Changes in photosynthesis, growth, and sugar content of commercial sugarcane cultivars and Erianthus under flood conditions

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ABSTRACT

Sugarcane (Saccharum spp.) is an economical crop in the tropical and subtropical countries. However, because of global climate change, flooding has become problematic, particularly during the rainy season, in Thailand. We investigated the effects of floods on three commercial sugarcane cultivars, namely NiF8, U-thong 6 (UT6), and U-thong 9 (UT9), as well as Erianthus spp. Growth was assessed using a pot experiment in a glasshouse with two treatments: (1) control and (2) 60 d of flooding followed by 30 d of normal conditions. In comparison with control, during prolonged flooding, Erianthus showed greatly decreased CO₂ assimilation, whereas NiF8, UT6, and UT9 showed slightly declined CO₂ assimilation. Growth in plants subjected to 60 d of flooding was less influenced by floods while sucrose content was not affected except in UT6. During flooding, some roots died, resulting in plants compensating adventitious roots to offset the negative effects of root death and to assist them in maintaining their growth, which appeared from the submerged nodes, with different characteristics for each cultivar. However, 30 d after draining, roots remained damaged, while adventitious roots died, resulting in lesser growth as compared with the control, but it did not significantly affect sucrose content and sugar yield. This study suggests that sugarcane plants need to produce the adventitious roots to compensate their roots’ death during flooding and require time to recover their root system after flooding for obtaining the optimum yield and quality at harvest.

Abbreviations: A, CO₂ assimilation; d, day; DAT, days after treatment; DO, dissolved oxygen; EC, electronic conductivity; hr, hour; LA, leaf area; mo, month; UT6, U-thong 6; UT9, U-thong 9; yr, year

Sugarcane (Saccharum spp.) is an economically important crop for sugar and bioenergy production in many tropical and subtropical countries. High sucrose content in cane is one of the priorities for sugarcane farmers and sugar mills to obtain high price and sugar yield, respectively. Moreover, the residues or by-products of sugar mills, biomass, and bioethanol, can be utilized as an alternative source of energy. In Thailand, sugarcane production has dramatically increased as a result of an encouragement by the government for switching arable lands from rice to sugarcane for better returns (USDA Foreign Agriculture Service, 2014). However, because of the rising global temperature accompanied with changes in weather and climate, which results in more frequent and more severe flooding, negative effects on sugarcane are often observed, particularly during the rainy season. Furthermore, the change from paddy fields to sugarcane fields may increase the risk of floods and cause problems for cane growers especially in the central basin. Two predominant sugarcane planting patterns exist: (1) at the end of the rainy season (October–January) in irrigated areas and (2) in the early part of the rainy season (April–May) in rain-fed areas. The rainy season is from May to September and there are two rainfall peaks in May and August (Chokngamwong & Chiu, 2006). During the rainy season, sugarcane planted during the early part of the rainy season is 5–6 mo of age, coinciding with the grand growth phase (4–10 mo), which is important for cane formation, elongation, and accumulation of yield (Gascho, 1985). Thus, flooding at this stage may adversely affect growth and eventually cause negative effects on yield and quality of sugarcane during the maturation or ripening phase.

Generally, the extent of damage by flooding on sugarcane differs between the genotypes, environmental condition, stage of growth, and duration of stress (Gomathi et al., 2014). Cane and sugar yield decreased because of decrease
in photosynthesis, root development, leaf area (LA), LA index (LAI), tiller production, stalk height, and sucrose yield (Gomathi et al., 2014; Viator et al., 2012; Webster & Eavis, 1972). However, previous study reported that flooding for 15–30 d when sugarcane was 6 mo old did not affect CO₂ assimilation, sucrose content, stem and total dry weight while LA was reduced (Jaiphong et al., 2016). Sugarcane growth has been shown to be restricted via decrease in metabolic activity of roots because of hypoxia occurring during flood conditions (Gomathi et al., 2014). Plants adapt to flooding by developing adventitious roots with well-developed aerenchyma to assist the maintenance of root activity and the supply of required oxygen, and also contribute to higher dry matter accumulation (Drew, 1997; Gilbert et al., 2007; Gomathi et al., 2014; Jaiphong et al., 2016). Recently, the genus Erianthus, one of the Saccharum complex, has become important as a genetic resource in sugarcane breeding for biomass production because of its tolerance to extreme conditions, such as drought and flooding. A previous study identified root development of Erianthus in saturated soil as deep as 250 cm, whereas the root of Napier grass was found at < 135 cm from the ground. Meanwhile, the pot experiment reported Erianthus increased biomass production and had well-developed aerenchyma on the roots of plants grown under waterlogged conditions (Matsuo et al., 2001). Moreover, inter-generic and inter-specific Saccharum hybrids with Erianthus arundinaceus and S. spontaneum grew well under a flooded condition for 6 mo (Deren et al., 1991). Thus, Erianthus is a potential genetic resource in sugarcane breeding not only for higher biomass production and drought tolerance but also for flood tolerance.

To the best of our knowledge, information regarding physiological characteristics and growth ability of commercial cultivars and Erianthus under a flooded condition is lacking. The objective of the present study was to determine changes in photosynthesis, growth, and sugar content in three commercial sugarcane cultivars and Erianthus under long-term flood conditions and after the change to normal conditions. Moreover, morphological changes and development of adventitious roots were analyzed for gaining a better understanding of its adaptive significance of tolerance.

Materials and methods
Study site, plant material, and treatment
A pot experiment was conducted in a glasshouse at the University of the Ryukyus, Okinawa, Japan (26°15′ N, 127°45′ E; altitude 127 m) from May 2014 to Feb 2015. Three sugarcane cultivars, NiF8, U-thong 6 (UT6), and U-thong 9 (UT9), and Erianthus spp (Erianthus) were used. NiF8 is the most popular and commercial cultivar in Japan and has been reported to have flood tolerance because of less affected growth and well-developed adventitious roots to compensate for original roots during flooding (Hidaka & Karim, 2007; Jaiphong et al., 2016). Erianthus is one of the genus in Saccharum complex, adapting well to the environment, and an important genetic resource for sugarcane. Both were received from Tropical Agriculture Research Front, Japan International Research Center for Agricultural Science (JIRCAS) at Ishigaki, Okinawa. The other two sugarcane cultivars, UT6 and UT9, were introduced from Suphan Buri Farm Crops Research Center, Department of Agriculture, Thailand. Pest-checking was performed at the plant protection station Ministry of Agriculture, Forestry and Fisheries of Japan in Okinawa, 1 yr before being used for the experiment. UT6 and UT9 were commercial cultivars, but there is no report of their flooding tolerance, though they are recommended to be planted in a central region of Thailand where there is a possibility of flooding every year.

The experiment simulated the planting pattern in Thailand. Matured stems of sugarcane and Erianthus were selected for making seedlings, afterward fertile nodes were cut then germinated in a tray on 15 May 2014. One mo after, seedlings were transplanted into 1/2000 a Wagner pots (a: are unit, pot diameter is 25 cm with 500 cm² surface area) filled with dark red soil (Shimajiri mahji), sand, and peat moss (1:1:1, v/v). Initially, an automatic drip irrigation system was used to water the plants for 15 min (495 mL) every morning. The level of irrigation was then doubled 3 mo after transplanting by watering the plants at noon as well, and tripled 5 mo after transplanting through an additional watering at evening. Through the experiment, tillers of sugarcane cultivars were immediately removed after emergence to avoid the competition within a plant and to understand better the treatment effects by focusing on the main stems, except Erianthus which has a great number of tillers.

Flooding treatment began during the rainy season (May–September) when the sugarcane plants were 4–6 mo of age, i.e. during the grand growth phase. Six mo after transplanting (21 November), uniform plants were selected and used for the experiment. Two treatments consisting of the control (C) and flooding (F) were established. Control plants were irrigated with an equivalent amount of 50% (v/v) of soil moisture, whereas during the flooding treatment, plants were submerged up to 35 cm above the soil surface in 45 L plastic buckets for 60 d. Subsequently, water was drained and plants were irrigated to the same extent as the control for 30 d.

Eighteen plants were prepared for each treatment. Plants were weekly fertilized by replacing irrigation with 500 mL of Hoagland’s nutrient solution composed of 4 mM
KNO₃, 6 mM Ca(NO₃)₂·4H₂O, 2 mM MgSO₄·7H₂O, 2 mM KH₂PO₄, 0.5 μM CuSO₄·5H₂O, 6.3 μM MnSO₄·5H₂O, 2 μM ZnSO₄·7H₂O, 25 μM H₃BO₃, 0.3 μM Na₂MoO₄·2H₂O, and 0.1 mM Fe(III)-ethylene diamine tetra acetic acid. During flooding treatment, the solution was not added into the flooding water but re-applied after draining. Plants were arranged with 40 × 90 cm spacing between plant and row in a completely randomized design.

**Growth and sugar content evaluation**

Three plants of each treatment were sampled 1 d before the treatment started (−1), 60 d, and 90 d after the treatment started (DAT) to examine plant growth, damage by flooding, plant adaptation, and sucrose content. LA of the entire plant was measured using a leaf area meter (Li-3100, Li-COR). For stem sampling, stems were cut from the base, and stem length, the distance from the soil surface to the node of the fifth leaf below the top visible dewlap leaf, and stem weight were measured. Each stem was evenly separated into bottom, middle, and top by stem length and squeezed using a three-roller mill to obtain sugarcane juice from each part. For root sampling, adventitious roots appearing from the submerged stem were separately collected and dried in an oven at 80 °C for 48 hr to determine their dry weights. After cutting the stem, underground roots in the pots were washed with water to separate soil, and once roots were dry, their dry weights were determined in the same way as adventitious roots. Underground root dry weight was determined for a single plant in each sugarcane cultivar, whereas Erianthus root included the tiller roots because it was difficult to separate roots of main stem from those of tillers. Therefore, root weight and total dry weight per plant of Erianthus was not compared with the three sugarcane cultivars. All parts of the sugarcane cultivars including leaf, dead leaf, leaf sheath, shoot (the upper part of stem), stem, root, and adventitious root were dried in an oven at 80 °C for 48 hr to determine their total dry weight. The juice was diluted 50 times with distilled water and filtered with a 0.45 μm membrane filter (ADVANTEC), following which the sugar content was analyzed by high-performance liquid chromatography system (LC-20A, Shimadzu) using a column SCR-101 N with oven temperature of 50 °C, flow rate of 0.8 ml/min, and degassed extra pure water as the mobile phase. Sugar yield was roughly calculated using the following equation:

Sugar yield = sucrose content (%)/100 × stem weight (g) × 0.5

where the value 0.5 represents the mean efficiency of the squeezing machine, as calculated by (1 – bagasse weight)/stem weight.

**Photosynthesis measurement**

Photosynthesis rates were measured in third upper fully expanded leaves taken from three plants per treatment on −1, 9, 22, 30, 45, 56, 78, and 90 DAT using a portable photosynthesis measurement system (LCpro-SD, ADC) equipped with an LED chamber (5.8 cm²). The soil plant analysis development (SPAD) values were then measured on the same leaf using a chlorophyll meter (SPAD-502, Konica Minolta). All measurements were conducted between 10:00 am to 02:00 pm at a photosynthetic flux density of 2000 μmol m⁻² s⁻¹, leaf temperatures of 25–30 °C, leaf to air vapor pressure difference of 1.5–3.5 kPa, and ambient CO₂ concentration.

**Transition of water in flooding treatments**

The O₂ concentration of the floodwater was assessed with a dissolved oxygen meter (ID-150, Iijima) using a plastic pipe with holes set around the root zone. The pipes were covered by the aluminum net and set vertically by filling the soil into the pot with a pH meter (B-71X, Horiba) and an electronic conductivity (EC) meter (B-771, Horiba). The oxygen level gradually decreased until 20 DAT, after which it remained constant at <1.0 mg L⁻¹. The pH did not change significantly in plant pots but increased in the water in the plastic buckets (check 1) and in water in the plastic buckets with pot soil (check 2). EC increased consistently in all pots, particularly in Erianthus pots, whereas check 1 was stable (Figure 1). The averages of daily maximum and minimum temperatures were 35.0 ± 4.4 and 11.0 ± 2.8 °C, respectively, with an average relative humidity of 69.27% ± 11.5%.

**Statistic**

Results are given as means ± standard deviations. Mean values between the control and flooding treatments were compared using t-test.

**Results**

**CO₂ assimilation**

At an early stage of flooding on 9 DAT, CO₂ assimilation (A) was not significantly different between the control and flooded plants in any sugarcane cultivars and Erianthus. Subsequently, A gradually decreased in accordance with the stomatal closure in all cultivars. Flooded plants of Erianthus showed a clear decrease in A when flooding was prolonged: A decreased to 3.7–4 μmol m⁻² s⁻¹ on 45 and 56 DAT, respectively, while those of Nif8, UT6, and UT9 were decreased to 10.7, 23.6, and 21.6 μmol m⁻² s⁻¹, respectively, on 56 DAT. After draining, all plants showed an increase in A but remained lower than the control even
the sugarcane cultivars were consistently lower. The total dry weight also did not significantly differ between control and flooding (Table 2).

Root and adventitious root growth

Adventitious roots that emerged from root primordia at the nodes under water and aerial nodes were found a few days after flooding in all sugarcane cultivars and Erianthus. On 60 DAT, UT6 had the highest dry weight (6.3 g stalk⁻¹) (Table 1). The characteristics and quantity of emerged roots were dependent on the cultivar. Erianthus only produced a few roots per node irrespective of node position. NiF8, UT6, and UT9 showed the highest dry weights at node number 5, 4, and 3 above the ground, respectively, and gradually showed a decrease in submerged nodes according to depth and the nodes near the water level 30 d after draining (Figure 2). Flooding decreased the SPAD value only in NiF8 though those in the other cultivars were unaffected (Figure 3).

Growth of shoot and yield

On 60 DAT, the LA data of Erianthus was not collected due to low LA in the control plants because of a broken irrigation tube located in the control plants, resulting in wilting leaves. LA of NiF8, UT6, and UT9 did not significantly but decrease in comparison with the control and flooded plants. Some parameters related to plant growth were decreased by flooding but no significance except a decrease in leaf dry weight of UT6, number of nodes of UT9, and stem diameter of NiF8. Flooding did not even affect stem weight significantly but reduced those of Erianthus, NiF8, and UT9, whereas that of UT6 slightly increased. After flooding, the total dry weight hardly changed (Table 1).

Similarly to the sampling 60 DAT, most of growth parameters were lowered by flooding. LA and leaf dry weight of all the sugarcane cultivars and Erianthus in the flooding treatment remained lower than the control on 90 DAT or 30 d after draining and especially those of UT6 significantly decreased by about 20%, respectively. Stem weight of Erianthus in the flooding treatment was slightly higher than that of the control, whereas those of the sugarcane cultivars were consistently lower. The total dry weight also did not significantly differ between control and flooding (Table 2).
of stem. Sucrose content of NiF8 and UT9 in flooding was not significantly different from the control plants (Figure 6). After draining and re-irrigation for 30 d, no significant difference in sucrose content was found (Table 3).

**Discussion**

In the present study, the decrease in A in flooded plants concurred with the results of a previous study that explained the decrease in A as being because of the slow diffusion of CO₂ in water and the decreased availability of light, resulting in a decreased flow rate of assimilates to the root. However, the decrease in A was dependent on many factors such as genotypes, environmental conditions, stage of growth, and duration of stress (Gomathi et al., 2014). All flooded sugarcane cultivars and Erianthus showed a gradual decrease in A during flooding (Figure 2). The results of the present study were consistent with the findings of previous studies that 30 d flooding with 35 cm deep above the soil did not affect A of NiF8 cultivar (Jaiphong et al., 2016), while the 7 d periodic cycle (during Feb–Aug) showed an unaffected A to Ho 01–12 (energy cane), HoCP 96–540 (sugarcane), and L99–226 (sugarcane) but decreased A of L79-1002 (energy cane) by 50 and 48% in plant cane and ratoon cane, respectively (Viator et al., 2012). Furthermore, these results were in accordance with a previous study that reported a neutral or positive response of A to periodic 7 d flooding (Glaz et al., 2004a) while the periodic flooding cycle caused a neutral or positive response, as plants continued transpiration (Chabot et al., 2002). SPAD value gradually decreased when flooding was prolonged in NiF8, however, the reduction of A by flooding was not only associated with the decreasing SPAD value considering that that of Erianthus was not decreased in the present study, whereas A was greatly decreased under a flooding condition.

After flooding, one of the immediate effects was the absence of oxygen, and a change from aerobic to anaerobic environment affected the growth and functions of roots. On 60 d after flooding, some roots showed symptoms of blackening and rotting. The data revealed that flooding decreased the root dry weight in all sugarcane cultivars and Erianthus, particularly in UT6 where root dry weight was decreased down to 44%. These results were consistent with a previous study that, in the absence of oxygen, root hairs died and eventually turned to blacken and rot, resulting in the entire underground root being choked, and root respiration also being impaired, thereby affecting important metabolic activities of plants (Gomathi et al., 2014). Sugarcanes and Erianthus compensated for the original root death by producing adventitious roots that emerged from the root primordia at nodes under the water and from aerial nodes by

**Sugar content and sugar yield**

Among the sugarcane cultivars, NiF8 had the highest sucrose content and sugar yield on both 60 and 90 DAT, followed by UT6 and UT9, whereas Erianthus contained almost no sugar due to the low stem weight and sucrose content. On 60 DAT, sucrose content was negatively affected by flooding in UT6, but no significant difference between the control and flooding treatments was confirmed in NiF8 and UT9. By contrast, flooding gave a positive effect on sucrose content of Erianthus. (Table 3). Analysis of sugarcane juice separately collected from three parts revealed that sucrose content of UT6 was significantly reduced by flooding at the bottom and middle part (Figures 4 and 5). After draining, these roots no longer grew, and subsequently dried up.
Figure 3. Changes in SPAD value during flooding (1–60 d) and after draining (61–90 d).
Notes: * and ** indicate significant differences between the control and flooded plants at \( p < 0.05 \) and 0.01, respectively, and ns not significant (\( n = 3 \)).

Table 1. Effects of flooding on LA, leaf dry weight, stem weight, stem length, number of node, internode length, stem diameter, root dry weight, adventitious root dry weight, and total dry weight at 60 DAT.

| Cultivar | LA | Leaf dry weight | Stem weight | Stem length | Number of node |
|----------|----|----------------|-------------|-------------|---------------|
|          | cm\(^2\) stalk\(^{-1}\) | g stalk\(^{-1}\) | g stalk\(^{-1}\) | cm stalk\(^{-1}\) | node stalk\(^{-1}\) |
| Erianthus | 4277a | 3812a | 57.6a | 48.4a | 81.1a | 69.3a | 145.3a | 132.6a | 13.6a | 13.0a |
| NIF8     | 3664a | 3447a | 48.6a | 43.1b | 732.6a | 735.0a | 131.0a | 131.0a | 15.3a | 13.3a |
| UT6      | 3940a | 3289a | 47.7a | 40.2a | 673.7a | 604.0a | 109.6a | 98.6a | 15.0a | 13.6a |

Table 2. Effects of flooding on LA, leaf dry weight, stem weight, stem length, number of node, internode length, stem diameter, root dry weight, adventitious root dry weight, and total dry weight at 90 DAT.

| Cultivar | LA | Leaf dry weight | Stem weight | Stem length | Number of node |
|----------|----|----------------|-------------|-------------|---------------|
|          | cm\(^2\) stalk\(^{-1}\) | g stalk\(^{-1}\) | g stalk\(^{-1}\) | cm stalk\(^{-1}\) | node stalk\(^{-1}\) |
| Erianthus | 288a | 231a | 3.0a | 2.8a | 85.6a | 87.3a | 148.0a | 155.3a | 13.0a | 13.0a |
| NIF8     | 4587a | 4143a | 61.5a | 54.6a | 1028.7a | 971.6a | 203.3a | 190.6a | 1.9 | 1.9 |
| UT6      | 4315a | 3582b | 56.8a | 46.1b | 874.6a | 804.0a | 156.0a | 149.3a | 1.9 | 1.9 |
| UT9      | 4420a | 3997a | 52.4a | 47.1a | 746.3a | 723.0a | 130.3a | 118.3b | 1.9 | 1.9 |

Notes: Means followed by the same lower case are not statistically different at \( p < 0.05 \) between the control and flooding treatments (\( n = 3 \)). The units of root dry weight and total dry weight of the sugarcane cultivars are expressed as g stalk\(^{-1}\) and those of Erianthus as g plant\(^{-1}\).
Figure 4. Adventitious root development of UT6 (left) and dry weight of adventitious root at different nodes above the ground under water (35 cm deep above pot soil) (right) \((n = 3)\).

Figure 5. Growth and development of adventitious root under flooding.
hormonal imbalance that is induced by hypoxia in the submerged tissue, and were located in the upper layer of water, which has higher oxygen content (Gomathi et al., 2014). Three types of roots were produced after flooding: (1) those that emerged from the nodes that were located under the water; (2) those that developed from these first roots and grew upward against gravity, and; (3) those that emerged from aerial nodes above the water (Hidaka & Karim, 2007; Jaiphong et al., 2016). These data can explain that UT6 developed the number of roots and root size and length particularly in secondary roots. NiF8 and UT9 had similar characteristics of root growth, whereas Erianthus had a low dry weight and the number of roots at the node above the ground under water, which developed slowly (Figures 4 and 5). Subsequently, a high percentage of original root death of UT6 may have resulted from development of adventitious roots to maintain plant activity and survive under a flooding condition, while the other sugarcane cultivars and Erianthus showed lower percentage of original root death and lower quantity of adventitious roots.

Table 3. Effects of flooding on sucrose content in press juice and sugar yield.

| Cultivars | Sucrose (g 100 g⁻¹) | Sugar yield (g stalk⁻¹) |
|-----------|---------------------|-------------------------|
|           | Control | Flood | Control | Flood |
| Erianthus | 4.3b     | 7.3a  | 1.7a    | 2.6a   |
| NiF8      | 22.9a   | 23.1a | 110.7a  | 103.8a |
| UT6       | 19.6a   | 18.6b | 71.7a   | 68.4a  |
| UT9       | 17.9a   | 18.2a | 60.5a   | 55.1a  |

Notes: Means followed by the same lower case are not statistically different at \( p < 0.05 \) between the control and flooding treatments \((n = 3)\).

increasing numbers during prolonged flooding. It has previously been reported that flooding decreased the primary root weight, whereas plants stimulated adventitious roots with well-developed aerenchyma (Gilbert et al., 2008). These roots developed as a result of the flooding condition, which may result in a decrease in sugar yield.

Figure 6. Sucrose content in sugarcane juice of the three different stem parts of stem as bottom (B), middle (M), and top (T).

Notes: Bars show SD. * and ** indicate significant differences between the control and flooded plants at \( p < 0.05 \) and \( p < 0.01 \), respectively, and ns not significant \((n = 3)\).
After flooding for 60 d, the symptoms by flooding were not clearly observed. Leaves remained green, except NiF8 in which the lower leaves turned yellow during prolonged flooding. However, LA decreased in all the sugarcane cultivars and Erianthus. These decreases may have resulted from the compensation by adventitious roots adopting the function of the original roots. A previous study reported that plant growth was inhibited due to the lack of nutrition and water uptake, whereas the development of adventitious roots and aerenchyma may have helped plants maintain water and nutrient uptake; moreover, these roots adapted better to flooding than the original roots (Begum et al., 2013; Gomathi et al., 2014; Laan et al., 1991). Plants produced roots, and ethylene-dependent death and lysis formed continuous gas-filled channels (aerenchyma) to assist plants maintaining root activity and supplying the necessary oxygen (Drew, 1997). Because of the oxygen concentration of the root zone, internal aeration in plants may be achieved by increasing the root porosity (Gomathi et al., 2014). Plants exposed to 60 d of flooding showed a slightly decreased growth rate in all the sugarcane cultivars and Erianthus. This result was related to the findings of previous studies that flooding inhibited leaf expansion and decreased LA, LAI, and leaf weight (Gilbert et al., 2007; Gomathi et al., 2014; Jaiphong et al., 2016), whereas flooding for <3 mo less damaged LAI (Gilbert et al., 2008). Flooding also decreased stem weight on 90 DAT, which is consistent with a previous finding that water logging over 15–60 d at the grand growth phase decreased yield by approximately 5–30% because of the lack of nutrition and water uptake (Gomathi et al., 2014), while 3 mo of flooding decreased the yield by 18–37% in plant cane and 61–63% in a second ratoon (Gilbert et al., 2008). However, growth and yield loss may depend on the tolerance of the cultivar, as it has been shown that there is loss in yield in CP 95–1376 but not in CP 95–1429 (Glaz et al., 2004b), whereas high water table had no effect on yields of CP 72–2086 and CP 82–1172 but adversely affected CP 80–1743, resulting in a decrease in yield by 25.1% (Glaz et al., 2002). Thus, plants may require more time to recover their root system and growth.

From this study, each of the sugarcane cultivars was thought to have its advantages to survive under a flood condition. Sugar yield, which is the most important factor for sugar refinery, was lowered by flooding in all the cultivars on 90 DAT; however, the decreases were not statistically significant, suggesting flooding for 60 d at this growth stage had little effects on sugarcane. These results are supported by previous studies that 30 d flooding did not affect sucrose content in the flooded plants of NiF8 cultivar compared to the control plants (Jaiphong et al., 2016); 2 d of periodic flooding in each of eight 14 d cycles increased cane and sucrose yield in the CP 72–2086 and CP 80–1827 cultivars (Glaz & Gilbert, 2006); and sugar yields were not affected in CP 72–1210 when grown in a high water table (Pitts et al., 1990). We could not confirm clear effects of Erianthus on flooding tolerance in this study, but it would be worth using Erianthus as a genetic resource since it had higher sucrose content and sugar yield than control on 60 DAT.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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