.4	11.4	12.8	12.7	11.4	12.2	12.3	12.2	12.0
	Late	11.5	10.8	11.9	12.1	11.3	11.5	11.5	11.5	11.5
	Mean	11.4	11.1	12.4	12.4	11.3	11.9	11.9	11.9	11.8
	$LSD^{(0.05)}$: Ratooning time 0.24; Variety 0.54; Ratooning time.Variety 0.60									
TSH	Early	9.5	11.6	8.3	9.3	10.0	11.4	10.7	10.3	10.1
	Late	7.2	7.8	8.4	7.1	7.9	9.0	7.7	8.3	7.9
	Mean	8.4	9.7	8.4	8.2	9.0	10.2	9.2	9.3	9.0
	$LSD^{(0.05)}$: Ratooning time ns; Variety 1.0; Ratooning time.Variety 2.4									

It is also worth noting that despite using released varieties, the difference in sugar yield between the top performing variety and the poorest performing variety was approximately 20 % (higher in the plant cane crop). This highlights the importance of growing the right variety on the right block, and the potential penalty for getting this decision incorrect. It suggests greater effort could be placed on optimising variety performance after release, and that this could result in an industry benefit.

6.2 Field waterlogging experiment

6.2.1 Stalk population development

Stalk counts were conducted during the development of the plant crop (Figure 6.6). Analysis of this data using a repeated measure procedure in GenStat v16.1 showed highly significant ($P<0.01$) treatment.time and variety.time interactions as well as a significant ($P<0.05$) treatment.variety.time interaction.

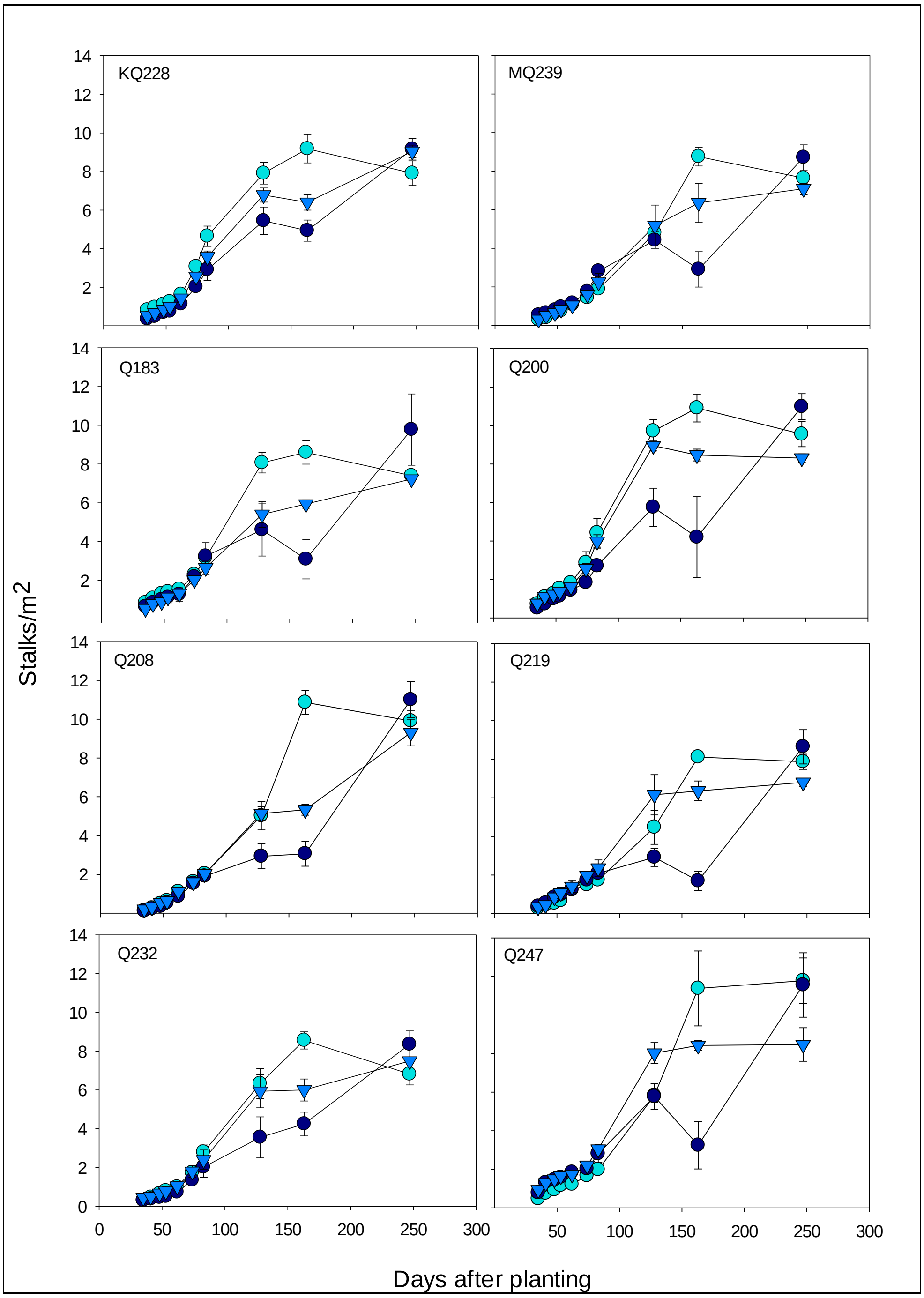


Figure 6.6 Stalk population development for eight varieties in control (●), waterlogged early (●) and waterlogged late (▼) treatments

This complex interaction was mostly associated with the last three stalks counts following the imposition of waterlogging treatments (Figure 6.7). In control plots, KQ228$^{\phi}$, Q200$^{\phi}$ and Q182$^{\phi}$ initially had the highest stalk populations. Between 128 and 163 DAP, Q208$^{\phi}$ and Q247$^{\phi}$ developed significantly more shoots than other varieties and had a similar stalk population to Q200$^{\phi}$.
The ranking of varieties remained stable from that point. In the early waterlogging treatment, the stalk population of most varieties declined between 128 and 163 DAP. This was particularly evident in Q247$^{\phi}$ and Q219$^{\phi}$, whereas Q232$^{\phi}$ and Q208$^{\phi}$ maintained stalk numbers in this period. Stalk populations increased after 163 DAP, due to significant suckering, most likely associated with the lack of a crop canopy following waterlogging and increased light availability. In the late waterlogging treatment, stalk populations mostly remained stable between 128 and 163 DAP.

This differed from the control where the stalk population of some varieties was still increasing. Q208$^{\text{\textphi}}$ and KQ228$^{\text{\textphi}}$ stalk populations increased between 163 and 247 DAP, possibly also associated with suckering.

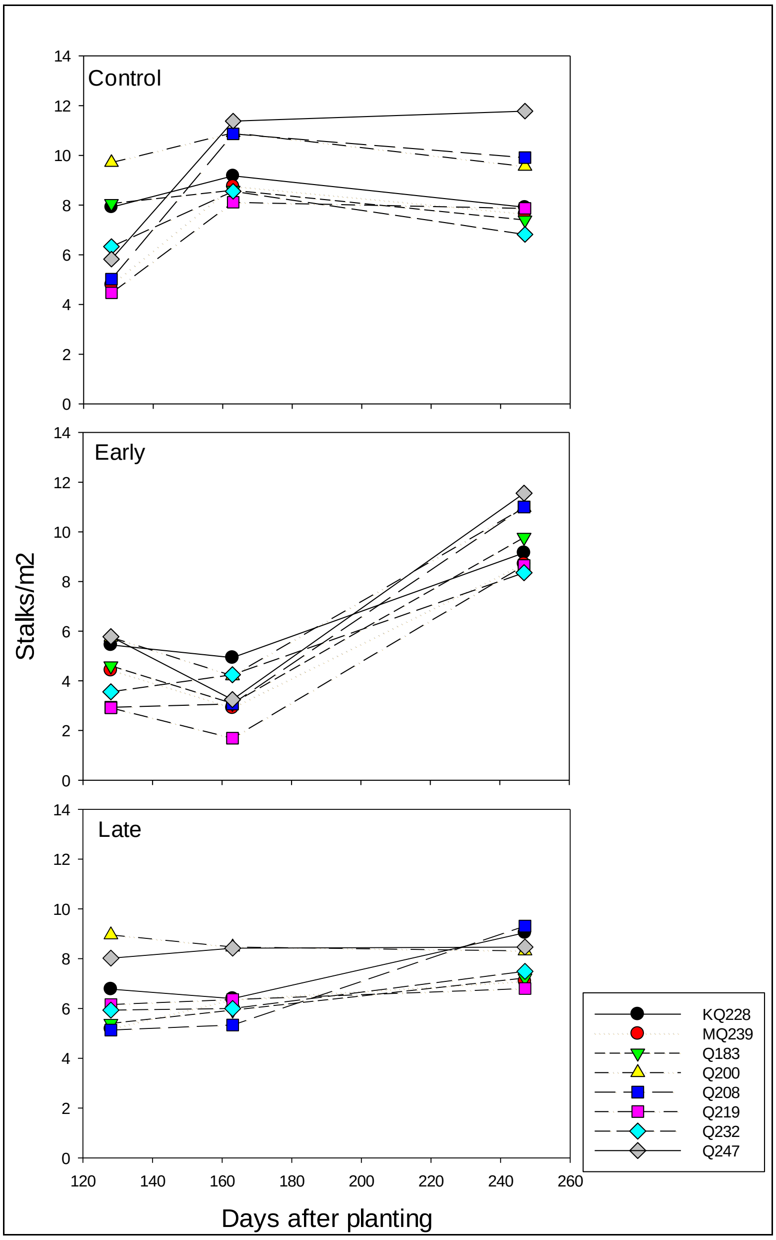


Figure 6.7 Stalk populations of eight varieties between 129 and 247 days after planting in three treatments: Control (top); Early waterlogging (middle) and Late waterlogging (bottom)

Stalks counts were also taken in the ratoon crop on 30 November 2016, prior to 2016-2017 treatments being imposed (Table 6.12). Any treatments effects at this stage were a carry-over from waterlogging of the plant crop. Stalk populations for each variety tended to be similar across treatments, however, Q200$^{\text{\textphi}}$ showed significantly fewer stalks in the early treatment than the control and Q219$^{\text{\textphi}}$ and Q183$^{\text{\textphi}}$ had significantly higher stalk population in the early treatment than the control.

Table 6.12 Stalk population of eight varieties in a waterlogging experiment near Ingham on 30 November 2016

Variety	Waterlogging treatment			Mean
	Control	Early	Late	
KQ228	12.7	13.1	14.1	13.3
MQ239	12.2	13.0	13.0	12.7
Q183	9.0	12.4	10.1	10.5
Q200	14.6	10.4	12.8	12.6
Q208	6.4	7.7	8.6	7.6
Q219	8.0	10.4	10.6	9.7
Q232	10.5	10.4	10.5	10.5
Q247	11.4	13.3	14.1	12.9
Mean	10.6	11.3	11.7	
LSD$^{(0.05)}$: Variety 1.39; Treatment ns; VxT 2.4				

6.2.2 Biomass

There were significant differences in fresh biomass, dry biomass and cane yield among treatments and varieties (Table 6.13) 244 DAP. However, the treatment.variety interaction was not significant for any trait at this time. The early waterlogging treatment had lower biomass and cane yield than the control and late waterlogging treatments. There was no difference between the control and late waterlogging treatments, possibly due to dry conditions during February which favoured growth in the late waterlogging treatment over the control as it was likely to have had more available moisture in the soil profile.

Table 6.13 Biomass (fresh and dry) and cane yield 244 DAP at the Ingham waterlogging trial

Treatment	Variety	Fresh biomass (t/ha)	Dry biomass (t/ha)	Cane yield (t/ha)
Control	KQ228	76.8	12.8	55.5
	MQ239	79.6	14.2	59.4
	Q183	92.5	15.7	70.2
	Q200	81.8	13.9	58.6
	Q208	73.7	13.1	55.4
	Q219	69.5	11.1	54.0
	Q232	88.2	16.5	68.1
	Q247	82.4	13.4	57.7
	Mean	80.6	13.8	59.9
Early	KQ228	41.5	5.9	26.7
	MQ239	34.8	6.4	21.9
	Q183	45.8	7.2	28.7
	Q200	39.8	6.5	25.8
	Q208	41.0	6.9	28.2
	Q219	25.4	3.9	16.9
	Q232	51.5	8.3	33.4
	Q247	31.2	5.7	17.6
	Mean	38.9	6.3	24.9
Late	KQ228	72.5	12.5	54.5
	MQ239	82.6	17.5	63.4
	Q183	77.9	14.4	60.1
	Q200	90.1	17.9	68.5
	Q208	70.8	12.8	54.8
	Q219	66.2	11.2	51.0
	Q232	87.2	19.1	66.5
	Q247	77.6	17.0	56.1
	Mean	78.1	15.3	59.4
LSD (0.05) treatment		37.0	5.3	27.7

6.2.3 Relative water content

No difference in RWC was found between waterlogging treatments at 152 DAH (Table 6.14). Some significant differences were found among varieties, with Q232$^{\Phi}$ having significantly higher RWC than many varieties and Q247$^{\Phi}$ having significantly lower RWC than many varieties. The treatment.variety interaction was not significant. Waterlogging stress can be similar to drought stress due to the impairment of the root system and inability to take up water. Symptoms include wilting, which should result in changes to RWC. The lack of any differences in this experiment at 152 DAH may be associated with recovery from waterlogging stress in the early treatment following drainage, ability of more advanced cane to withstand waterlogging stress or slower development of stress in advanced cane in the late treatment, or the sampling procedure was not sufficient in order to identify any differences in RWC due to treatments.

Table 6.14 Relative water content of eight sugarcane varieties 152 DAH. Assessment made following early waterlogging treatment and during the late waterlogging treatment

Variety	Waterlogging treatment			
	Control	Early	Late	Mean
KQ228$^{\Phi}$	0.931	0.898	0.926	0.918
MQ239$^{\Phi}$	0.913	0.917	0.920	0.916
Q183$^{\Phi}$	0.929	0.886	0.933	0.916
Q200$^{\Phi}$	0.932	0.935	0.938	0.935
Q208$^{\Phi}$	0.942	0.916	0.931	0.930
Q219$^{\Phi}$	0.922	0.898	0.916	0.912
Q232$^{\Phi}$	0.942	0.943	0.941	0.942
Q247$^{\Phi}$	0.906	0.873	0.897	0.892
Mean	0.927	0.908	0.925	0.920

LSD$^{(0.05)}$Treatment ns; Variety 0.02; Treatment.Variety ns

6.2.4 Aerial root assessment

The extent of aerial roots and the number of above ground nodes containing aerial roots were increased by both early and late waterlogging treatments (Table 6.15). The development of adventitious roots at the soil/ water surface (Figure 6.8) is a well-known waterlogging tolerance response in order for the root system to acquire oxygen. Some varieties developed aerial roots higher up the stem, particularly MQ239$^{\Phi}$ and Q183$^{\Phi}$. However, the treatment.variety interaction was not significant, which indicates that the response was similar for all varieties.

Table 6.15 Rating for the degree of aerial roots and number of nodes with aerial roots

Variety	Aerial root rating				No. nodes with aerial roots			
	Control	Early	Late	Mean	Control	Early	Late	Mean
KQ228	1.7	2.8	3.0	2.5	1.1	1.9	2.1	1.7
MQ239	1.8	2.9	2.8	2.5	2.2	3.2	2.5	2.6
Q183	1.8	3.0	3.0	2.6	1.9	3.5	2.5	2.6
Q200	1.5	3.0	3.0	2.5	0.5	2.8	1.9	1.7
Q208	1.5	3.0	3.0	2.5	0.6	2.2	2.2	1.6
Q219	1.8	2.9	3.0	2.5	1.0	2.5	2.2	1.9
Q232	1.5	2.8	2.8	2.4	1.0	1.4	2.1	1.5
Q247	1.8	3.0	3.0	2.6	1.0	3.3	2.3	2.2
Mean	1.7	2.9	2.9	2.5	1.2	2.6	2.2	2.0
LSD$^{(0.05)}$: Variety ns; Treatment 0.16, V.T ns					Variety 0.5; Treatment 0.5; V.T ns			

Figure 6.8 Adventitious rooting on the soil surface under waterlogging conditions at the Ingham trial site

6.2.5 Crop traits at harvest

6.2.5.1 Plant crop

Waterlogging treatments had no overall effect on stalk numbers at final harvest of the plant crop (Table 6.16), despite the temporal changes in stalk populations during the waterlogging periods (Figure 6.6). Variety effects were evident with Q247$^{\Phi}$, Q208$^{\Phi}$ and Q200$^{\Phi}$ having significantly higher stalk population than some other varieties (Table 6.16). A treatment.variety interaction was only evident when control and late treatments were analysed separately. This was associated with Q183$^{\Phi}$, Q200$^{\Phi}$ and Q208$^{\Phi}$ having significantly lower stalk population in the late waterlogging treatment in comparison to controls. Whereas other varieties had similar stalk populations in these two treatments at final harvest.

Waterlogging treatments had a significant effect on stalk weight at final harvest of the plant crop. The early treatment had significantly smaller stalks than both the control and late treatments. Variety effects were also evident with Q232$^{\Phi}$ and MQ230$^{\Phi}$ having significantly heavier stalk than many other varieties. The treatment.variety interaction was not significant.

Percent millable stalk was significantly higher in the control and late treatments than the early waterlogging treatment. Q208$^{\Phi}$ and Q219$^{\Phi}$ had high percent millable stalk whereas MQ239$^{\Phi}$ and Q247$^{\Phi}$ were low. These differences are often an indication of maturity in the crop with percent millable stalk increasing as the canopy declines. Values can be distorted by side shooting following flowering. No treatment. Variety interaction was evident for this crop trait at final harvest of the plant crop.

The late treatment had significantly higher crop percent dry matter than the control, and significant variety effects were also evident with Q200$^{\Phi}$ having higher dry matter content than Q208$^{\Phi}$, Q219$^{\Phi}$ and Q247$^{\Phi}$. No significant interaction effects were evident.

Table 6.16 Plant crop traits at harvest

Yield trait	Waterlogging Treatment	Variety								Mean
		KQ228	MQ239	Q183	Q200	Q208	Q219	Q232	Q247	
Stalks/m^2	Control	7.4	6.8	7.2	9.3	9.6	6.9	6.3	9.5	7.9
	Early	8.1	7.6	6.3	7.9	8.9	6.9	7.2	9.1	7.8
	Late	6.6	7.1	5.3	7.6	7.3	6.9	6.2	8.4	6.9
	Mean	7.4	7.2	6.3	8.3	8.6	6.9	6.6	9.0	7.5
	LSD $^{(0.05)}$: Treatment ns; Variety 0.7; Treatment.Variety ns									
	LSD $^{(0.05)}$ Control vs Early: Treatment ns; Variety 1.0; Treatment.Variety ns									
	LSD $^{(0.05)}$ Control vs Late: Treatment 0.46; Variety 0.75; Treatment.Variety 1.1									
Stalk wt (kg)	Control	1.7	1.6	1.6	1.4	1.3	1.3	1.9	1.3	1.5
	Early	1.0	1.2	1.2	0.9	1.0	0.9	1.4	0.9	1.1
	Late	1.3	1.7	1.4	1.1	1.2	1.4	2.0	1.1	1.4
	Mean	1.3	1.5	1.4	1.1	1.1	1.2	1.8	1.1	1.3
	LSD $^{(0.05)}$: Treatment 0.16; Variety 0.15; Treatment.Variety ns									
	LSD $^{(0.05)}$ Control vs Early: Treatment 0.20; Variety 0.18; Treatment.Variety ns									
	LSD $^{(0.05)}$ Control vs Late: Treatment ns; Variety 0.20; Treatment.Variety ns									
%MS	Control	88.5	85.8	86.1	89.3	88.1	88.0	88.4	85.0	87.4
	Early	81.9	80.7	82.0	81.4	84.5	82.7	84.6	78.9	82.1
	Late	85.6	84.8	85.3	84.5	89.7	88.0	84.3	84.3	85.8
	Mean	85.3	83.8	84.5	85.1	87.4	86.2	85.8	82.7	85.1
	LSD $^{(0.05)}$: Treatment 2.6; Variety 2.1; Treatment.Variety ns									
	LSD $^{(0.05)}$ Control vs Early: Treatment 5.1; Variety 2.6; Treatment.Variety ns									
	LSD $^{(0.05)}$ Control vs Late: Treatment 0.62; Variety 2.4; Treatment.Variety ns									
Crop % DM	Control	27.0	29.7	28.9	28.6	27.3	26.5	27.8	28.6	28.0
	Early	30.0	29.4	28.7	30.4	27.0	27.6	26.9	27.7	28.4
	Late	30.9	29.1	29.4	31.1	29.0	28.1	31.7	28.3	29.7
	Mean	29.3	29.4	29.0	30.0	27.8	27.4	28.8	28.2	28.7
	LSD $^{(0.05)}$: Treatment 1.4; Variety 1.6; Treatment.Variety ns									
	LSD $^{(0.05)}$ Control vs Early: Treatment ns; Variety ns; Treatment.Variety ns									
	LSD $^{(0.05)}$ Control vs Late: Treatment ns; Variety ns; Treatment.Variety ns									

6.2.5.2 First ratoon

Overall waterlogging treatments had no effect on stalk population at final harvest of the first ratoon crop (Table 6.17). Variety effects were evident with Q247$^{\Phi}$ and Q200$^{\Phi}$ having significantly higher stalk numbers than some other varieties, and Q183$^{\Phi}$ having the lowest stalk numbers. These results are similar to those observed in the plant crop. No treatment.variety interactions were found.

As was the case in the plant crop, stalk weight was reduced in the early waterlogging treatment and no difference was found between the control and late treatments. Variety effects were generally inversely related to stalk population, with Q200$^{\Phi}$ and Q247$^{\Phi}$ having low stalk weights. This has been reported previously in sugarcane (Bell and Garside 2005). No significant treatment.variety interactions were found.

Percent millable stalk at final harvest of the first ratoon crop was not affected by waterlogging treatments. Q208$^{\Phi}$ and MQ239$^{\Phi}$ had higher percent millable stalk than Q247$^{\Phi}$ and Q232$^{\Phi}$.
No significant treatment.variety interactions were found.

Crop percent dry matter was not affected by waterlogging treatments at final harvest of the first ratoon crop. MQ239$^{\Phi}$ and Q232$^{\Phi}$ had significantly higher percent dry matter than Q183$^{\Phi}$ and Q247$^{\Phi}$. No significant treatment.variety interactions were found.

Table 6.17 First ratoon crop traits at harvest

Yield trait	Waterlogging Treatment	Variety								Mean
		KQ228	MQ239	Q183	Q200	Q208	Q219	Q232	Q247	
Stalks/m^2	Control	7.6	8.0	6.3	9.8	7.1	7.1	7.6	7.9	7.7
	Early	9.2	8.7	7.2	9.2	7.6	7.2	8.9	9.2	8.4
	Late	8.2	8.3	6.2	9.8	8.3	8.2	7.9	10.1	8.4
	Mean	8.3	8.3	6.6	9.6	7.6	7.5	8.1	9.1	8.1
	LSD $^{(0.05)}$: Treatment ns; Variety 0.9; Treatment.Variety ns									
	LSD $^{(0.05)}$ Control vs Early: Treatment ns; Variety 1.0; Treatment.Variety ns									
	LSD $^{(0.05)}$ Control vs Late: Treatment ns; Variety 1.02; Treatment.Variety ns									
Stalk wt (kg)	Control	1.1	1.3	1.2	0.8	1.2	1.2	1.3	0.9	1.1
	Early	0.8	0.8	1.0	0.6	0.8	0.9	0.9	0.5	0.8
	Late	1.0	1.3	1.3	0.9	0.9	1.1	1.1	0.9	1.1
	Mean	1.0	1.1	1.2	0.8	1.0	1.1	1.1	0.8	1.0
	LSD $^{(0.05)}$: Treatment 0.12; Variety 0.13; Treatment.Variety ns									
	LSD $^{(0.05)}$ Control vs Early: Treatment 0.26; Variety 0.18; Treatment.Variety ns									
	LSD $^{(0.05)}$ Control vs Late: Treatment 0.08; Variety 0.17; Treatment.Variety ns									
%MS	Control	83.5	84.4	81.8	83.1	86.6	85.5	82.0	80.6	83.4
	Early	81.2	82.1	79.1	81.0	84.6	79.4	79.3	76.5	80.4
	Late	84.0	83.7	82.9	81.7	83.1	82.8	80.8	79.9	82.4
	Mean	82.9	83.4	81.3	81.9	84.8	82.5	80.7	79.0	82.1
	LSD $^{(0.05)}$: Treatment ns; Variety 1.9; Treatment.Variety ns									
	LSD $^{(0.05)}$ Control vs Early: Treatment ns; Variety 2.3; Treatment.Variety ns									
	LSD $^{(0.05)}$ Control vs Late: Treatment ns; Variety 1.0; Treatment.Variety ns									
Crop % DM	Control	30.5	32.6	28.5	31.6	29.3	28.4	30.6	29.2	30.1
	Early	30.4	32.3	29.9	29.3	30.7	28.8	32.3	30.5	30.5
	Late	29.6	31.3	29.5	31.6	31.1	28.2	32.5	29.7	30.4
	Mean	30.2	32.1	29.3	30.8	30.4	28.5	31.8	29.8	30.3
	LSD $^{(0.05)}$: Treatment ns; Variety 1.6; Treatment.Variety ns									
	LSD $^{(0.05)}$ Control vs Early: Treatment ns; Variety 2.2; Treatment.Variety ns									
	LSD $^{(0.05)}$ Control vs Late: Treatment ns; Variety 1.5; Treatment.Variety ns									

6.2.5.3 Nitrogen uptake and NUE

Overall, the N concentration of leaf and cabbage and millable stalk at harvest of the first ratoon crop was not affected by waterlogging treatments (Table 6.18). However, a significant treatment.variety interaction was evident for leaf and cabbage N concentration. This was associated with Q183$^{\Phi}$ having significantly lower N concentration in the control than the early treatment whereas Q232$^{\Phi}$ had significantly higher N concentration in the leaf and cabbage of control treatments than the early and late treatments. Q219$^{\Phi}$ had significantly higher N concentration in the leaf and cabbage of the early treatment than the late treatment. These differences are not easily explained and may be of little consequence. Some varieties had higher tissue N concentration and total crop N content than others. Q219$^{\Phi}$ and KQ228$^{\Phi}$ and Q183$^{\Phi}$ had high N concentration in millable stalk. Q232$^{\Phi}$ Q219$^{\Phi}$, KQ228$^{\Phi}$ and MQ239$^{\Phi}$ accumulated high total N content in the above ground biomass. MQ239$^{\Phi}$ and Q200$^{\Phi}$ accumulated significantly more total crop N in the control and late treatments than the early treatment. Whereas Q247$^{\Phi}$ had significantly higher total crop N in the late treatment in comparison to the early treatment. There was no effect of treatments or varieties on nitrogen utilisation efficiency.

Table 6.18 Crop leaf and cabbage (LC) and millable stalk (MS) percent N concentration, total crop N content (kg/ha) and nitrogen utilisation efficiency (tc/kg crop N) of the first ratoon crop of eight varieties subjected to waterlogging treatments

Trait	Treatment	KQ228	MQ239	Q183	Q200	Q208	Q219	Q232	Q247	Mean
LC% N	Control	0.51	0.54	0.51	0.56	0.64	0.64	0.70	0.59	0.58
	Early	0.55	0.61	0.63	0.63	0.65	0.69	0.56	0.63	0.62
	Late	0.52	0.62	0.54	0.60	0.60	0.59	0.56	0.68	0.59
	Mean	0.52	0.59	0.56	0.59	0.63	0.64	0.61	0.63	0.60
	LSD $^{(0.05)}$: Treatment ns; Variety 0.06; Treatment.Variety 0.1									
MS%	Control	0.16	0.12	0.16	0.12	0.13	0.18	0.11	0.11	0.14
	Early	0.14	0.13	0.18	0.14	0.16	0.21	0.10	0.13	0.15
	Late	0.19	0.14	0.15	0.15	0.14	0.16	0.11	0.10	0.14
	Mean	0.16	0.13	0.16	0.13	0.14	0.18	0.10	0.11	0.14
	LSD $^{(0.05)}$: Treatment ns; Variety 0.02; Treatment.Variety ns									
Total Crop N (kg/ha)	Control	52.7	54.9	46.4	46.5	46.7	55.8	59.0	39.9	50.3
	Early	47.0	39.4	43.5	29.9	34.6	47.3	49.2	29.4	40.0
	Late	53.2	60.7	46.3	55.1	43.6	54.1	54.7	50.0	52.2
	Mean	51.0	51.7	45.4	43.8	41.7	52.4	54.3	39.8	47.5
	LSD $^{(0.05)}$: Treatment ns; Variety 5.5; Treatment.Variety 12.8									
N utilisation efficiency (tc/kg crop N)	Control	1.28	1.51	1.31	1.41	1.58	1.30	1.32	1.44	1.39
	Early	1.24	1.23	1.01	1.31	1.20	0.94	1.26	1.09	1.16
	Late	1.21	1.34	1.32	1.17	1.27	1.33	1.28	1.29	1.28
	Mean	1.24	1.36	1.21	1.30	1.35	1.19	1.29	1.27	1.28
	LSD $^{(0.05)}$: Treatment ns; Variety ns; Treatment.Variety ns									

6.2.6 Yield

6.2.6.1 Plant crop

Sugarcane dry biomass, cane yield, CCS and sugar yield at final harvest of the plant crop are shown in Table 19. Waterlogging had a significant negative effect on crop biomass, cane yield and sugar yield. The early treatment produced significantly lower cane and sugar yield than the late treatment. The difference between the early and late treatments may also have been associated with time spent under waterlogging conditions, however, observations from the site were that symptoms took longer to develop and were less severe when waterlogging was imposed later in development. The loss of 35.9 tc/ha (37 % loss) due to an early waterlogging event which was imposed for 35 days, suggests a loss of 1 tc/ha/day. This can be compared to work by Roach and Mullins which suggested a loss of 0.5 tc/ha/day when the water-table was within 50 cm of the soil surface (Rudd and Chardon 1977). The difference could potentially be explained by more severe conditions in this experiment as the water-table was maintained at or slightly above the soil surface, and given the time for the soil profile to drain, the stress would have been experienced for longer than the 35 day period. In the late treatment, 15.8 tc/ha (16.3 % loss) was lost due to a waterlogging event which was imposed for 19 days. This resulted in a slightly reduced loss of 0.83 tc/ha/day. The impact of early waterlogging events on young plant cane clearly causes very large reductions in yield. Planting poorly drained blocks as early as possible should reduce the risk and also the severity of impact if an early waterlogging event occurred.

The treatment.variety interaction was significant for cane and sugar yield (Table 6.19), and was mostly associated with varying performance of varieties when subjected to the late waterlogging treatment. All varieties performed poorly when waterlogging was imposed early. MQ239$^{\Phi}$, Q247$^{\Phi}$, Q219$^{\Phi}$ and to a lesser extent Q232$^{\Phi}$ achieved similar yield in the control and late waterlogging treatments whereas all other varieties showed a significant decline. This suggests that these varieties are more tolerant, but this tolerance isn't present when crops are very young.

Crop CCS was not affected by waterlogging treatments. MQ239$^{\Phi}$, Q219$^{\Phi}$ and Q232$^{\Phi}$ had lower CCS than KQ228$^{\Phi}$, Q208$^{\Phi}$ and Q247$^{\Phi}$.

Table 6.19 Plant crop biomass, cane yield, CCS and sugar yield at final harvest

Yield trait	Waterlogging Treatment	Variety								Mean
		KQ228	MQ239	Q183	Q200	Q208	Q219	Q232	Q247	
Dry biomass (t/ha)	Control	30.9	31.3	32.0	32.6	32.0	24.5	35.1	30.3	31.1
	Early	23.3	24.4	19.9	20.2	20.7	15.6	25.4	19.0	21.0
	Late	26.0	32.2	22.7	28.2	24.9	27.1	35.2	28.3	28.1
	Mean	26.7	29.3	24.9	27.0	25.9	22.4	31.9	25.9	26.7
	LSD $^{(0.05)}$ *:Treatment 3.1; Variety 3.6; Treatment.Variety ns*									
	LSD $^{(0.05)}$ *:Control vs Early: Treatment 6.4; Variety 4.6; Treatment.Variety ns*									
	LSD $^{(0.05)}$ *:Control vs Late: Treatment ns; Variety 4.7; Treatment.Variety ns*									
TCH	Control	100.5	90.3	95.4	101.7	103.6	81.3	112.4	90.2	96.9
	Early	63.5	66.8	57.2	54.9	64.4	46.8	80.7	53.9	61.0
	Late	72.1	94.3	66.2	76.7	77.1	84.7	93.0	84.6	81.1
	Mean	78.7	83.8	72.9	77.8	81.7	70.9	95.4	76.2	79.7
	LSD $^{(0.05)}$ *:Treatment 14.3; Variety 9.3; Treatment.Variety 18.7*									
	LSD $^{(0.05)}$ *:Control vs Early: Treatment 29.7; Variety 11.9; Treatment.Variety ns*									
	LSD $^{(0.05)}$ *:Control vs Late: Treatment ns; Variety 11.6; Treatment.Variety 19.5*									
CCS	Control	16.1	14.8	15.4	16.2	15.1	14.6	14.2	16.1	15.3
	Early	16.1	14.7	14.8	15.3	15.0	14.7	14.3	15.4	15.0
	Late	15.8	14.4	15.5	16.6	16.3	14.8	14.7	16.3	15.6
	Mean	16.0	14.7	15.2	16.0	15.5	14.7	14.4	16.0	15.3
	LSD $^{(0.05)}$ *:Treatment ns; Variety 0.5; Treatment.Variety ns*									
	LSD $^{(0.05)}$ *:Control vs Early: Treatment ns; Variety 0.6; Treatment.Variety ns*									
	LSD $^{(0.05)}$ *:Control vs Late: Treatment 0.2; Variety 0.6; Treatment.Variety ns*									
TSH	Control	16.2	13.4	14.8	16.4	15.7	11.8	15.9	14.6	14.8
	Early	10.3	9.8	8.5	8.5	9.6	7.0	11.5	8.3	9.2
	Late	11.4	13.5	10.3	12.7	12.6	12.6	13.7	13.8	12.6
	Mean	12.6	12.3	11.2	12.6	12.6	10.4	13.7	12.2	12.2
	LSD $^{(0.05)}$ *:Treatment 2.6; Variety 1.4; Treatment.Variety 3.1*									
	LSD $^{(0.05)}$ *:Control vs Early: Treatment 5.4; Variety 1.8; Treatment.Variety ns*									
	LSD $^{(0.05)}$ *:Control vs Late: Treatment ns; Variety 1.8; Treatment.Variety 3.0*									

6.2.6.2 First ratoon crop

In the first ratoon crop, biomass, cane and sugar yield were reduced in the early waterlogging treatment but not the late waterlogging treatment (Table 6.20). The loss of 23.7 tc/ha (34 % loss) due to an early waterlogging event which was imposed for 49 days, suggests a loss of 0.48 tc/ha/day. Sugarcane ratoon crops develop more quickly than plant cane and it was noted that the crop was more advanced when the early treatment was imposed. The length of time the crop was exposed to waterlogging was increased due to slow development of symptoms. In addition to this, the lack of any overall difference between the control and late treatments also suggests that more advanced development of sugarcane assists its tolerance to waterlogging. It is known that stage of development influences tolerance. Gomathi et al. (2015) suggested that sugarcane is most susceptible in the first 3-4 months of development and comparatively tolerant at 5 - 9 months of age.

The treatment.variety interaction was significant for crop biomass, cane and sugar yield at harvest of the first ratoon crop. This interaction was associated with KQ228$^{\phi}$ performing relative well in the early treatment whereas all other varieties showed a significant loss of yield, and the relative poor performance of Q208$^{\phi}$ in the late treatment whereas all other varieties had similar yields in the control and late treatments. Results like this may explain why ratings for waterlogging tolerance in QCANESelectTM can varying among regions.

The crop stage when waterlogging is experienced, whether it is plant or ratoon cane, the severity of waterlogging all have an effect on crop response.

Crop CCS was not affected by waterlogging treatments. MQ239$^{\phi}$, Q219$^{\phi}$ and Q232$^{\phi}$ had lower CCS than Q247$^{\phi}$, Q200$^{\phi}$ and KQ228$^{\phi}$.

Table 6.20. First ratoon crop biomass, cane yield, CCS and sugar yield at final harvest

Yield trait	Waterlogging Treatment	Variety								Mean
		KQ228	MQ239	Q183	Q200	Q208	Q219	Q232	Q247	
Dry biomass (t/ha)	Control	24.4	31.6	21.2	24.9	24.5	23.9	29.0	20.6	25.0
	Early	21.5	19.0	16.5	13.3	15.0	16.0	24.9	12.5	17.3
	Late	22.2	30.1	21.7	24.7	20.5	23.9	28.2	23.8	24.4
	Mean	22.7	26.9	19.8	21.0	20.0	21.3	27.3	19.0	22.2
	LSD $^{(0.05)}$:Treatment 4.1; Variety 2.1; Treatment.Variety 4.7									
	LSD $^{(0.05)}$:Control vs Early: Treatment 8.5; Variety 2.9; Treatment.Variety 6.5									
	LSD $^{(0.05)}$:Control vs Late: Treatment ns; Variety 2.7; Treatment.Variety ns									
TCH	Control	66.8	81.7	60.9	65.5	72.7	71.8	77.9	56.8	69.2
	Early	56.9	48.1	43.6	36.9	41.5	44.5	61.0	31.3	45.5
	Late	63.0	80.8	60.8	64.2	54.5	70.3	70.0	64.0	66.0
	Mean	62.2	70.2	55.1	55.5	56.2	62.2	69.6	50.7	60.2
	LSD $^{(0.05)}$:Treatment 10.9; Variety 5.0; Treatment.Variety 12.0									
	LSD $^{(0.05)}$:Control vs Early: Treatment 21.9; Variety 6.2; Treatment.Variety 16.6									
	LSD $^{(0.05)}$:Control vs Late: Treatment ns; Variety 6.1; Treatment.Variety 13.5									
CCS	Control	12.5	11.2	12.6	12.8	12.5	11.8	11.8	13.3	12.3
	Early	12.8	11.5	12.2	12.6	12.6	11.5	12.1	13.0	12.3
	Late	12.2	11.5	12.3	12.5	12.2	11.4	11.7	13.3	12.2
	Mean	12.5	11.4	12.4	12.6	12.4	11.5	11.9	13.2	12.2
	LSD $^{(0.05)}$:Treatment ns; Variety 0.5; Treatment.Variety ns									
	LSD $^{(0.05)}$:Control vs Early: Treatment ns; Variety 0.8; Treatment.Variety ns									
	LSD $^{(0.05)}$:Control vs Late: Treatment ns; Variety 0.5; Treatment.Variety ns									
TSH	Control	8.3	9.1	7.7	8.4	9.1	8.4	9.2	7.6	8.5
	Early	7.3	5.5	5.3	4.6	5.2	5.0	7.4	4.1	5.6
	Late	7.7	9.3	7.5	8.0	6.7	8.0	8.2	8.5	8.0
	Mean	7.8	8.0	6.8	7.0	7.0	7.2	8.2	6.7	7.3
	LSD $^{(0.05)}$:Treatment 1.3; Variety 0.7; Treatment.Variety 1.5									
	LSD $^{(0.05)}$:Control vs Early: Treatment 2.6; Variety 0.8; Treatment.Variety 2.0									
	LSD $^{(0.05)}$:Control vs Late: Treatment ns; Variety 0.9; Treatment.Variety 1.7									

6.2.6.3 Cumulative yield

Cumulative cane and sugar yield was calculated by adding plant and first ratoon data. This was done to better understand overall crop performance under waterlogging conditions. Cumulative cane and sugar yield was significantly reduced by the early (36 % loss over the two crops) and late (12 % loss over the two crops) treatments. A highly significant treatment.variety existed for both cumulative cane and sugar yield (Figure 6.9). All varieties showed a significant decline in cumulative cane and sugar yield in the early treatment, but this decline was more severe for Q208$^{\phi}$ and Q200$^{\phi}$, and to a lesser extent Q247$^{\phi}$ (evident for cumulative sugar yield but not cumulative cane yield). For the late treatment, MQ239$^{\phi}$, Q219$^{\phi}$ and Q247$^{\phi}$, showed no loss of cumulative cane or sugar yield whereas all other varieties showed a significant decline. While Q232$^{\phi}$'s cumulative cane and sugar yield declined significantly in both waterlogging treatments, it was still one of the top performers across all treatments. This highlights an important issue, in some cases varieties that are tolerant to stress are not the best producers. Q219$^{\phi}$ in this experiment is a good example, as it appears to have better waterlogging tolerance than other varieties, but it performed poorly under control conditions.

In terms of overall variety performance across all treatments, which could be looked at as performance across different seasons with varying climatic conditions, Q232$^{\phi}$ and MQ239$^{\phi}$ produced significantly more cane than other varieties. For cumulative sugar yield, the top varieties were Q232$^{\phi}$, KQ228$^{\phi}$ and MQ239$^{\phi}$.

Given that the site was a heavy clay soil in a wet environment, soil moisture content in control plots was likely to have been saturated for some period in both seasons. With this in mind, Q232⏀ appears to withstand these conditions better than other varieties, indicating it does have some tolerance.

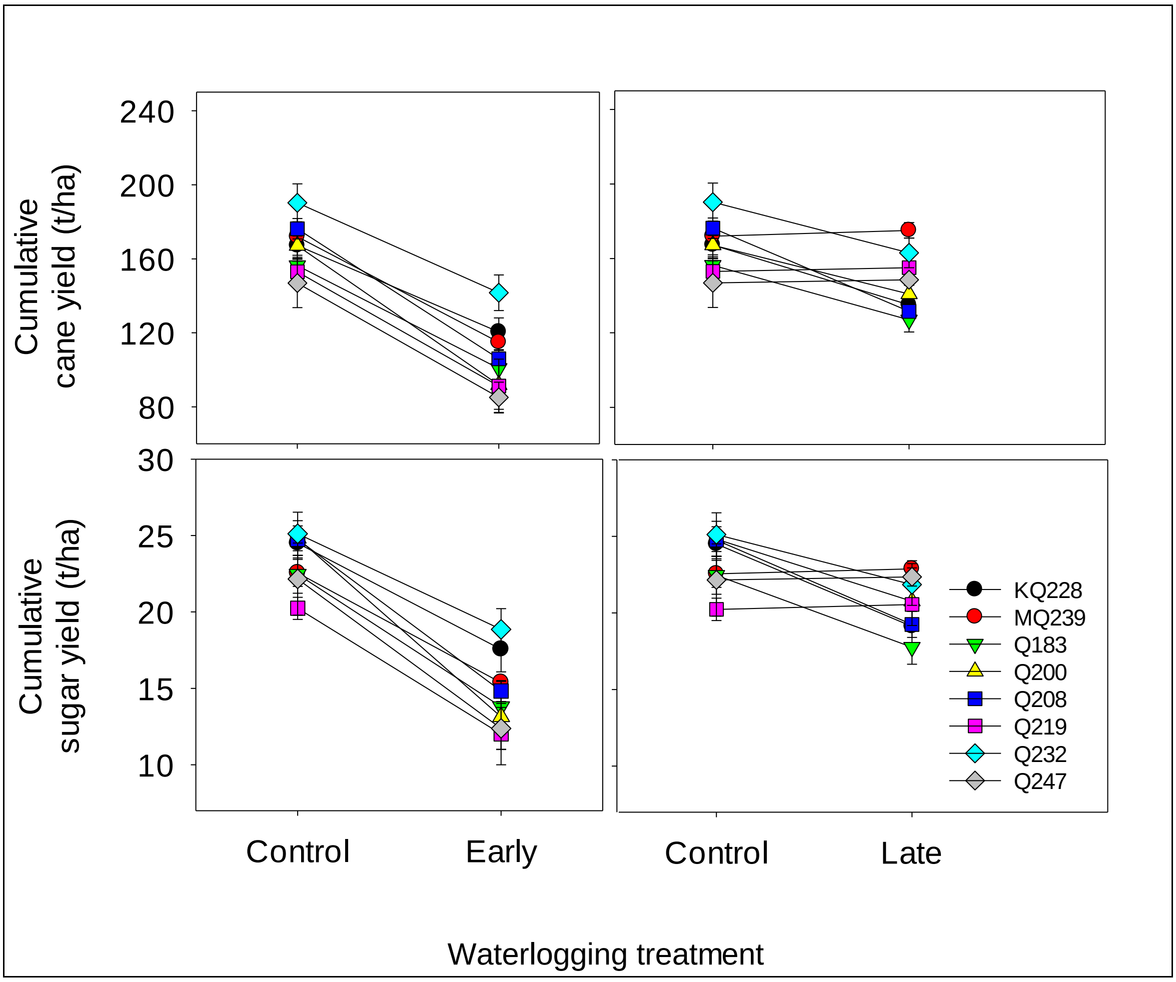


Figure 6.9 Cumulative cane (top) and sugar (bottom) yield of eight varieties subjected to waterlogging early or late in the development of both plant and first ratoon crops

6.2.7 Crop phenotype, N uptake and performance

There does not appear to be any obvious link between crop phenotype and performance in this experiment. Varieties that performed better in waterlogging treatments (Q232⏀, MQ239⏀, Q247⏀ and Q219⏀) tended to have varying growth characteristics. Q232⏀ had low stalk numbers in comparison to other varieties, but these stalks were larger than those produced by other varieties. Q247⏀ had high stalk numbers, but these stalks were relative light in comparison to other varieties. Q232⏀ had high RWC in comparison to some other varieties. This could suggest that its performance at the site is linked to physiological traits associated with crop water relations (water uptake, transpiration, stomatal conductance), but further work would be required to understand this better. Work conducted by The University of Melbourne with Q232⏀ suggested that it produced aerenchyma like tissue in adventitious roots to a greater extent than Q247⏀ (Rosli 2016).

In this experiment ratings of aerial roots and the number of nodes with aerial roots were inconclusive.

Some differences in total crop N among varieties under the waterlogging treatments were observed.

The ability to take up nitrogen under waterlogged conditions may be an important trait associated with performance due to the high losses associated with denitrification and inability of an impaired root system to explore the soil profile or take up N. However, no consistent pattern was found.
For example, Q208$^{\Phi}$ performed poorly in the late waterlogging treatment in the first ratoon crop in comparison to other varieties, but was able to acquire a similar amount of N in above ground biomass as the control. This would suggest that N uptake was not responsible for this observation. Varieties that performed well at the site (Q232$^{\Phi}$) and those that appeared to have greater waterlogging tolerance (Q219$^{\Phi}$, MQ239$^{\Phi}$) also had the highest total Crop N. However, this was not the case for Q247$^{\Phi}$, and other varieties like Q183$^{\Phi}$ also accumulated relatively high total crop N.

Sugarcane has been shown to have a wide range of physiological/biochemical response to waterlogging. These include formation of adventitious roots, development of aerenchyma, piping of stalks, alcohol dehydrogenase activity, antioxidant enzyme activity, and others (Gomathi et al. 2015). Further work on these aspects of sugarcane waterlogging tolerance could potentially result in a more definitive method of screening tolerance of commercial cultivars. This is most likely to occur through metabolomics approaches.

6.2.8 Tolerance ratings

Comparing the results from this experiment to waterlogging tolerance ratings in QCANESelect™ (Table 5.2), some differences exist. MQ239$^{\Phi}$ and Q219$^{\Phi}$ are rated as having good tolerance, which is consistent with trial results. Q247$^{\Phi}$ is rated as having average tolerance. In the trial Q247$^{\Phi}$ performed relatively poorly when waterlogged early but performed well when waterlogged late. QCANESelect™ could potentially include more specific information like this. Q232$^{\Phi}$ is rated as average tolerance in QCANESelect™. Data from the trial indicates it is possibly better than this, it performed well on a poorly drained soil in a low lying position in the landscape. Q208$^{\Phi}$ has a variable rating in QCANESelect™ depending on the region it is grown. In most regions it is rated as good, whereas trial results suggest it was poor. If this is a more accurate reflection of its tolerance, the large proportion of Q208$^{\Phi}$ grown throughout the industry could contribute to the productivity risk during very wet seasons. Q183$^{\Phi}$ is rated as poor in the Northern coastal and Central regions, and good in the Herbert and Burdekin. Data from this experiment is more consistent with a poor rating. KQ228$^{\Phi}$ performed relatively well when waterlogged early, specifically in the first ratoon crop. It has a rating of either average or poor depending on the region, an average rating would be more consistent with the trial result reported here. Q200$^{\Phi}$ rating ranges from good to poor, results from the trial, particularly the early treatment are more consistent with an average to poor rating. It should be noted that one experiment in one region is unlikely to provide sufficiently rigorous information to change QCANESelectTM ratings, but the information should be considered when the ratings are discussed.

6.3 Waterlogging pot experiments

6.3.1 Developing a method to impose waterlogging on sugarcane grown in pots

6.3.1.1 Experiment 1

Despite the lack of a statistically significant difference, plants growing whilst submerged in water, without fibrated sugarcane stalk, had greater dry biomass than the controls (Table 6.21).
This indicated that the irrigation frequency of controls was inadequate and was adjusted for other experiments.

Whilst 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.

Whilst 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 6.21 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$^{\phi}$	Q208$^{\phi}$
Control	no	9.8	8.4
Waterlogging	no	12.2	10.4
	yes	9.8	10.2
	LSD(0.05)	*ns*	*ns*

6.3.1.2 Experiment 2

Submerging pots in water and water with added fibrated sugarcane stalk significantly reduced total biomass, both shoot and roots (Table 6.22). 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 6.23).

Table 6.22 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 6.23 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 6.10). 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) can't 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).

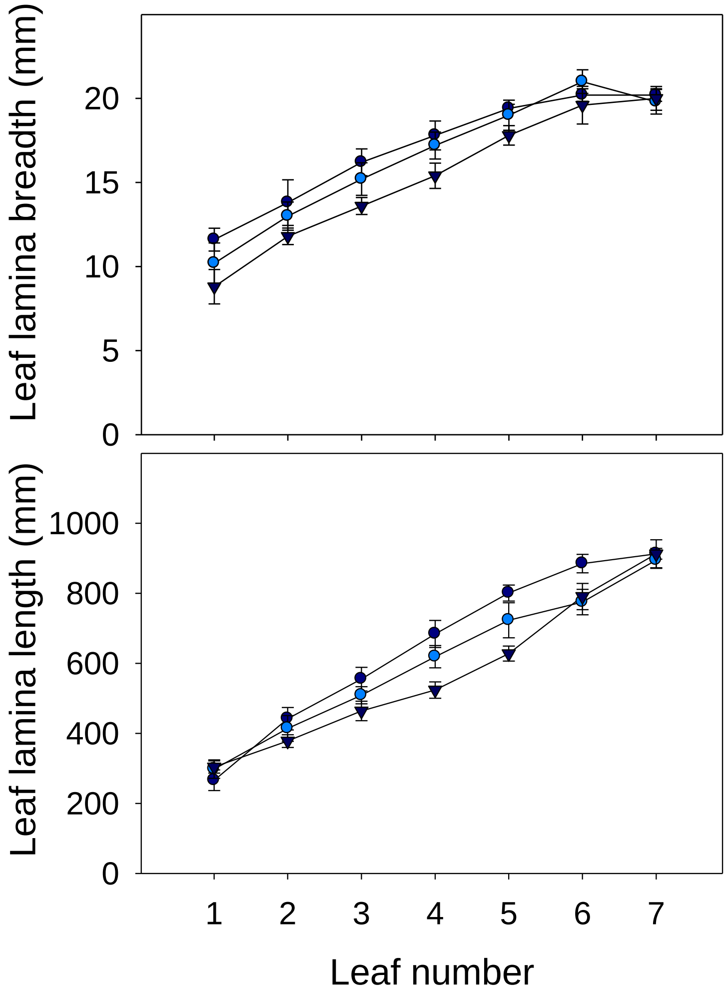


Figure 6.10 Leaf lamina length and breadth for control (●), waterlogged (●) and waterlogged +fibrated sugarcane stalk (▼) treatments. Errors + SEM

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 6.24). 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 6.24 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*

6.3.1.3 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 6.25).

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$^{\text{TM}}$, 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 6.11). 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 6.25 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			

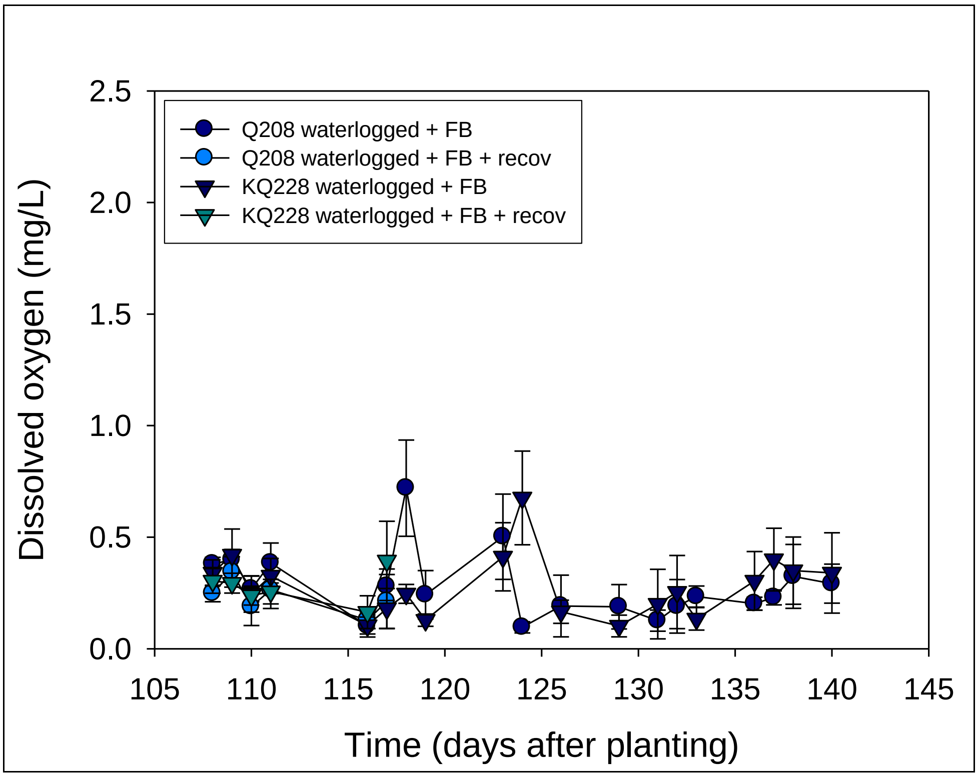


Figure 6.11 Dissolved oxygen concentration of water in waterlogging treatments. Error bars + SEM

6.3.1.4 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 6.12). Again, this result is a typical waterlogging response (Gomathi *et al.* 2015).

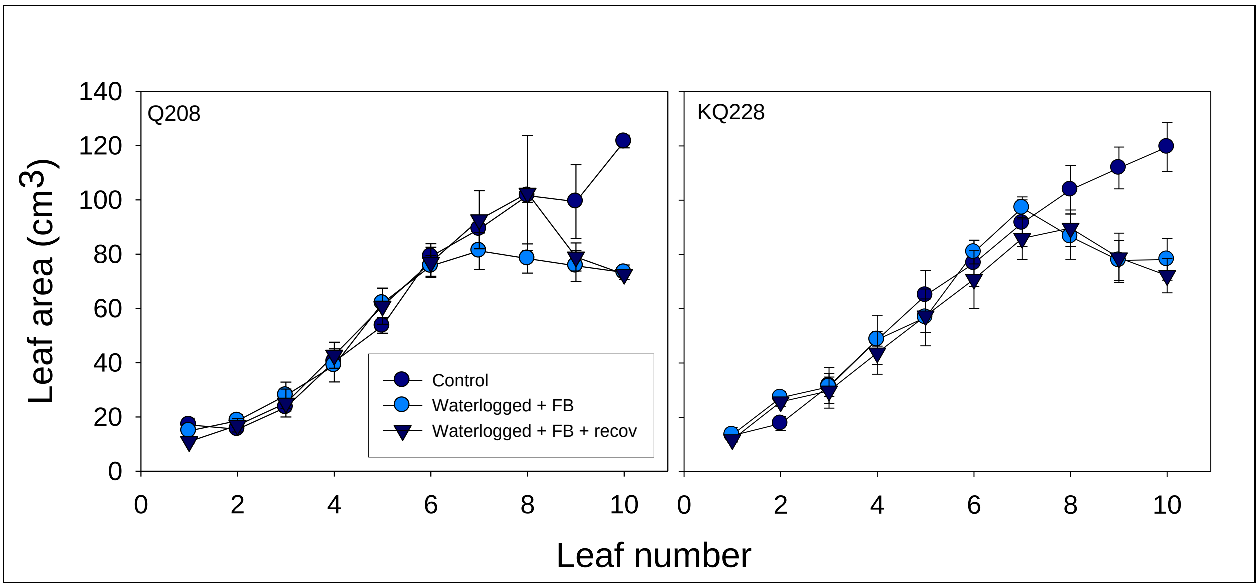


Figure 6.12 Leaf area development for Q208^{A} and KQ228^{A} in control, waterlogged and waterlogged + recovery treatments. Error bars + SEM

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 6.26). 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$^{\text{Φ}}$ but not KQ228$^{\text{Φ}}$. 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$^{\text{Φ}}$ and KQ228$^{\text{Φ}}$ (despite their ratings in QCANESelect$^{\text{TM}}$). Future work should try include varieties that are known to have either poor or good tolerance.

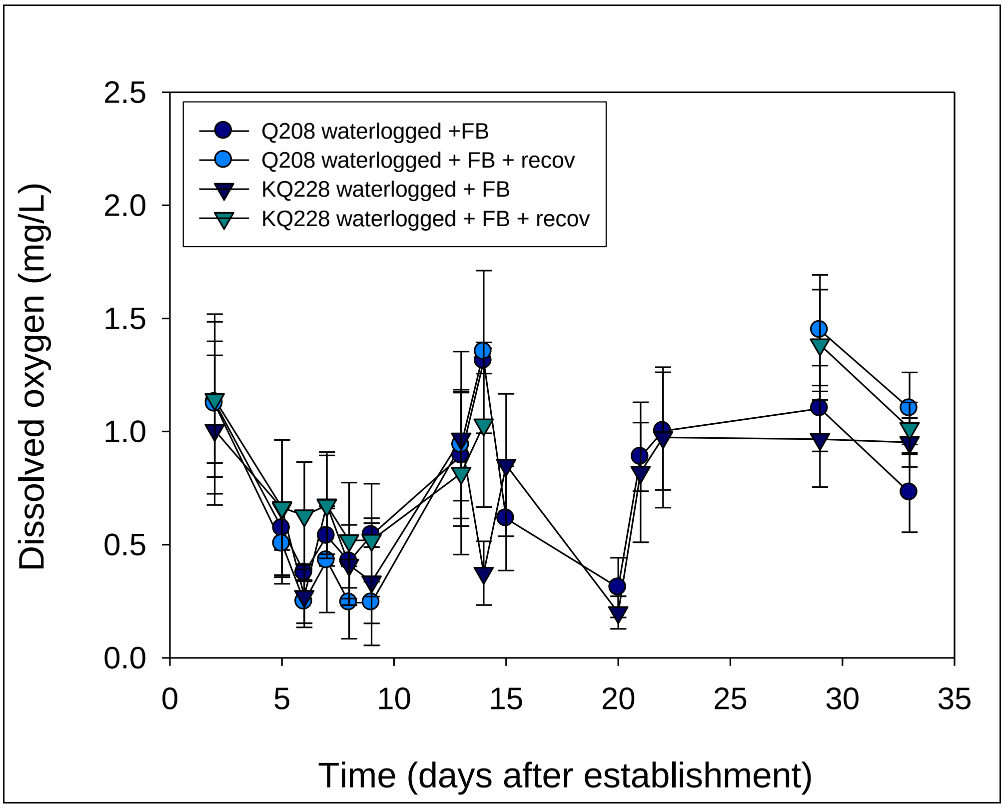


Figure 6.13 Dissolved oxygen (mg/L) concentration of water collected from within the root zone of waterlogged pots. Error bars ± SEM

DO concentration within waterlogged pots (Figure 6.13) 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.

Figure 6.14 KQ228$^{\Phi}$ in control (top) and waterlogged + FB (bottom) treatments

Table 6.26 Plant traits following the waterlogging of two sugarcane varieties in pots in experiment 4

Trait	Treatment	Variety		Mean (Treat)
		KQ228$^{\Phi}$	Q208$^{\Phi}$	
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

The four experiments show the development of a method to impose waterlogging on sugarcane growing in pots. 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.

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.

6.3.2 Screening of sugarcane varieties for waterlogging tolerance in pots

6.3.2.1 Experiment 1

Dissolved oxygen concentration was maintained between 1 - 2 mg/L for the duration of the trial (Figure 6.15). This is consistent with values recorded in a waterlogged sugarcane field near Ingham (Burry *et al.* 2004). Much of the stress associated with waterlogging is attributed to anaerobic conditions in the soil profile.

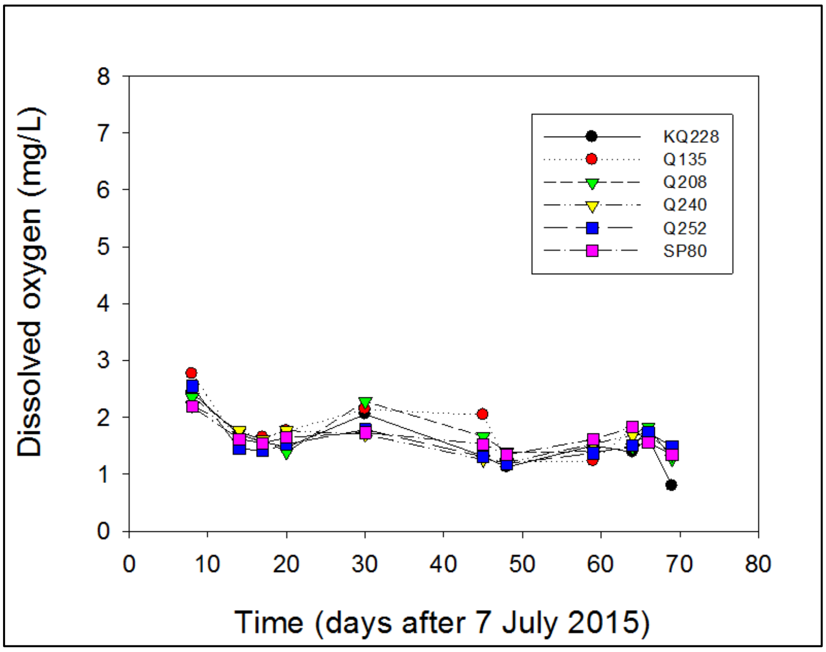


Figure 6.15 Dissolved oxygen concentration (mg/L) in pots in the waterlogged treatment

Waterlogging significantly reduced leaf lamina length for all varieties (Figure 6.16). A highly significant treatment.variety.leaf number effect was associated with varieties having produced differing numbers of leaves prior to the treatment effect being evident. As an example, Q240$^{\phi}$ had produced seven leaves, whereas Q208$^{\phi}$ had only produced four leaves. This could suggest that while all varieties were planted on the same date, differences in germination and early establishment may have resulted in different 'physiological ages' among varieties at the time treatments were implemented. This could potentially have affected results as sugarcane tends to tolerate waterlogging better when more advanced (Gomathi et al. 2015). Leaf extension rate of sugarcane is affected by water stress (Inman-Bamber and Spillman 2002). Waterlogging can result in similar symptoms as water deficit due to the impairment of the root system under anaerobic conditions. In contrast to lamina length, leaf lamina width was not affected by waterlogging treatments (Figure 6.17).

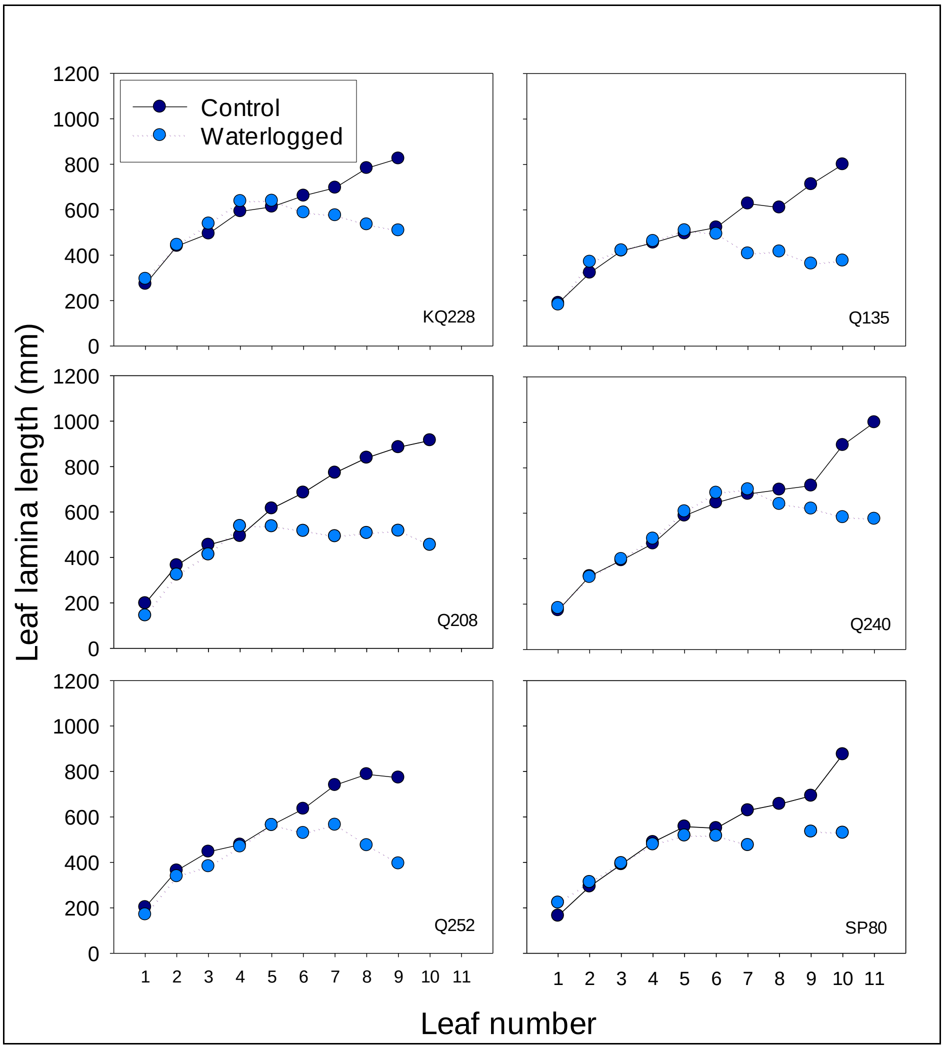


Figure 6.16 Leaf lamina length of six varieties in waterlogged and control treatments

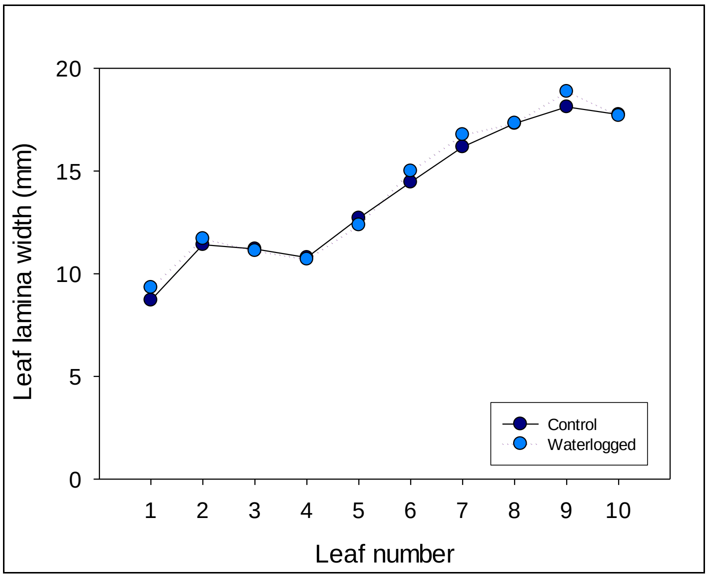


Figure 6.17 Mean leaf lamina width of six sugarcane varieties in waterlogged and control treatments

Waterlogging treatments significantly reduced tiller population development (Table 6.27). This effect was particularly evident 62 and 94 DAP, when tillering was increasing rapidly in control pots.

While tillering among varieties also differed over time (not shown), the treatment.variety.time effect was not significant, indicating that the changes in treatment effects over time were similar for all varieties. Tiller numbers were higher in the waterlogging + recovery treatment than the waterlogging treatment that was maintained throughout the experiment. Given the lack of a significant treatment.variety.time interaction, this also suggests that none of the varieties showed any difference in recovery from waterlogging.

Table 6.27 Mean effect of waterlogging treatments on tiller numbers over time

Treatment	Days after planting					Mean
	33	47	55	62	94	
Control	0.2	1.3	2.4	3.6	10.8	3.6
Waterlogging	0.2	0.9	1.3	1.4	2.7	1.3
Waterlogging and Recov.	0.1	0.9	1.3	2.5	5.9	2.1
Mean	0.2	1.0	1.7	2.5	6.5	2.4
LSD$^{(0.05)}$:	*Treatment 0.4; Time 0.4; Treatment.time 0.7*					

Analysis of the harvest data was performed using two methods. Initially the experiment was analysed using two factors (treatment and varieties), randomised within a block design. Subsequently, performance in the waterlogged treatments was calculated relative to the control plot in each replicate. This data was then analysed with only variety as a factor (Table 6.28). The first analysis showed significant treatment and variety effects, but no significant interactions. Fresh biomass, dry biomass and stalk number were all reduced due to waterlogging (Figure 6.18). Percent dry matter was not affected by either treatment or varieties. In the second analysis significant variety effects were found within the waterlogging treatment but not the waterlogging + recovery treatment. Differences among varieties, due to waterlogging, were particularly evident for stalk numbers, but trends ($P < 0.1$) also existed for fresh and dry biomass. From this data it appeared that Q240$^{\Phi}$, Q232$^{\Phi}$ and Q183$^{\Phi}$ were more tolerant than varieties Q247$^{\Phi}$, SP80, Q208$^{\Phi}$ and Q135. In some cases this is consistent with ratings in QCANESelectTM (Q232$^{\Phi}$ rated good and Q135 rated as poor in the Central region), but not in others (Q183$^{\Phi}$ rated as poor and Q208$^{\Phi}$ rated as good in the Central region). However, as indicated previously, ratings for a variety within QCANESelect™ are inconsistent across regions (Table 5.2). Therefore, a varieties actual waterlogging tolerance is unclear.

The analyses indicated that any differences in tolerance among varieties were more likely to be expressed when varieties were maintained in a permanent waterlogging treatment. Therefore, the treatment that included periods of recovery from waterlogging stress were not pursued any further.

Table 6.28 The effect of waterlogging on nine sugarcane varieties grown in pots at Mackay

Trait	Variety	Treatment			Relative performance	
		Control	WL	WL + Recov	WL	WL + Recov
Fresh wt (g/pot)	KQ228	381.8	136.4	227.2	0.36	0.61
	Q135	245.0	88.6	159.0	0.38	0.65
	Q183	484.2	226.8	300.6	0.48	0.67
	Q208	299.6	54.0	188.6	0.18	0.63
	Q232	457.4	358.2	294.2	0.80	0.69
	Q240	483.8	318.4	319.4	0.71	0.70
	Q247	325.4	77.0	173.8	0.24	0.55
	Q252	315.0	123.8	168.8	0.44	0.58
	SP80	383.2	79.8	193.2	0.23	0.54
	$LSD^{(0.05)}$: Treat 40.8; Variety 70.7; Treat x Var. ns				*0.43 (P = 0.07)*	*ns*
Stalk no.	KQ228	16.2	4.0	12.4	0.24	0.75
	Q135	19.6	4.0	10.4	0.22	0.54
	Q183	17.4	7.0	10.2	0.43	0.60
	Q208	13.2	1.6	8.8	0.12	0.67
	Q232	22.0	10.8	16.4	0.47	0.80
	Q240	18.2	9.2	12.0	0.50	0.67
	Q247	17.8	1.2	8.2	0.07	0.46
	Q252	14.8	5.4	11.2	0.35	0.80
	SP80	17.0	2.6	8.8	0.17	0.52
	$LSD^{(0.05)}$: Treat 1.3; Variety 2.3; Treat x Var. ns				*0.17*	*ns*
%DM	KQ228	25.9	27.7	24.2	1.08	0.93
	Q135	24.3	23.7	21.6	0.99	0.89
	Q183	24.7	21.6	24.1	0.88	0.98
	Q208	24.2	26.7	23.2	1.10	0.96
	Q232	23.6	18.5	22.4	0.78	0.95
	Q240	25.0	19.7	22.3	0.79	0.90
	Q247	23.6	20.6	20.9	0.88	0.89
	Q252	24.1	22.9	22.9	0.96	0.96
	SP80	24.3	25.2	23.8	1.03	0.98
	$LSD^{(0.05)}$: Treat ns; Variety ns; Treat x Var. ns				*ns*	*ns*
Dry biomass (g/pot)	KQ228	98.8	29.1	54.8	0.30	0.56
	Q135	59.3	16.9	34.6	0.29	0.59
	Q183	118.7	49.0	72.0	0.42	0.64
	Q208	72.7	12.9	43.3	0.18	0.60
	Q232	107.8	65.8	66.3	0.62	0.66
	Q240	119.6	56.8	71.7	0.50	0.62
	Q247	76.9	15.6	36.3	0.21	0.49
	Q252	75.2	25.3	38.6	0.37	0.55
	SP80	93.0	17.3	45.1	0.20	0.52
	$LSD^{(0.05)}$: Treat 8.0; Variety 13.9; Treat x Var. ns				*0.3 (P = 0.08)*	*ns*

Figure 6.18 Pots containing Q208$^{\Phi}$ in control (left), waterlogged (middle) and waterlogging+recovery treatments prior to sampling on 30 September 2015

6.3.2.2 Experiment 2

Dissolved oxygen concentrations within the root zone (Figure 6.19) were maintained throughout the experiment at levels similar to those recorded in waterlogged sugarcane fields (Burry *et al.* 2004). These low levels of dissolved oxygen are likely to have affected root function and imposed the desired stress on plants growing in pots.

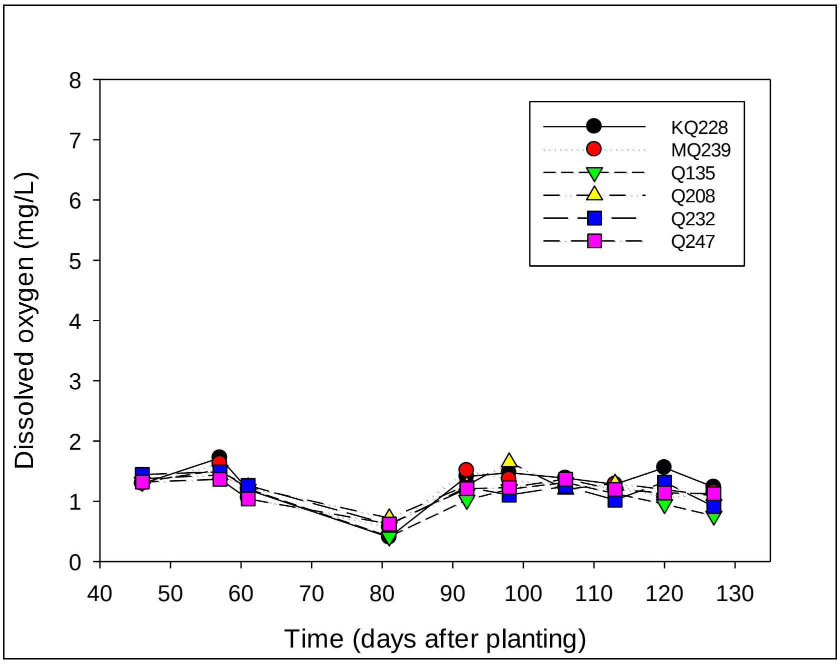


Figure 6.19 Dissolved oxygen concentration (mg/L) in pots in the waterlogged treatment

Analysis of leaf lamina length data revealed significant treatment.leaf number and variety.leaf number (not shown) interactions. There was also a trend ($P<0.1$) for the treatment.variety interaction. The waterlogging early treatment caused a significant decline in leaf lamina length from leaf 7 (Figure 6.20), whereas a difference was only evident between waterlogging late and the control for leaf 12. The treatment.variety trend was associated with mean leaf lamina length of Q200$^{\phi}$ being similar across treatments, whereas for most other varieties leaf lamina length declined significantly in the waterlogging early treatment. Only KQ228$^{\phi}$, Q183$^{\phi}$ and Q135 showed a decline in leaf lamina length in the waterlogging late treatment (Table 6.29).

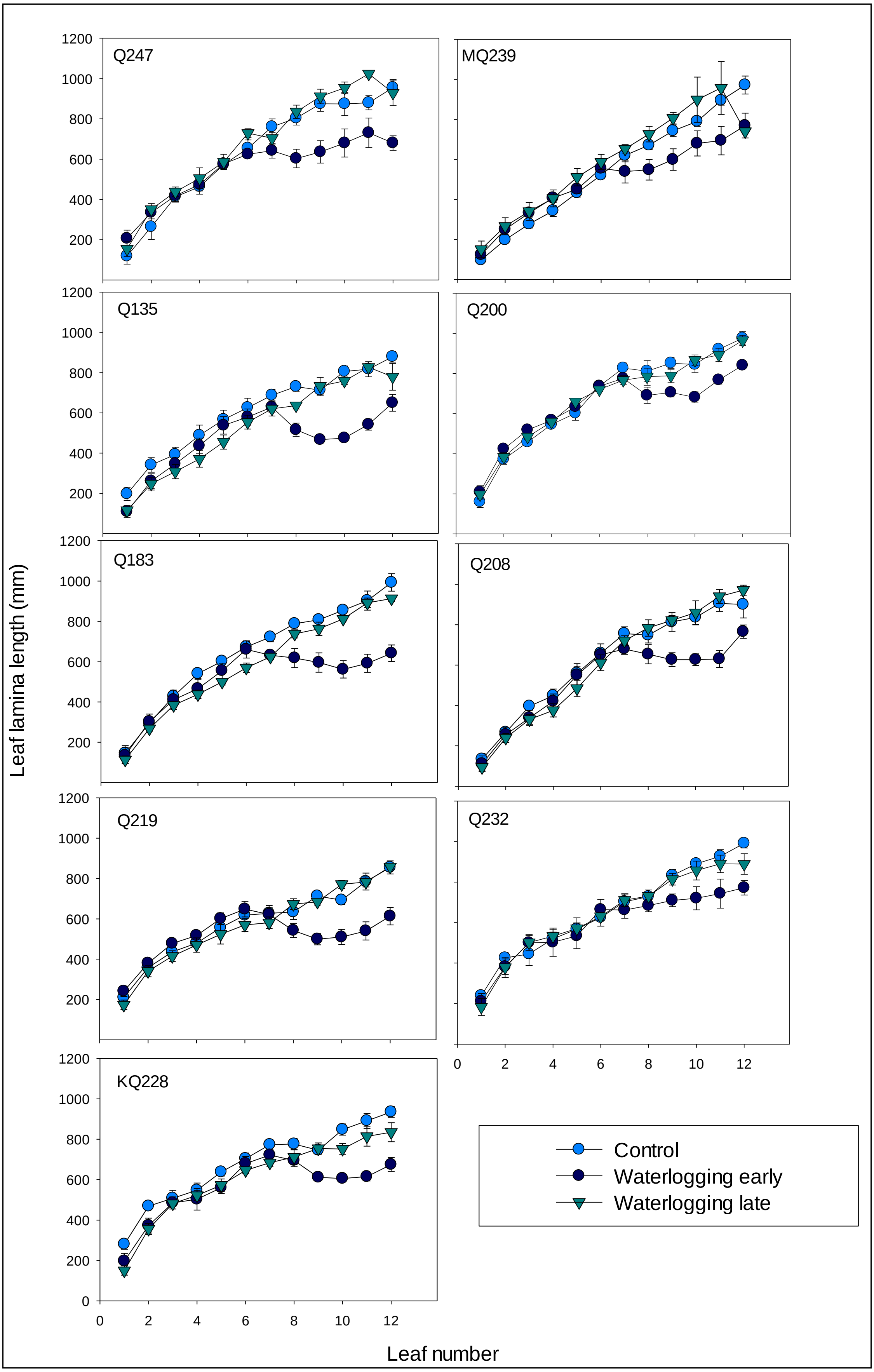


Figure 6.20 Effect of waterlogging on leaf lamina length of nine sugarcane varieties grown in pots

Table 6.29 Mean leaf lamina length (mm) for sugarcane varieties grown in pots under waterlogging conditions

Treatment	Variety								
	Q247	MQ239	Q232	KQ228	Q219	Q208	Q200	Q183	Q135
Control	635.7	546.7	658	676.3	580.3	618.8	676.9	646.2	603.8
Waterlogging early	552.9	495.6	590.4	560.2	515.9	526.1	629.2	514.3	462.4
Waterlogging late	676.7	598.1	640.7	607.4	570.1	602.9	671.8	584.5	533.7
LSD (0.05) Treatment.variety: 56.4									

Analysis of leaf lamina maximum width data revealed significant variety (not shown), variety.time (not shown) and treatment.variety.time (not shown) interaction effects. In general waterlogging treatments had no effect on leaf lamina maximum widths (Figure 6.21). The significant 3-way interaction appeared to be due to random differences between treatments for some varieties and leaf numbers, and did not appear to be of any physiological significance.

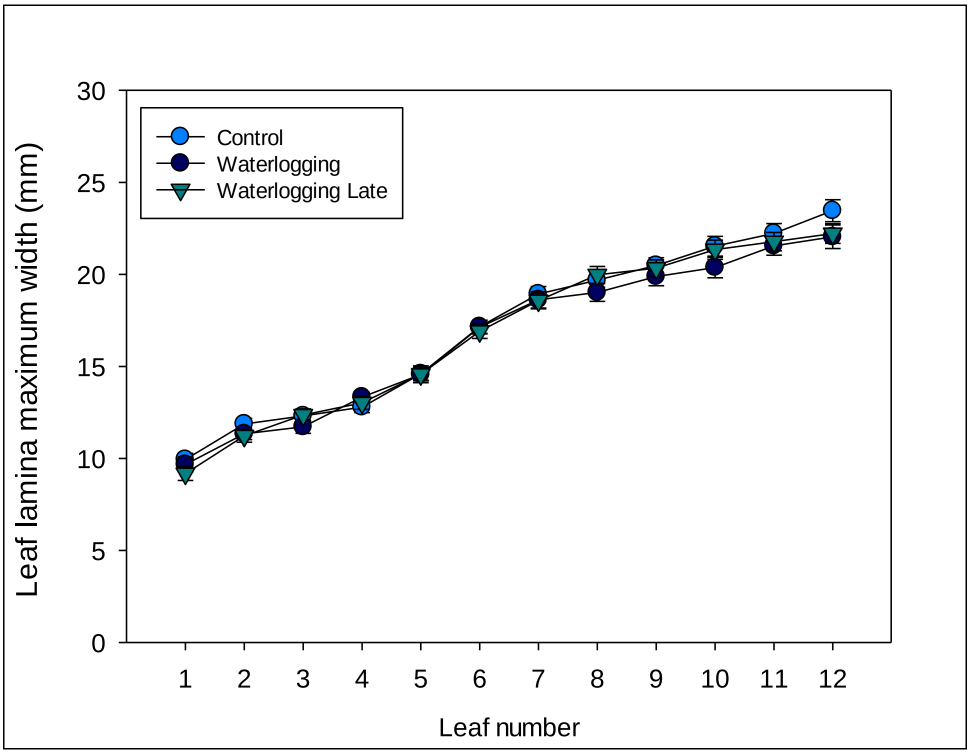


Figure 6.21 Mean leaf lamina maximum width of nine sugarcane varieties exposed to waterlogging treatments

The height of the primary shoot within each pot was measured throughout the experiment. Significant treatment.time (Figure 6.22), variety.time (not shown) and treatment.variety (Table 6.30) interactions were found. Stalks in the waterlogging treatment were significantly taller than both the control and waterlogging late treatment from 80 DAP. Gomathi *et al.* (2014) indicate that waterlogging reduces plant height. Work by Bajpaj and Chandra (2015) shows stalk height increased with waterlogging whereas Gilbert *et al.* (2008) found no difference in stalk height due to flooding. Striker (2012) indicated that an increase in plant height is a common response to partial submergence, along with the development of aerenchyma tissue. An increase in plant height increases the proportion of biomass above water level which facilitates the oxygenation of submerged tissue through aerenchyma.

The increase in mean plant height due to waterlogging was not statistically significant for Q208$^{\Phi}$ and MQ239$^{\Phi}$, whereas it was for all other varieties (Table 6.30).

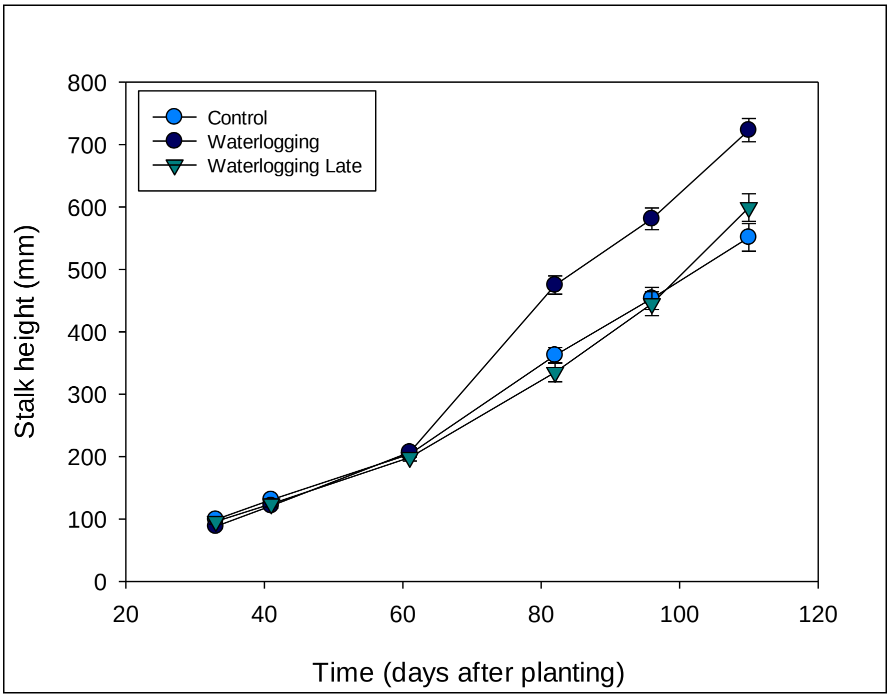


Figure 6.22 Mean primary stalk height over time for sugarcane varieties subjected to waterlogging in pots

Table 6.30 Mean primary stalk height (mm) for nine varieties subjected to waterlogging (Waterlogging – WL; Waterlogging Late – WL Late)

Variety	Treatment			Mean
	Control	WL	WL Late	
KQ228	269	344	280	297
MQ239	313	358	265	317
Q135	239	334	255	276
Q183	276	337	326	312
Q200	336	433	328	366
Q208	392	414	381	396
Q219	281	344	261	296
Q232	273	358	306	312
Q247	276	382	303	322
Mean	296	367	302	322
LSD$^{(0.05)}$: Treatment 17; Variety 30; Treatment.Variety 52				

Analysis of tiller population development showed significant treatment.time, variety.time and treatment.variety.time interactions (Table 6.31). In general, the waterlogging treatment reduced tiller population from 82DAP for most varieties. Differences between control and waterlogging late treatments were not as clear. Q183$^{\phi}$ and Q208$^{\phi}$ showed significantly lower tiller numbers in the waterlogging late treatment from 82DAP, but KQ228$^{\phi}$, Q219$^{\phi}$, Q232$^{\phi}$ and Q247$^{\phi}$ showed no change in tiller numbers in this treatment.

Table 6.31 Tiller population development (tillers/pot) for nine varieties subjected to waterlogging in pots

Variety	Treatment	Days after planting						Mean
		33DAP	41DAP	61DAP	82DAP	96DAP	110DAP	
KQ228	Control	0.2	3.0	7.0	13.4	13.6	12.8	8.3
	Waterlogging	0.0	2.0	5.0	9.8	8.2	8.4	5.6
	Waterlogging Late	0.4	3.0	6.8	13.2	12.2	10.0	7.6
	Mean	0.2	2.7	6.3	12.1	11.3	10.4	
MQ239	Control	0.2	2.0	6.6	14.4	13.6	12.8	8.3
	Waterlogging	0.0	1.6	2.6	8.2	7.6	5.8	4.3
	Waterlogging Late	0.0	0.0	2.7	9.4	11.0	9.2	5.4
	Mean	0.1	1.5	4.2	10.7	10.7	9.3	
Q135	Control	0.0	2.4	7.0	18.0	18.0	16.2	10.3
	Waterlogging	0.0	1.6	4.8	9.2	9.0	9.4	5.7
	Waterlogging Late	0.2	3.0	7.8	15.0	15.4	16.2	9.6
	Mean	0.1	2.3	6.5	13.8	14.1	13.9	
Q183	Control	0.4	2.8	8.2	17.6	18.2	16.0	10.5
	Waterlogging	0.4	3.4	5.2	9.6	9.6	9.0	6.2
	Waterlogging Late	1.0	3.4	10.6	9.6	10.8	12.4	8.0
	Mean	0.6	3.2	8.0	12.3	12.9	12.5	
Q200	Control	0.2	2.2	8.4	19.0	19.8	15.0	10.8
	Waterlogging	0.4	2.6	4.4	17.4	14.0	10.4	8.2
	Waterlogging Late	0.6	2.6	7.2	14.8	17.2	18.0	10.1
	Mean	0.4	2.5	6.7	16.9	17.0	14.5	
Q208	Control	0.4	2.4	7.4	16.2	16.6	14.2	9.5
	Waterlogging	0.6	2.8	4.2	8.6	9.8	7.8	5.6
	Waterlogging Late	0.8	2.8	6.8	9.8	10.0	10.4	6.8
	Mean	0.6	2.7	6.1	11.5	12.1	10.8	
Q219	Control	0.6	2.4	5.6	14.8	15.2	14.0	8.8
	Waterlogging	0.4	2.8	3.8	7.8	9.8	9.0	5.6
	Waterlogging Late	0.6	3.0	6.2	11.8	12.8	12.6	7.8
	Mean	0.5	2.7	5.2	11.5	12.6	11.9	
Q232	Control	0.4	3.2	7.8	16.4	16.6	14.6	9.8
	Waterlogging	1.0	2.8	4.8	9.8	12.4	12.0	7.1
	Waterlogging Late	1.2	2.8	6.0	15.0	15.4	14.8	9.2
	Mean	0.9	2.9	6.2	13.7	14.8	13.8	
Q247	Control	0.0	2.0	6.4	15.4	14.8	13.2	8.6
	Waterlogging	0.2	1.6	3.2	8.4	5.6	4.4	3.9
	Waterlogging Late	0.2	2.2	6.6	11.8	12.0	13.8	7.8
	Mean	0.1	1.9	5.4	11.9	10.8	10.5	
	LSD$^{(0.05)}$: Variety.time 1.9; Treatment.variety.time 3.3							

At final harvest (Table 6.32) differences among treatments were shown to be statistically significant. Fresh biomass, dry biomass and stalks population were greater in control pots in comparison to the waterlogging early and waterlogging late treatments. Fresh and dry biomass was lower in the waterlogged early than late treatment. There were also significant variety effects for fresh biomass and stalk population but no significant treatment.variety interactions for any trait.

Table 6.32 Plant traits at final harvest of nine sugarcane varieties grown in pots in control, waterlogged early and waterlogged late treatments

		Variety									Treatment
Trait	Treatment	KQ228	MQ239	Q135	Q183	Q200	Q208	Q219	Q232	Q247	mean
Fresh biomass (g/pot)	Control	1605	1746	1739	1663	1310	1869	1525	1853	1643	1661
	Waterlogging early (WE)	763	850	1257	1037	1146	937	1148	1298	883	1035
	Waterlogging late (WL)	1069	893	1233	1409	1114	1086	1154	1382	1320	1184
	Variety mean	1146	1163	1410	1370	1190	1297	1276	1511	1282	1294
	LSD (0.05): Treatment 124.3; Variety 215.4; Treat.Variety ns										
	WE relative to control	0.51	0.51	0.77	0.64	0.88	0.50	0.77	0.72	0.56	0.65
	WL relative to control	0.71	0.51	0.76	0.89	0.85	0.58	0.82	0.75	0.82	0.74
	Mean relative (variety)	0.61	0.51	0.77	0.76	0.86	0.54	0.79	0.73	0.69	0.70
	LSD (0.05): Variety 0.18; Treatment 0.09; Treatment.Variety ns										
Dry biomass (g/pot)	Control	312	366	340	373	303	369	301	366	339	341
	Waterlogging early (WE)	167	180	239	221	285	257	242	267	169	225
	Waterlogging late (WL)	217	177	228	276	246	258	211	273	277	240
	Variety mean	232	241	269	290	278	295	251	302	262	269
	LSD (0.05): Treatment 29.7; Variety ns; Treat.Variety ns										
	WE relative to control	0.57	0.50	0.76	0.62	0.95	0.79	0.82	0.73	0.53	0.70
	WL relative to control	0.76	0.48	0.73	0.80	0.81	0.71	0.75	0.74	0.83	0.73
	Mean relative (variety)	0.66	0.49	0.74	0.71	0.88	0.75	0.78	0.74	0.68	0.72
	LSD (0.05): Variety ns; Treatment ns; Treatment.Variety ns										
Stalks/pot	Control	16.2	13.4	19.2	16.8	20.6	16.4	14.8	18.6	19.2	17.2
	Waterlogging early (WE)	10.6	7.0	12.4	9.2	18.2	9.8	8.6	13.0	10.6	11.0
	Waterlogging late (WL)	11.2	8.4	10.4	9.2	16.0	11.4	10.4	16.2	12.2	11.7
	Variety mean	12.7	9.6	14.0	11.7	18.3	12.5	11.3	15.9	14.0	13.3
	LSD (0.05): Treatment 1.26; Variety 2.18; Treat.Variety ns										
	WE relative to control	0.66	0.54	0.69	0.63	0.92	0.60	0.59	0.71	0.54	0.65
	WL relative to control	0.68	0.67	0.56	0.60	0.77	0.69	0.74	0.87	0.65	0.69
	Mean relative (variety)	0.67	0.61	0.63	0.61	0.85	0.64	0.67	0.79	0.60	0.67
	LSD (0.05): Variety ns; Treatment ns; Treatment.Variety ns										

Data were also analysed using performance of the waterlogging treatments relative to control (Table 6.32). This analysis showed a significant difference in relative fresh biomass among varieties. Q200$^{\Phi}$ was able to maintain fresh biomass in waterlogged treatments at 0.86 of the control. This appears to correlate with mean leaf lamina length data where Q200$^{\Phi}$ was the least affected by waterlogging treatments (Table 6.29). MQ239$^{\Phi}$ and Q208$^{\Phi}$ showed the worst relative performance with fresh biomass at 0.51 and 0.54 of the control treatment, respectively. Interestingly, both these varieties showed a reduced response to waterlogging treatment in terms of stalk height. This could support the suggestion that increased stalk height is a beneficial adaptive mechanism (Sticker 2012). Both these varieties have been rated as having good waterlogging tolerance in QCANESelect™. They were the slowest to emerge as seedlings in this pot experiment.

A significant difference between the waterlogged early and late treatments was found when relative fresh biomass was analysed. While the interaction with varieties was not statistically significant, it appeared that this could be mostly attributed to better performance of KQ228$^{\Phi}$, Q183$^{\Phi}$ and Q247$^{\Phi}$ in the late treatment. KQ228$^{\Phi}$ and Q247$^{\Phi}$ maintained tiller numbers in the late treatment. As MQ239$^{\Phi}$ and Q208$^{\Phi}$ did not show improved relative performance in the waterlogged late treatment, this could suggest that slow emergence was not a major factor causing poor performance in the waterlogged early treatment. Changes in variety response with crop stage/ age could complicate attempts to rate varieties for waterlogging tolerance.

6.3.2.3 Experiment 3

As in other experiments, dissolved oxygen concentrations within the root zone (Figure 6.23) were maintained throughout the experiment at levels similar to those recorded in waterlogged sugarcane fields (Burry *et al.*, 2004).

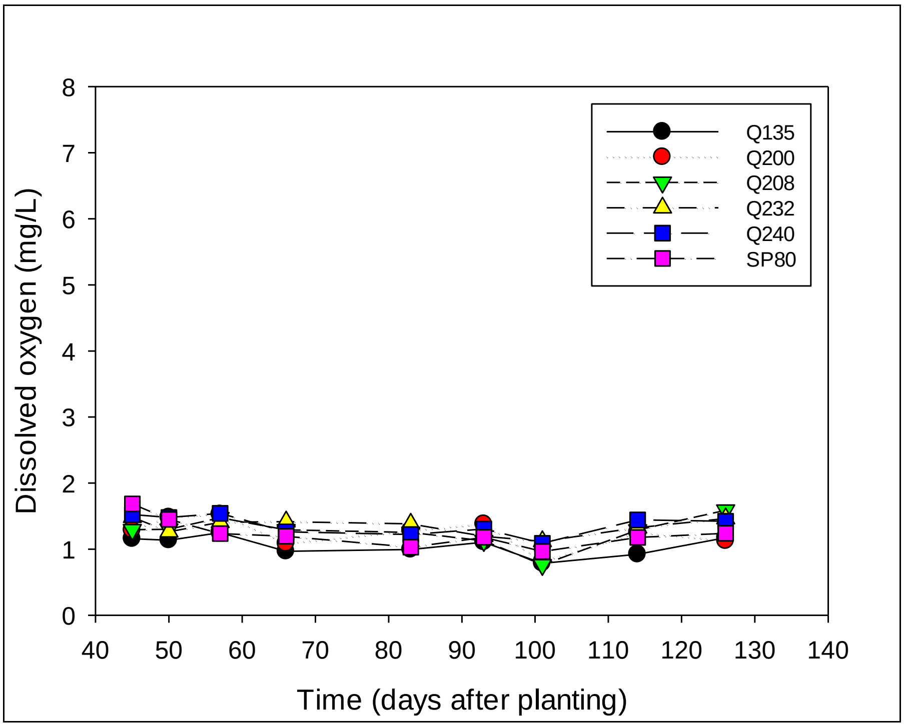


Figure 6.23 Dissolved oxygen concentration (mg/L) in pots in the waterlogged treatment

The WL early treatment was submerged on 16 May 2016. Leaf and tiller counts conducted on 10 May 2016 and 1 June 2016, respectively, showed significant differences among the varieties at this time (Table 6.33). MQ239$^{\Phi}$, Q240$^{\Phi}$ and Q247$^{\Phi}$ produced significantly more leaves than Q135, Q253$^{\Phi}$ and Q232$^{\Phi}$. Tillering was more advanced in Q240$^{\Phi}$, Q253$^{\Phi}$ and MQ239$^{\Phi}$ than Q135 and SP80.

Table 6.33 Differences in leaf and tiller numbers for nine sugarcane varieties during the early stages of development

Variety	WL early	
	No. leaves on 10/5/16	No. tillers on 1/6/16
MQ239	3.0	2.4
Q135	1.6	0.6
Q200	2.4	1.8
Q208	2.2	1.4
Q232	1.4	1.4
Q240	2.8	3.8
Q247	2.6	1.8
Q253	1.8	2.6
SP80	2.2	1.0
LSD$^{(0.05)}$	*0.7*	*1.1*

Analysis of leaf lamina length data showed significant treatment.leaf number (not shown), variety.leaf number (not shown) and a treatment.variety.leaf number interaction (Figure 6.24). For most varieties, leaf lamina lengths declined with waterlogging treatments. The timing and magnitude of these differences varied among varieties and account for the significant 3-way interaction. No difference in leaf lamina lengths due to waterlogging was evident for Q240$^{\Phi}$.

However, Q240$^{\Phi}$ did show a reduction in leaf lamina lengths with waterlogging in Experiment 1. Therefore, it is difficult to interpret this data for Q240$^{\Phi}$. Leaf lamina maximum width showed a significant treatment.leaf number interaction (Figure 6.25). However this was due to a small difference among treatments at leaf 10. It appear unlikely that this is of physiological significance. Waterlogging reduced tillering (Table 6.34), but no interaction between treatment and varieties suggests that all nine varieties responded in a similar manner. This appear inconsistent with data from Experiment 2 where some varieties performed differently in the waterlogged late treatment.

Table 6.34 Mean effect of waterlogging on tiller production over time

Treatment	Days after planting			Mean
	50	76	99	
Control	3.1	7.1	9.1	6.4
Waterlogging early	1.9	2.8	4.4	3.0
Waterlogging at leaf 5	2.8	3.6	4.5	3.7
Mean	2.6	4.5	6.0	
LSD$^{(0.05)}$: Treatment 0.6; Time 0.4; Treatment.time 0.8				

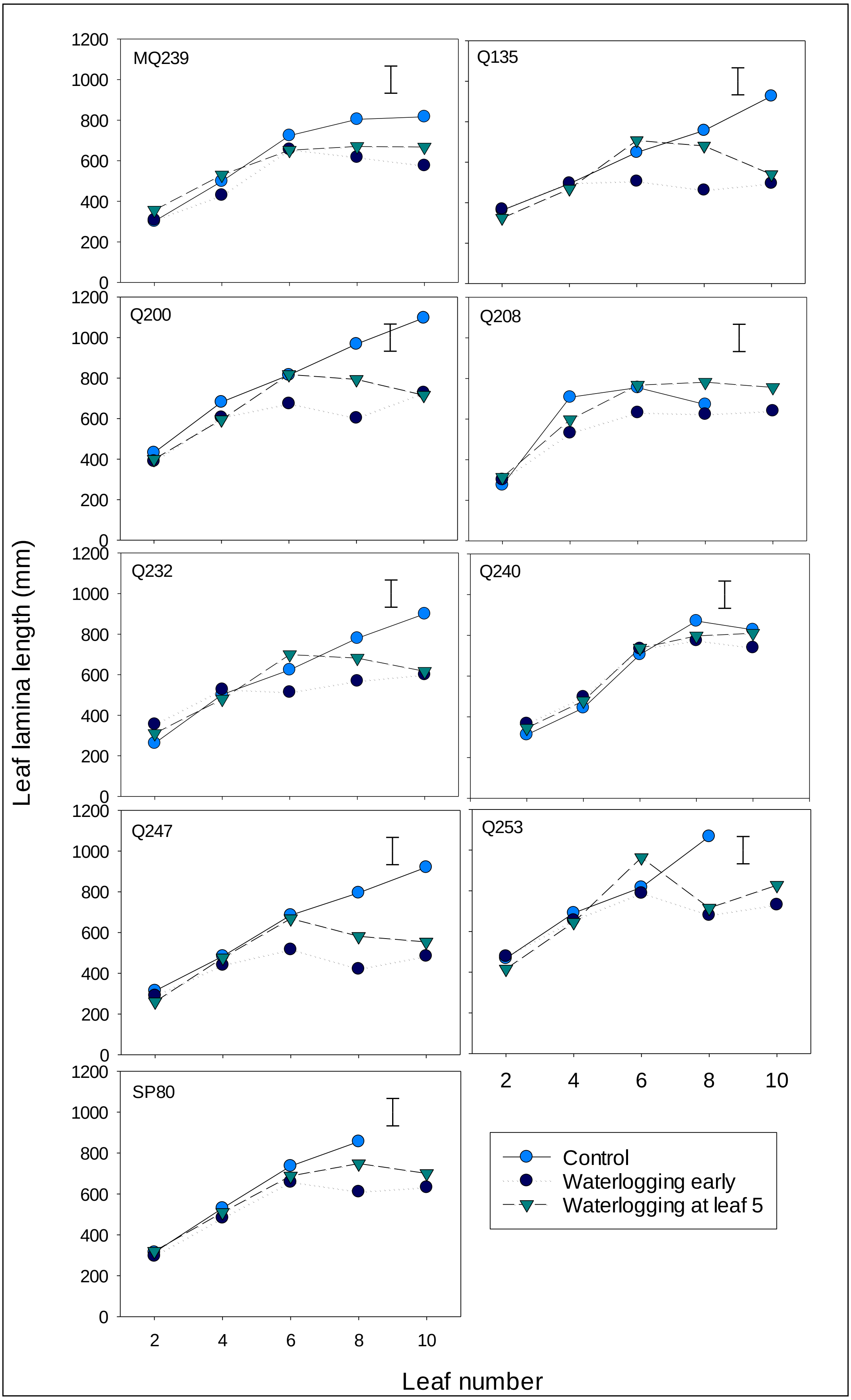


Figure 6.24 Effect of waterlogging on leaf lamina length of nine sugarcane varieties grown in pots

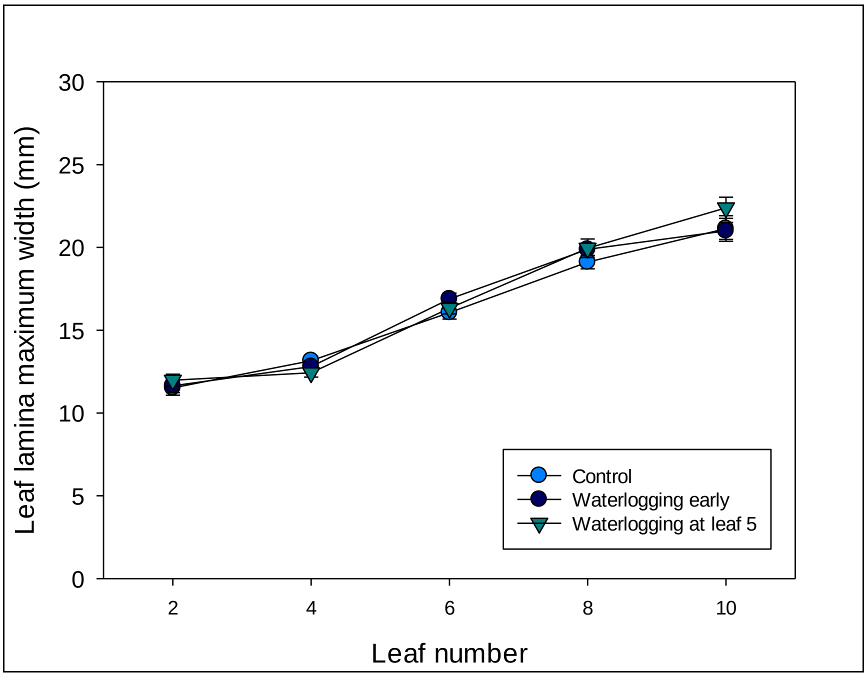


Figure 6.25 Mean leaf lamina maximum width of nine sugarcane varieties exposed to waterlogging treatments

As in experiment 2, height of the primary stalk was increased with waterlogging treatments (Figure 6.26). The treatment.variety.time interaction was close to statistical significance (P=0.053). This appeared to be due to Q240$^{\Phi}$ and Q247$^{\Phi}$ showing less difference between control and waterlogged treatments than other varieties (not shown).

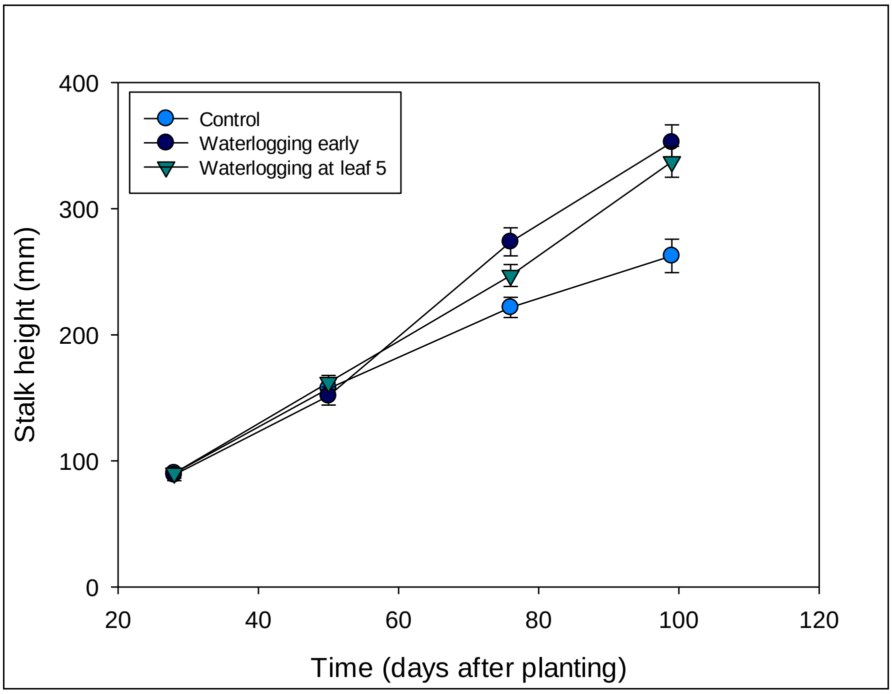


Figure 6.26 Mean effect of waterlogging on primary stalk height (mm) over time

Statistically significant treatment and variety effects were found for all crop traits at harvest except crop percent dry matter (Table 6.35). Treatment effects were associated with reduced stalk number, fresh biomass and dry biomass for both waterlogging treatments in comparison to the control. No statistically significant differences were found between the two waterlogging treatments.

This suggests that the small differences in development, highlighted in Table 6.33, did not influence performance of varieties in the waterlogging treatments. Differences between varieties were mainly due to better performance by Q240$^{\phi}$ and Q253$^{\phi}$ and poor performance of Q135, Q208$^{\phi}$ and Q247$^{\phi}$.

Table 6.35 Crop traits at harvest

Trait	Treatment	Variety									Mean
		MQ239	Q135	Q200	Q208	Q232	Q240	Q247	Q253	SP80	
Shoots per pot	Control	16.0	17.8	23.2	13.2	17.0	18.8	14.4	11.4	17.6	16.6
	WL early	6.6	8.0	9.4	6.4	7.2	18.4	7.4	9.6	5.4	8.7
	WL at leaf 5	7.6	7.8	8.2	4.8	7.4	16.8	5.4	7.0	7.0	8.0
	Mean (Varieties)	10.1	11.2	13.6	8.1	10.5	18.0	9.1	9.3	10.0	11.1
	LSD$^{(0.05)}$	*Treatment 1.6; Variety 2.7; Treatment.Variety 4.7*									
	WL early relative to control	0.42	0.46	0.45	0.50	0.44	1.01	0.47	0.85	0.30	0.55
	WL at leaf 5 relative to control	0.48	0.45	0.38	0.37	0.45	0.88	0.40	0.63	0.41	0.49
	Mean relative to control	0.45	0.45	0.42	0.44	0.45	0.94	0.44	0.74	0.35	0.52
	LSD$^{(0.05)}$	*Treatment ns; Variety 0.21; Treatment.Variety ns*									
Fresh biomass (g/pot)	Control	569.0	398.0	500.2	505.4	508.2	667.2	445.0	724.4	470.8	532.0
	WL early	250.0	130.4	223.8	148.8	192.2	484.6	165.8	405.8	180.6	242.4
	WL at leaf 5	358.4	217.4	319.0	198.6	262.2	409.4	192.6	377.2	286.0	291.2
	Mean (Varieties)	392.5	248.6	347.7	284.3	320.9	520.4	267.8	502.5	312.5	355.2
	LSD$^{(0.05)}$	Treatment 55 ; Variety 96; Treatment.Variety ns									
	WL early relative to control	0.55	0.35	0.55	0.30	0.39	0.78	0.44	0.59	0.38	0.48
	WL at leaf 5 relative to control	0.85	0.56	0.71	0.42	0.55	0.64	0.45	0.58	0.58	0.59
	Mean relative to control	0.70	0.46	0.63	0.36	0.47	0.71	0.44	0.58	0.48	0.54
	LSD$^{(0.05)}$	*Treatment ns; Variety ns; Treatment.Variety ns*									
Dry biomass (g/pot)	Control	105.3	70.8	107.3	94.8	87.8	130.1	80.4	126.3	85.9	98.7
	WL early	44.6	23.5	42.5	30.3	32.1	80.6	28.9	77.0	32.0	43.5
	WL at leaf 5	58.8	31.3	62.4	35.4	43.6	63.9	30.9	70.5	45.4	49.1
	Mean (Varieties)	69.6	41.9	70.7	53.5	54.5	91.5	46.7	91.3	54.4	63.8
	LSD$^{(0.05)}$	*Treatment 9.9; Variety 17.1; Treatment.Variety ns*									
	WL early relative to control	*0.50*	*0.37*	*0.47*	*0.35*	*0.39*	*0.68*	*0.45*	*0.65*	*0.39*	*0.47*
	WL at leaf 5 relative to control	*0.72*	*0.47*	*0.63*	*0.39*	*0.55*	*0.51*	*0.40*	*0.60*	*0.52*	*0.53*
	Mean relative to control	*0.61*	*0.42*	*0.55*	*0.37*	*0.47*	*0.60*	*0.42*	*0.62*	*0.45*	*0.50*
	LSD$^{(0.05)}$	*Treatment ns; Variety ns; Treatment.Variety ns*									
% Dry matter	Control	18.7	17.8	21.7	18.6	17.2	19.4	18.0	17.7	18.3	18.6
	WL early	18.9	18.1	17.5	20.8	16.9	17.1	16.4	19.6	27.4	19.2
	WL at leaf 5	17.7	14.9	19.7	17.7	17.6	16.9	15.9	18.5	17.3	17.3
	Mean (Varieties)	18.5	16.9	19.7	19.0	17.3	17.8	16.8	18.6	21.0	18.4
	LSD$^{(0.05)}$	*Treatment ns; Variety ns; Treatment.Variety ns*									
	WL early relative to control	1.01	1.03	0.82	1.12	0.99	0.90	0.92	1.12	1.46	1.04
	WL at leaf 5 relative to control	0.95	0.85	0.92	0.95	1.03	0.89	0.88	1.06	0.95	0.94
	Mean relative to control	0.98	0.94	0.87	1.03	1.01	0.89	0.90	1.09	1.20	0.99
	LSD$^{(0.05)}$	*Treatment ns; Variety ns; Treatment.Variety ns*									

The treatment.variety interaction was only statistically significant for shoots per pot. This was due to Q240$^{\phi}$, and to a lesser extent Q253$^{\phi}$, having similar stalk numbers for all treatments, whereas other varieties had fewer stalks in the waterlogging treatments. Despite Q240$^{\phi}$ maintaining stalk numbers in the waterlogged treatments, biomass was reduced. The lack of statistically significant interaction effects for either fresh or dry biomass suggests that variety performance in waterlogged conditions was similar. Tolerance ratings based on this data would most likely be unreliable.

A statistically significant variety effect for shoots per pot was found when relative performance data was analysed. This effect was also due to the maintenance of stalk numbers in waterlogged treatments of Q240$^{\phi}$. No other statistically significant differences in relative performance data were found for other traits in this experiment. Based on these results, tolerance ratings using relative performance of varieties from this experiment would also most likely be unreliable.

Although not statistically significant, Q240$^{\phi}$ produced the highest fresh biomass, dry biomass and relative fresh and dry biomass in the waterlogged early treatments. It maintained stalk population, leaf length and stalk height was not increased as much as other varieties due to waterlogging. It was also more advanced than other varieties when treatments were imposed (Table 6.33).

6.3.2.4 Experiment 4

As in all other pot experiments, dissolved oxygen concentration was maintained below 2 mg/L for the duration of the experiment (Figure 6.27).

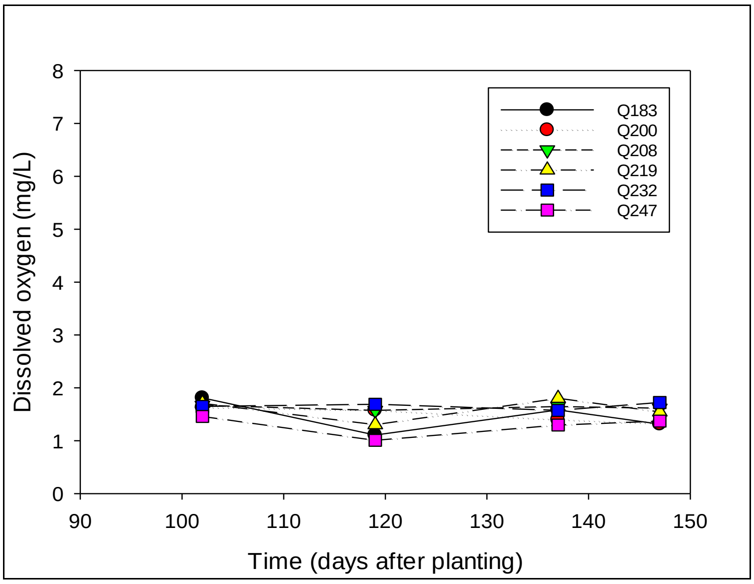


Figure 6.27 Dissolved oxygen concentration within the root zone of six sugarcane varieties subjected to waterlogging in pots

Unlike other pot experiments, no statistically significant effects of waterlogging on leaf lamina length were found in Experiment 4 (Figure 6.28). It is not clear why this occurred, as treatments were imposed in a similar manner, and as indicated in Figure 6.27, anaerobic conditions were similar to those in other experiments. Differences among varieties were present and changed significantly with time (not shown). Leaf data was collected with a LiCor portable leaf area meter in this experiment, whereas in other experiments it was conducted manually. Possibly, this increased error associated with the data. However, given the changes shown in previous experiments, it appears unlikely that this can be solely attributed to a change in measurement methodology.

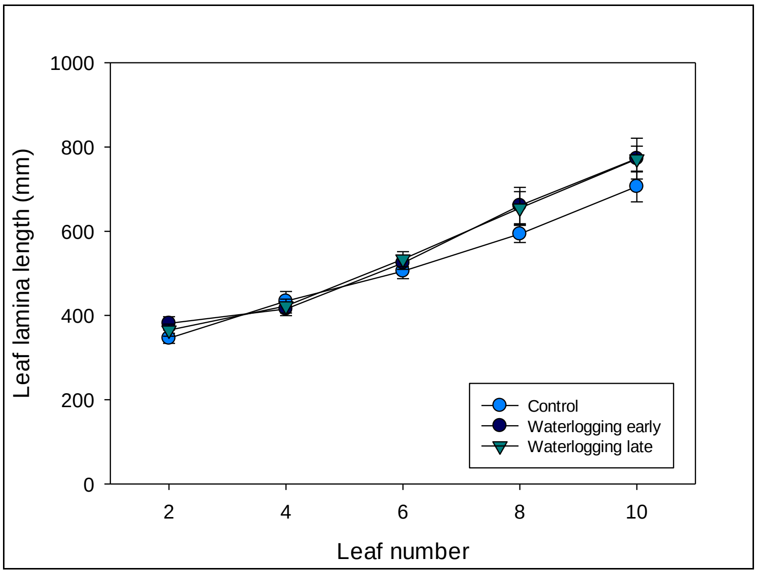


Figure 6.28 Mean Leaf lamina length of nine varieties subjected to waterlogging

Waterlogging treatments did not affect leaf lamina maximum width (Figure 6.29).

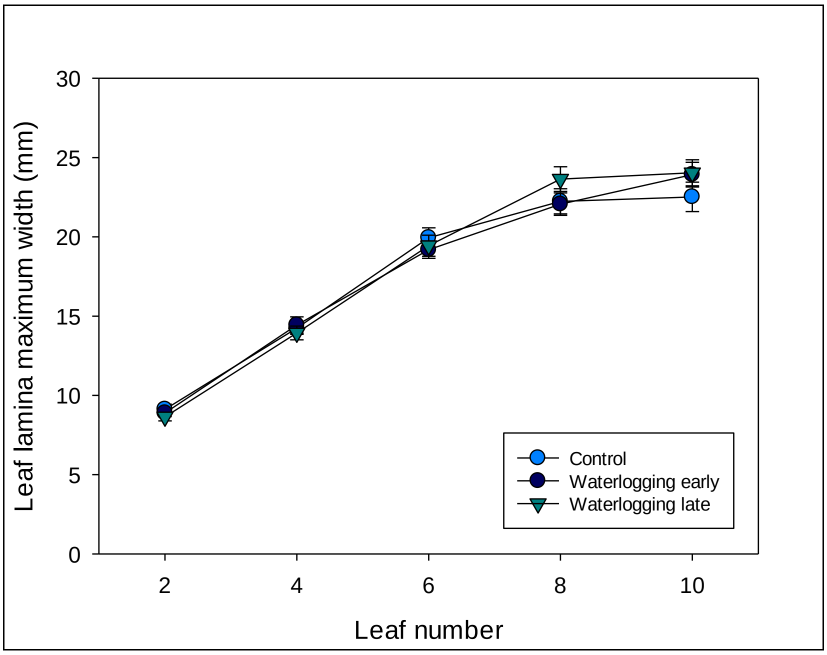


Figure 6.29 Mean leaf lamina maximum width for nine varieties subjected to waterlogging

Tillering was reduced by waterlogging in experiment 4 (Table 3.36). Significant treatment.time and variety.time interactions (not shown) were found. Treatment effects were evident 121 and 148 DAP. At 121 DAP, the waterlogged early treatment was lower than the control. At 148 DAP both waterlogging treatments were lower than the control. The treatment.variety.time interaction was not statistically significant, indicating tillering of all varieties was affected in a similar manner.

Table 6.36 Mean tiller population development over time for nine sugarcane varieties subjected to waterlogging

Treatment	Days after planting						Mean
	42	52	77	92	121	148	
Control	0.5	3.1	5.7	9.3	13.2	21.2	8.8
Waterlogging early	0.3	2.8	5.3	8.6	9.7	14.2	6.8
Waterlogging late	0.4	2.9	5.3	8.3	13.4	17.5	8.0
Mean	0.4	2.9	5.4	8.7	12.1	17.6	7.9
LSD$^{(0.05)}$:	Treatment 0.5; Time 0.5; Treatment.time 1.0						

At final harvest statistically significant treatment effects were found for shoots per pot, fresh biomass, dry biomass and crop percent dry matter (Table 3.37). Shoot population, fresh and dry biomass were all reduced in the two waterlogging treatments in comparison to the control. The late waterlogging treatment had significantly higher shoot numbers, significantly lower fresh biomass and similar dry biomass as the early waterlogging treatment. Lower fresh biomass was most likely due to this treatment being exposed to the waterlogging stress closer to the time of harvest. The plants had low moisture content (100 - % DM) indicating the inability of the root system to supply moisture. The early treatment was more adapted to conditions, with the development of adventitious roots on the soil-water surface. Significant variety effects were mostly associated with better performance of Q183(b and poor performance of Q135.

A significant treatment.variety interaction was found for fresh biomass. This was due to Q135, Q200$^{\Phi}$, Q219$^{\Phi}$, Q232$^{\Phi}$ and Q247$^{\Phi}$ not showing any loss of biomass in the early waterlogging treatment in comparison to the control. A similar trend (P<0.1) was evident for dry biomass.

Analysis of waterlogging treatment performance relative to the control revealed significant treatment effects for all traits and significant variety effects for shoot population and fresh biomass (Table 6.37). Treatments effects were similar to those discussed above between the early and late treatments. In terms of fresh biomass, the relative performance of Q247$^{\Phi}$ and Q232$^{\Phi}$ in waterlogging treatments was significantly better than KQ228$^{\Phi}$, MQ239$^{\Phi}$ and Q208$^{\Phi}$. For shoot population, the relative performance of Q232$^{\Phi}$ in waterlogging treatments was significantly better than all other varieties.

Table 6.37 Crop traits at harvest

Trait	Treatment	Variety									Mean
		KQ228	MQ239	Q135	Q183	Q200	Q208	Q219	Q232	Q247	
Shoots per pot	Control	26.6	19.6	21.2	24.6	28.4	14.8	23.6	21.8	19.2	22.2
	WL early	15.6	13.6	11.8	13.6	19.0	9.2	17.8	20.4	15.6	15.2
	WL late	20.0	16.0	18.4	19.2	24.2	12.6	16.2	23.6	16.2	18.5
	Mean (Varieties)	20.7	16.4	17.1	19.1	23.9	12.2	19.2	21.9	17.0	18.6
	LSD$^{(0.05)}$	*Treatment 1.5; Variety 2.6; Treatment.Variety ns (P=0.06)*									
	WL early relative to control	0.61	0.69	0.55	0.56	0.67	0.63	0.77	1.00	0.84	0.70
	WL late relative to control	0.77	0.83	0.86	0.81	0.85	0.89	0.70	1.17	0.89	0.86
	Mean relative to control	0.69	0.76	0.71	0.68	0.76	0.76	0.73	1.08	0.87	0.78
	LSD$^{(0.05)}$	*Treatment 0.10; Variety 0.20; Treatment.Variety ns*									
Fresh biomass (g/pot)	Control	527.8	619.4	408.0	807.8	437.0	645.8	433.2	501.8	371.6	528.0
	WL early	297.2	388.2	328.0	584.2	445.6	317.2	546.2	534.0	344.4	420.6
	WL late	283.6	224.6	230.0	493.8	286.6	236.4	171.4	392.6	325.2	293.8
	Mean (Varieties)	369.5	410.7	322.0	628.6	389.7	399.8	383.6	476.1	347.1	414.1
	LSD$^{(0.05)}$	*Treatment 58.2; Variety 100.8; Treatment.Variety 174.6*									
	WL early relative to control	0.57	0.65	0.89	0.73	1.02	0.50	1.28	1.03	0.94	0.85
	WL late relative to control	0.55	0.38	0.65	0.62	0.66	0.41	0.38	0.79	1.01	0.61
	Mean relative to control	0.56	0.52	0.77	0.68	0.84	0.45	0.83	0.91	0.97	0.73
	LSD$^{(0.05)}$	*Treatment 0.17; Variety 0.35; Treatment.Variety ns*									
Dry biomass (g/pot)	Control	124.5	143.5	99.1	251.1	114.1	160.7	102.4	150.3	85.5	136.8
	WL early	70.3	76.3	62.9	133.6	108.0	82.0	108.7	114.0	77.7	92.6
	WL late	86.7	63.0	52.6	131.5	91.5	67.8	42.3	96.9	79.5	79.1
	Mean (Varieties)	93.8	94.3	71.5	172.1	104.5	103.5	84.5	120.4	80.9	102.8
	LSD$^{(0.05)}$	*Treatment 17.4; Variety 30.1; Treatment.Variety ns (P=0.07)*									
	WL early relative to control	0.57	0.56	0.70	0.61	0.96	0.61	1.06	0.83	0.99	0.77
	WL late relative to control	0.78	0.46	0.62	0.61	0.80	0.47	0.41	0.75	1.13	0.67
	Mean relative to control	0.68	0.51	0.66	0.61	0.88	0.54	0.74	0.79	1.06	0.72
	LSD$^{(0.05)}$	*Treatment 2.1; Variety ns; Treatment.Variety ns*									
% Dry matter	Control	23.7	23.4	24.4	29.7	26.0	23.7	23.7	26.3	22.8	24.9
	WL early	22.8	19.8	19.2	22.8	23.9	24.8	19.8	21.0	23.1	21.9
	WL late	31.1	28.1	25.7	26.8	31.3	29.7	29.2	24.8	25.2	28.0
	Mean (Varieties)	25.9	23.8	23.1	26.4	27.1	26.1	24.2	24.1	23.7	24.9
	LSD$^{(0.05)}$	*Treatment ns; Variety ns; Treatment.Variety ns*									
	WL early relative to control	1.03	0.84	0.82	0.81	0.92	1.07	0.83	0.79	1.03	0.90
	WL late relative to control	1.37	1.20	1.10	0.96	1.21	1.28	1.23	0.98	1.12	1.16
	Mean relative to control	1.20	1.02	0.96	0.89	1.06	1.17	1.03	0.88	1.08	1.03
	LSD$^{(0.05)}$	*Treatment 0.12; Variety ns; Treatment.Variety ns*									

6.3.2.5 Combined analysis of pot experiments

Relative performance data for fresh biomass from all four pot experiments is shown in Table 6.38. Four varieties were common to all experiments (Q135, Q208$^{\Phi}$, Q232$^{\Phi}$ and Q247$^{\Phi}$). Statistical analysis of the combined data for these four varieties showed a statistically significant variety effect. The relative performance of Q208$^{\Phi}$ in waterlogged treatments was significantly worse than Q135, Q232$^{\Phi}$ and Q247$^{\Phi}$. This is in contrast to Q208$^{\Phi}$'s good rating in QCANESelect in most regions (Table 5.2).

Data from experiments two and four were also combined in a separate analysis. These two experiments included all varieties that were used in the Ingham field experiment.

The relative performance of Q208$^{\phi}$ and MQ239$^{\phi}$ in waterlogged treatments was worse than all other varieties. Q219$^{\phi}$, Q232$^{\phi}$, Q247$^{\phi}$ and Q200$^{\phi}$ were also shown to perform better than KQ228$^{\phi}$.

Table 6.38 Relative performance (fresh biomass) of sugarcane varieties in comparison to the control from four pot experiments

Experiment	Treatment*	Variety												
		Q135	Q183	Q200	Q208	Q219	KQ228	Q232	MQ239	Q240	Q247	Q252	Q253	SP80
1	WL	0.38	0.48		0.18		0.36	0.80		0.71	0.24	0.44		0.23
	WL + Recov	0.65	0.67		0.63		0.61	0.69		0.70	0.55	0.58		0.54
	Mean	0.51	0.57		0.41		0.49	0.74		0.70	0.39	0.51		0.39
2	WL early	0.77	0.64	0.88	0.50	0.77	0.51	0.72	0.51		0.56			
	WL late	0.76	0.89	0.85	0.58	0.82	0.71	0.75	0.51		0.82			
	Mean	0.77	0.76	0.86	0.54	0.79	0.61	0.73	0.51		0.69			
3	WL	0.35		0.55	0.30			0.39	0.55	0.78	0.44		0.59	0.38
	WL late	0.56		0.71	0.42			0.55	0.85	0.64	0.45		0.58	0.58
	Mean	0.46		0.63	0.36			0.47	0.70	0.71	0.44		0.58	0.48
4	WL early	0.89	0.73	1.02	0.50	1.28	0.57	1.03	0.65		0.94			
	WL late	0.65	0.62	0.66	0.41	0.38	0.55	0.79	0.38		1.01			
	Mean	0.77	0.68	0.84	0.45	0.83	0.56	0.91	0.52		0.97			
Overall mean		**0.63**	0.67	0.78	**0.44**	0.81	0.55	**0.71**	0.58	0.71	**0.63**	0.51	0.58	0.43
		LSD$^{(0.05)}$: Variety 0.1 (for comparison of Q135, Q208, Q232, Q240 only)												
Mean Exp 2 and 4		0.77	0.72	0.85	0.50	0.81	0.58	0.82	0.51		0.83			
		LSD$^{(0.05)}$: Variety 0.21												

Table 6.39 Ranked performance of varieties from the combined analysis of experiments two and four and waterlogging tolerance ratings from QCANESelect^{TM}

Variety	Mean relative fresh biomass	QCaneSelect*
Q208	0.50	Good-Poor
MQ239	0.51	Good
KQ228	0.58	Average-Poor
Q183	0.72	Good-Poor
Q135	0.77	Poor
Q232	0.81	Good-Average
Q219	0.81	Good
Q247	0.83	Average-Poor
Q200	0.85	Good-Poor
* ratings can be variable across regions		

A comparison of the mean relative performance of varieties in the four pot experiments to waterlogging tolerance ratings in QCANESelect™ does not provide any validation of the pot experiment method (Table 6.39). This is due to the variability of tolerance ratings in QCANESelect™. Where, a varieties rating isn't variable, the pot experiments would generally support the good rating of Q219$^{\phi}$, but not the good rating of MQ239$^{\phi}$ or the poor rating of Q135. It is not clear which rating is more reliable, the pot experiments have been conducted using a rigorous experimental approach, but are also an artificial environment in comparison to field conditions.

6.3.2.6 Comparison of pot and field experiments

Relative performance in pot experiments was compared to that in the field trial (Figure 6.30).

Mean relative fresh biomass from pot experiments two and four was compared to relative cumulative cane yield. MQ239$^{\Phi}$ performed poorly in pot experiments but showed very high relative performance in the field.

MQ239$^{\Phi}$ germinated slowly in pot experiments, a possible contributing factor in the pot experiments which were waterlogged when plants were significantly younger than the field experiment. MQ239$^{\Phi}$'s performance in the field is more consistent with its rating of good in QCANESelect™. Q200$^{\Phi}$ performed well in pot experiments but poorly in the field, its rating in QCANESelect™ is variable depending on region. Q219$^{\Phi}$, Q232$^{\Phi}$ and Q247$^{\Phi}$ performed well in both pot and field experiments. Q208$^{\Phi}$ performed poorly in both pot and field experiments. Given that there are both consistent and inconsistent results between the two experiment types, the reliability of the pot method is unclear. It is therefore unlikely that this method could be used solely to rate varieties for waterlogging tolerance at this stage.

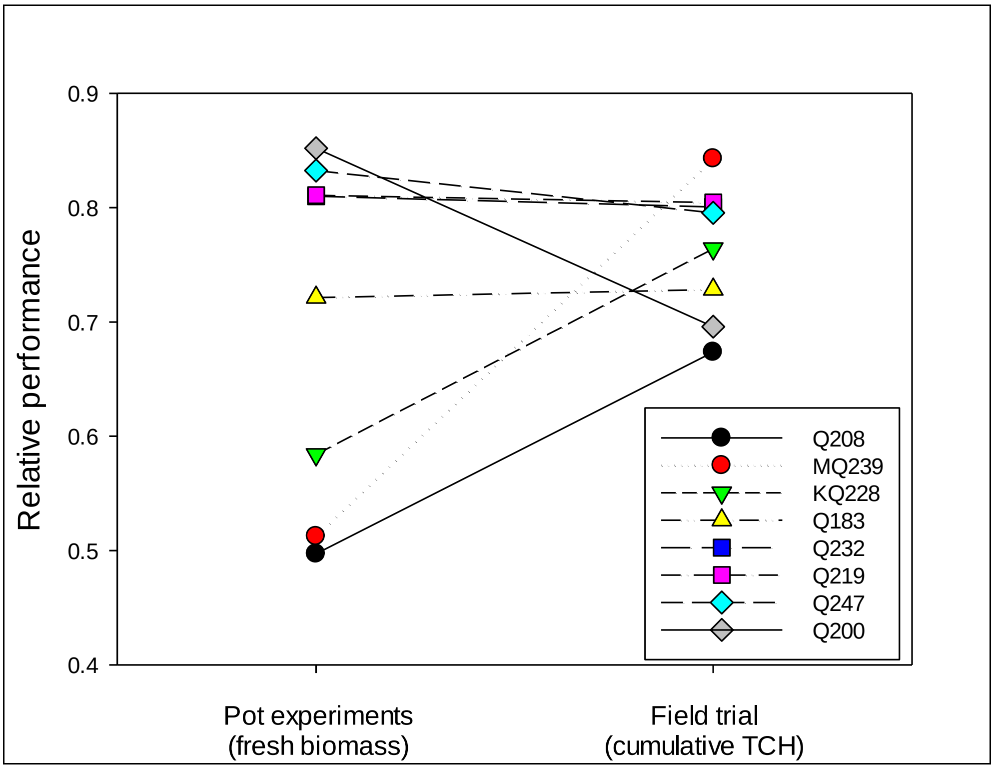


Figure 6.30 Comparison of relative performance of eight varieties in pot and field experiments

7 PUBLICATIONS

ASSCT papers:

Salter B, Park G, Kok E (2018) A field experiment to evaluate the response of sugarcane varieties to waterlogging. Proceedings of the Australian Society of Sugarcane Technologists (under preparation).

Salter B, Kok E (2016) Development of a method to impose waterlogging on sugarcane grown in pots. Proceedings of the Australian Society of Sugarcane Technologists (electronic format) 38. 12 p.

ASSCT poster:

Park G, Salter B (2017) The effect of waterlogging on eight sugarcane varieties grown on a heavy clay soil in the Herbert River. Proceedings of the Australian Society of Sugarcane Technologists (electronic format) 39. 229.

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9 APPENDIX

9.1 Appendix 1 METADATA DISCLOSURE

Table 9.1 Metadata disclosure 1

Data	All
Stored Location	SRA Mackay
Access	Available on request
Contact	Dr B Salter