A FIELD EXPERIMENT TO EVALUATE THE RESPONSE OF SUGARCANE VARIETIES TO WATERLOGGING

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Abstract

RECENT PRODUCTIVITY REVIEWS in the Herbert and Central regions identified strong negative correlations between excessive rainfall and productivity. Waterlogging has a significant effect on sugarcane productivity. It was estimated that yield is reduced by 0.5 t/ha for every day the water-table is within 50 cm of the soil surface. Waterlogging tolerance of sugarcane varieties is not assessed in the current variety selection program. Identification of varieties that perform better under waterlogged conditions is based on anecdotal observations from the field, after a variety is released. If a variety's tolerance to waterlogging was known closer to the time of release, growers could make informed decisions on whether particular varieties are best suited to their farm or blocks within their farm. A field experiment was conducted near Ingham where the waterlogging tolerance of eight sugarcane varieties was assessed. Waterlogging treatments were established at two crop stages (early and late) in both the plant and first ratoon crops, and were compared with an untreated control. Waterlogging plots were surrounded by a bund wall and flooded for a period of 1–1.5 months. 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. 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. The cumulative cane and sugar yield of Q232$^{\phi}$ declined significantly in both waterlogging treatments, but it was one of the better performers across all treatments. Given that the site was poorly drained and control plots most likely experienced periods of saturation, Q232$^{\phi}$ also appeared to have better waterlogging tolerance. This work has implications for tolerance ratings in QCANESelect™.

Introduction

Recent reviews of productivity in the Australian sugarcane industry have highlighted the negative impact of excessive rainfall. In the Herbert, productivity was negatively correlated with November rainfall, although differences among sub-regions were noted (Garside *et al.*, 2014). November rainfall is likely to be an indicator of an early start to the wet season. In the Central region, seasons with low spring and very high wet season rainfall were associated with low productivity (Salter and Schroeder, 2012).

In Tully, rainfall was also negatively correlated with cane yield, with the period from July to September having the greatest influence on productivity over the past two decades (Skocaj and Everingham, 2014). A number of studies (Lawes *et al.*, 2002; DiBella *et al.*, *2008*, McDonald *et al.*, 1999) have also identified a negative effect of harvesting crops late in the season on yield the following year.

This is most likely to be associated with the occurrence of excessive rainfall, waterlogging and prolonged periods of low radiation earlier in the crops growth, and particularly during critical phases of tillering and stalk elongation.

Waterlogging is an abiotic stress that limits the potential productivity of sugarcane in a number of regions. Stress is associated with low dissolved oxygen concentration in the soil profile limiting the ability of the root system to function (Gomathi *et al.*, 2015). Solar radiation is reduced and nitrogen use efficiency is also affected by periods of excessive rainfall, but waterlogging contributes significantly to the decline in yield potential during excessively wet seasons. Previous work has shown that sugarcane lost 0.5 t/ha for every day the watertable was within 50 cm of the soil surface (Rudd and Chardon, 1977).

Growers can reduce the occurrence of waterlogging through management practices. These include: laser levelling blocks, improving existing drainage systems, mound planting, and planting earlier to avoid waterlogging when the crop is small (Reghenzani and Roth, 2006). Planting varieties with waterlogging tolerance is beneficial and, in combination with management practices, offers the best approach to reduce the impact of waterlogging on productivity. However, current 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 variability in ratings for some varieties across regions (Salter and Kok, 2016).

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’ 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 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). Screening genotypes for waterlogging tolerance in pots has been explored, particularly during early stages of development (Burry *et al.*, 2004; Salter and Kok, 2016).

This paper describes a field experiment to test the waterlogging tolerance of current commercial varieties. Accurate information on waterlogging tolerance would assist growers to make informed decisions, based on more robust data, about variety selection on farm and lead to improved productivity.

Materials and methods

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. 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 first ratoon), with the plant crop harvested on 8 September 2016 and the first ratoon crop on 5 August 2017. Crops were fertilised with 120 kg N/ha using a 50:50 mixture of Urea and Agromaster Tropical (polymer coated urea). They 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%) at the site.

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

Varieties (Table 1) were selected with the intention of including varieties with both poor and good waterlogging 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 2). Waterlogging treatments were imposed by bunding the main plots and applying irrigation until the soil profile was saturated and water remained above the soil surface. Irrigation was re-applied to maintain the plot in this waterlogged condition until it was drained.

Table 1—Waterlogging tolerance ratings for sugarcane varieties across regions (QCANESelect^{TM}).

Variety	Region			
	Northern Coastal	Herbert (wet zone)	Burdekin	Central
Q247$^{\Phi}$		Average	Poor	Unknown
MQ239$^{\Phi}$		Good		
Q232$^{\Phi}$	Average	Average	Unknown	Good
KQ228$^{\Phi}$	Average	Poor	Average	Poor
Q219$^{\Phi}$	Good			
Q208$^{\Phi}$	Good	Good	Poor	Good
Q200$^{\Phi}$	Poor	Good	Average	Average
Q183$^{\Phi}$	Poor	Good	Good	Poor

Table 2—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

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).

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 (MS), and green leaf and cabbage (LC). 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 at 70 °C until a constant dry weight was attained.

These data were 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).

Nitrogen content and nitrogen use efficiency

At the harvest of the first ratoon crop, a subsample of the MS and LC 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).

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). In some cases, the early or late waterlogging treatment was removed from the analysis in order to explore interaction effects. Stalk counts over time were analysed with a repeated measures ANOVA model.

Results and discussion

Stalk population development

Stalk counts were conducted during the development of the plant crop (Figure 1). Highly significant ($P<0.01$) treatment.time and variety.time interactions as well as a significant ($P<0.05$) treatment.variety.time interaction were found.

This complex interaction was mostly associated with the last three stalk counts following the imposition of waterlogging treatments. In control plots, KQ228$^{\phi}$, Q200$^{\phi}$ and Q183$^{\phi}$ 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 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.

In the late waterlogging treatment, stalk populations remained mostly stable between 128 and 163 DAP. This differed from the control where the stalk population of some varieties was still increasing. Q208$^{\phi}$ and KQ228$^{\phi}$ stalk populations increased between 163 and 247 DAP, possibly also associated with suckering.

Crop traits at harvest

Plant crop

Waterlogging treatments had no overall effect on stalk numbers at final harvest of the plant crop (Table 3), despite the temporal changes in stalk populations during the waterlogging periods (Figure 1). Variety effects were evident with Q247$^{\phi}$, Q208$^{\phi}$ and Q200$^{\phi}$ having significantly higher stalk population than some other varieties (Table 3). 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.

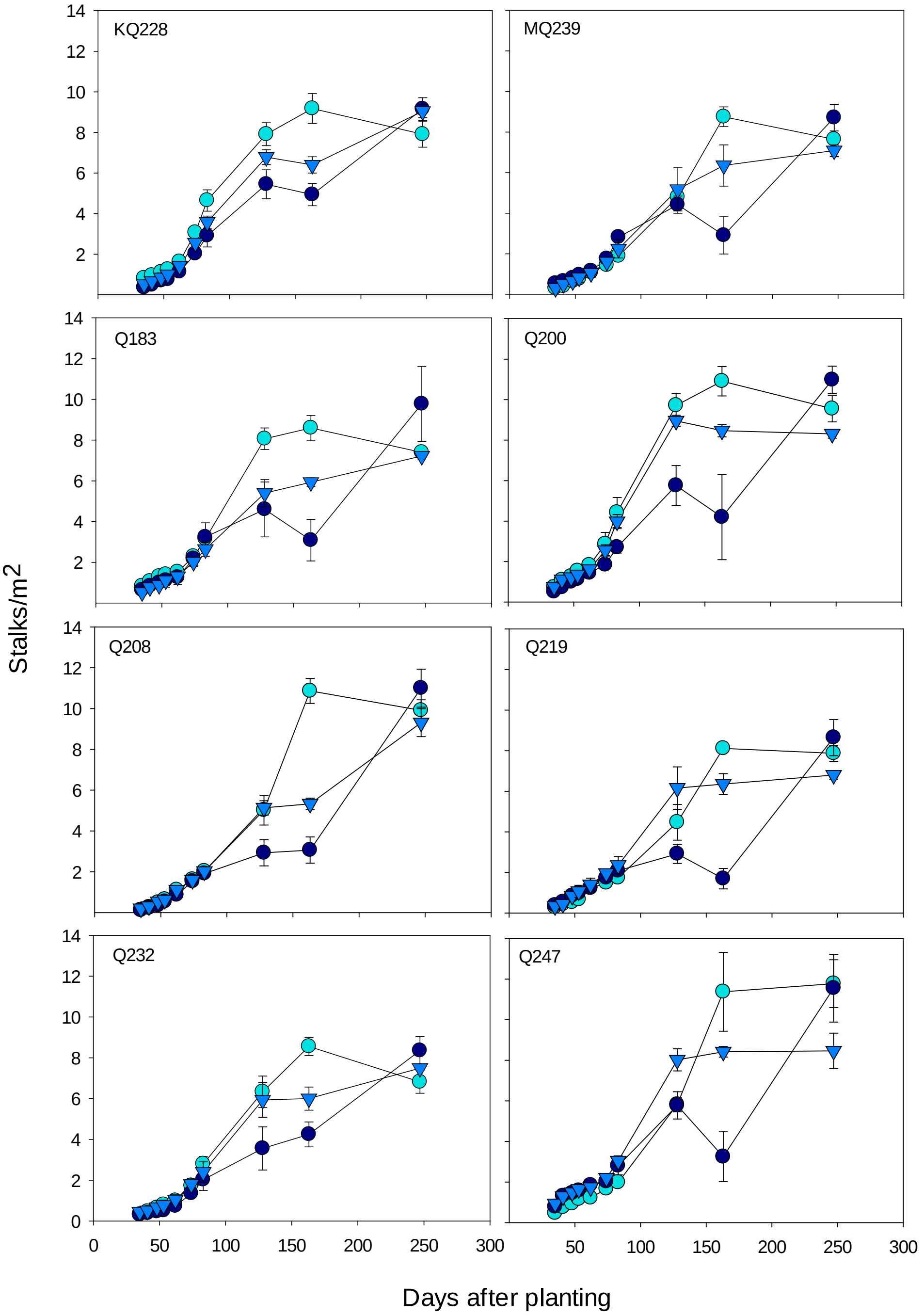

Fig. 1—Stalk population development for eight varieties in control (●), waterlogged early (●) and waterlogged late (▼) treatments. Error bars ± SEM.

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.

Table 3—Crop traits at the plant crop harvest of eight sugarcane varieties subjected to waterlogging.

Yield trait	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									

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.

First ratoon

Overall, waterlogging treatments had no effect on stalk population at final harvest of the first ratoon crop (Table 4). 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 4—Crop traits at the first ratoon crop harvest of eight sugarcane varieties subjected to waterlogging.

Yield trait	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									

Nitrogen uptake and NUE

Overall, the N concentration of MS and LC components at harvest of the first ratoon crop were not affected by waterlogging treatments (Table 5). However, a significant treatment.variety interaction was evident for LC N concentration. This was associated with Q183$^{\Phi}$ having significantly higher LC N concentration in the early treatment whereas Q232$^{\Phi}$ had significantly higher LC N concentration in the control than the early and late treatments. Q219$^{\Phi}$ had significantly higher LC N concentration in 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 MS. 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 with the early treatment. There was no effect of treatments or varieties on nitrogen utilisation efficiency.

Table 5—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% N	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									

Yield

Plant crop

Sugarcane dry biomass, cane yield, CCS and sugar yield at final harvest of the plant crop are shown in Table 6. 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 with 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 is experienced.

Table 6—Plant crop biomass, cane yield, CCS and sugar yield of eight varieties subjected to waterlogging.

Yield trait	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									

The treatment.variety interaction was significant for cane and sugar yield (Table 6), 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 is not present when crops are very young. CCS was not affected by waterlogging treatments. MQ239$^{\phi}$, Q219$^{\phi}$ and Q232$^{\phi}$ had lower CCS than KQ228$^{\phi}$, Q208$^{\phi}$ and Q247$^{\phi}$.

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 7). The loss of 23.7 tc/ha (34% loss) due to an early waterlogging event that 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.

Table 7—First ratoon crop biomass, cane yield, CCS and sugar yield at final harvest.

Yield trait	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*									

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 relatively 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 QCANESelect$^{\text{TM}}$ can vary 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. CCS was not affected by waterlogging treatments. MQ239$^{\Phi}$, Q219$^{\Phi}$ and Q232$^{\Phi}$ had lower CCS than Q247$^{\Phi}$, Q200$^{\Phi}$ and KQ228$^{\Phi}$.

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 interaction existed for both cumulative cane and sugar yield (Figure 2).

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 performers. 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$^{\Phi}$ appears to withstand these conditions better than other varieties, indicating it does have some tolerance.

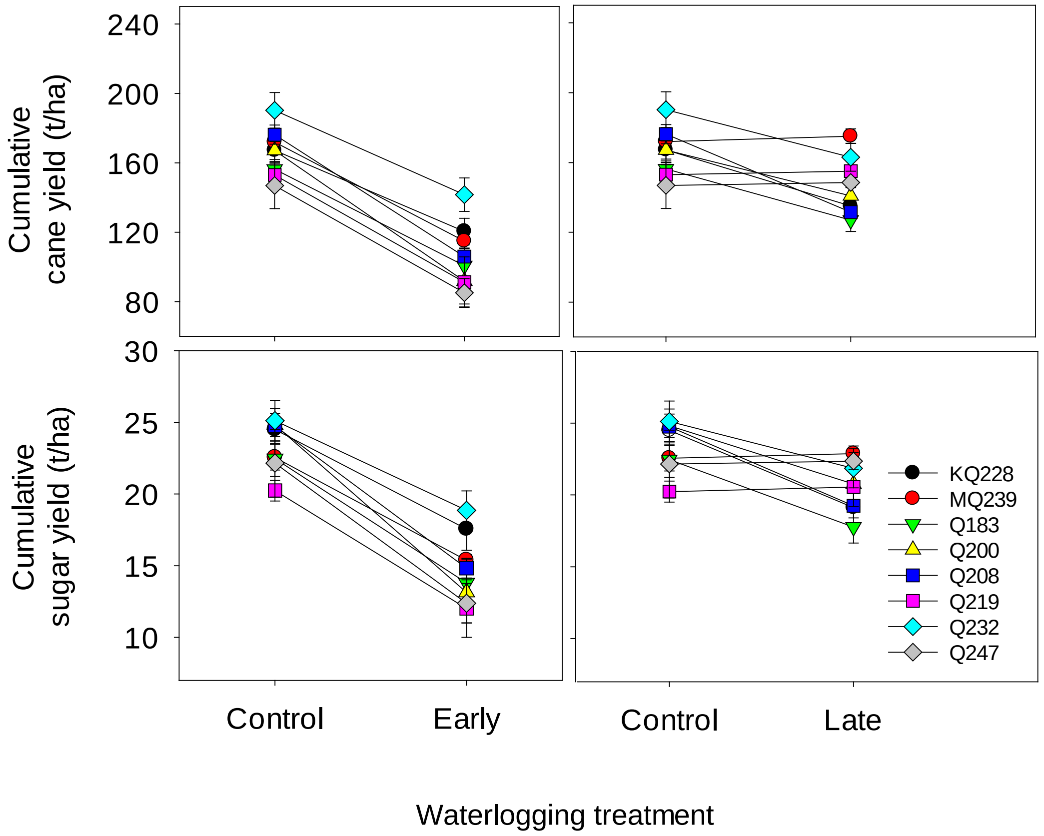

Fig. 2—Cumulative cane (top) and sugar (bottom) yield of eight varieties subjected to waterlogging early or late in the development of both plant and first ratoon crops.

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$^{\phi}$, MQ239$^{\phi}$, Q247$^{\phi}$ and Q219$^{\phi}$) tended to have varying growth characteristics. Q232$^{\phi}$ had low stalk numbers in comparison with other varieties, but these stalks were larger than those produced by other varieties. Q247$^{\phi}$ had high stalk numbers, but these stalks were relative light in comparison with other varieties.

Work conducted by The University of Melbourne with Q232$^{\phi}$ suggested that it produced aerenchyma like tissue in adventitious roots to a greater extent than Q247$^{\phi}$ (Rosli, 2016). In this experiment, ratings of aerial roots and the number of nodes with aerial roots were inconclusive (data not shown).

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 from 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 with 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 high total Crop N. However, this was not the case for Q247$^{\phi}$ and other varieties like Q183$^{\phi}$, which also accumulated relatively high total crop N.

Sugarcane has been shown to have a wide range of physiological 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.

Tolerance ratings

Some differences exist when results from this experiment are compared with waterlogging tolerance ratings in QCANESelect$^{\text{TM}}$. 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 this trial, Q247$^{\phi}$ performed relatively poorly when waterlogged early but performed well when waterlogged late. QCANESelect$^{\text{TM}}$ could potentially include more specific information like this. Q232$^{\phi}$ is rated as average tolerance in QCANESelect$^{\text{TM}}$.

Data from the trial indicate it is possibly better than this, as it performed well on a poorly drained soil in a low lying position in the landscape. Q208$^{\phi}$ has a variable rating in QCANESelect$^{\text{TM}}$ 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 are 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 QCANESelect$^{\text{TM}}$ ratings, but this new information should be considered.

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