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Original article

Morphological assessment of water stressed sugarcane: A comparison of waterlogged and drought affected crop

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ABSTRACT

Abiotic stress is recurrent occurring problem for sugarcane crop in terms of hindrance in achieving good and high production. In India, drought coverage is 2.97 lakh ha while 2.5 lakh ha under coverage of waterlogging which is one of the reasons behind low cane production and productivity due to alteration in metabolism, growth and development of the plant either in direct or indirect way. Therefore, we investigated the comparison of morphological losses in drought and waterlogging sugarcanes. Morphological parameters assessed were leaf length, leaf width, leaf area, stalk diameter, cane height, cane weight, internodes number and average internodal length. Also, total root weight, dry matter production of stalk, leaves and roots were observed. Results showed that leaf length was marginally increased in drought canes but it was not so in case of waterlogged canes. Besides, there was decrease in total root weight of sugarcane affected by drought by 16.99% while there was increase by 10.06% in waterlogging affected canes in comparison to normal grown canes. In cane height and stalk diameter, decrease by 18.28%, 7.52%, respectively, in drought and 11.41%, marginal decrease, respectively, in waterlogged affected canes as compared to normally grown canes. Average internodal length was also found to increase in both drought as well as waterlogged canes by 39.02% and 36.60%, respectively, in comparison to normal grown canes. Number of internodes was decreased more in drought affected canes than in waterlogged canes. This study concluded that there are higher morphological losses in sugarcane in drought condition than in waterlogging conditions with respect to normal grown canes.

1. Introduction

Sugarcane is an economical crop and is being grown in number of countries in the world. Due to its long growth cycle, sugarcane faces major environmental constrains that causes impact on its growth and development (Kumar et al., 2019). Considering the abrupt changes in weather conditions, occurrence of abiotic stress has become a recurrent problem. Abiotic stresses alter the metabolism, growth and development of sugarcane either directly or indirectly affecting the crop. Abiotic stresses on sugarcane, as a consequence of changing climate, affect soil health, growth and development of the crop, its chemical composition, accumulation and synthesis of sugar, availability of seed cane and also exacerbate other abiotic/biotic stresses which augment the losses incurred (Shrivastava et al., 2016). Among all abiotic stresses, water stress is the important one in perspective of sugarcane as this plant is known to be water loving crop. Zingaraetti et al. (2012) had defined water stress in plants as the condition where water supply reaches to plant in a very low amount or when intense transpira-

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tion rate is observed in plants. In sugarcane, water stress is responsible for yield variability as sugarcane is known to be water consuming crop (Lakshman and Robinson, 2014). There are two sorts of water stress condition, one is drought and other is waterlogging, considering the climate change problem. Drought in sugarcane is one of the chief problems responsible for worsening the production and productivity of sugarcane throughout the world (Khaled et al., 2018; Misra et al., 2020). Misra et al. (2016) had reported that it is one of the phenomenon's that are being observed regularly and recurrently. This problem is a result of low/deficient rainfall in sugarcane area along with high temperatures that restricts cane growth and development (Silva et al., 2013). Furthermore, this abiotic stress also causes water deficit condition to occur which hampers crop production by showing negative response towards biochemical and physiological processes (Kaushal, 2019; Garcia et al., 2020). Kariniki and Sahoo (2019) had given term to this abiotic stress as a creeping disaster. In India, drought is a serious threat throughout the country and approximately 2.97 lakh ha of area covered under sugarcane is prone to drought, causing hampering to the crop at one or the other stage of growth. Drought coupled with subsequent floods and waterlogging are severe problems in about 2.13 lakh ha in Eastern U.P., Orissa, Bihar, coastal Andhra Pradesh (Nair, 2011) and Maharashtra (Kolhapur area and Marthwada) (Swami et al., 2018). 70% of sugarcane yield and productivity is limited by prolonged water stress faced by the crop during its life stages (Gosal et al., 2009; Morison et al., 2008; Swami et al., 2018). Like many other crops, in sugarcane also, the CO_2 fixation is influenced by water stress (Ray et al., 2009). Water stress, worldwide is accentuated due to the climatic variability induced increased aridity in the regions all over the globe (Riaz et al., 2010). Waterlogging is another water stress problem which is also as important and recurrent as the problem of drought in sugarcane crop. This problem also causes losses in production and productivity of sugarcane (Misra et al., 2016; Krishna and Kamat, 2018). In India, 10–30% of sugarcane area is under such condition and causes 15–45% loss in cane yield and sugar recovery (Sanghera and Jamwal, 2019). Approx. 30–35% of cane area in Bihar faces this problem leading to low productivity without using waterlogging tolerant varieties (Gomathi, 2018). Various factors such as location, depth and duration of waterlogging, flow of water, amount of aerial roots as well as their presence/absence, growth phase of crop and genotypes/varieties, etc., are responsible for losses caused by waterlogging condition in sugarcane (Fukao et al., 2019).

Morphological changes are the first symptoms which are seen as an effect on sugarcane grown under drought and waterlogging conditions. Drought causes negative impact on growth parameters. Reduction in tillering, leaves discoloration, rolling of leaves, leaves folding and shredding are some of the morphological symptoms seen in sugarcane exposed to drought conditions (Kariniki and Sahoo, 2019). Reduced leaf area and narrower leaves as well as decrease in lipid peroxidation are some other characteristic features of canes affected with drought (Shrivastava and Srivastava, 2006). In waterlogging condition, piping in stalks and roots as well as development of adventitious roots are the common changes observed (Gomathi et al., 2018). Presence or absence of aerenchyma tissue is an important feature for surviving under such condition (Kovar and Kuchenbuh, 1994). Glaz et al. (2004) had revealed that canes which do not possess aerenchyma tissue under waterlogging condition had low yields. Several studies have been conducted to assess the losses in canes exposed to drought and waterlogging conditions as well as on improving the productivity and production under such condition but none of the study had showed comparative evaluation of canes grown under both water stress conditions. Thus, the present investigation was aimed to assess the comparison of morphological changes occurring in sugarcane under waterlogging and drought condition.

2. Materials and methods

2.1. Experimental details

The experiments were prepared at IISR, Lucknow (26°56′ N; 80°52′E; 111 m amsl) in completely randomized blocks design with 3 replications each in drought, waterlogging and well irrigated conditions having a plot size of gross: 6 m × 6 R × 0.75 m; Net: 5 m × 4 R × 0.75 m. The soil was prepared with IISR developed technologies and sugarcane (CoLk 94,184 variety) was planted in month of February (spring planting) in trench method with 75 cm row-to-row spacing and three bud setts used for planting. Fertilizer dosage was applied as per recommendation (150 kg N, 80 kg P_2O_5 ha^{-1} and 80 kg K_2O ha^{-1}). All the cultural practices developed at IISR, Lucknow such as timely spray of insecticide, fungicide and weedicide were applied for raising good and healthy crop.

2.2. Environment set up

To establish good and healthy crop, crop has been grown under all recommended practices up to 60 days after planting in all conditions. The stress condition was artificially imposed when crop naturally faces such condition, in drought experiment, during months of May to June which corresponds to tillering phase of crop up to grand growth phase while in waterlogging condition, during months of July-September which corresponds to grand growth phase.

2.3. Well irrigated condition

In this environment, all recommended cultural practices, viz., fertilizers, plant protection, irrigation has been applied to obtain maximum potential yield of the variety. Generally, at every tenth day we supplied irrigation in crop up to first onset of rainfall on basis of soil moisture content (SMC). Even during rainy season, field was critically observed for SMC and supplied irrigation accordingly. Above said activities have been performed up to maturity stage of the crop.

2.4. Drought condition

In this experiment, drought was artificially imposed by withholding irrigation during tillering stage (60 d.a.p.) of the crop up to grand growth stage (120 d.a.p.). The crop was planted in month of February so that tillering stage gets exposed to drought conditions that generally occur in month of May to June (dry season). During artificially imposed stress, to avoid all seepage and water infiltration, polythene sheet was laid out at a depth of 3 m around the drought field. Irrigation was withheld in drought experiment when soil water tension had reached a level of −60 kPa at 15 cm and −30 kPa at 30 cm soil depth. Relative water content (RWC) was determined for assessing drought condition along with soil moisture content (SMC). Samples for SMC were taken at 0–15 cm and 15–30 cm depth at periodical intervals after water was suspended. Installation of tensiometers in the field was done and monitoring of soil water status was performed.

2.5. Waterlogging condition

A deep plot (of 2.1 m) having concrete wall was constructed for waterlogging experiment where surplus amount of water gets filled in rainfall season (July-September). For crop to get artificially imposed by waterlogging condition planting was done in second half of February so as to ensure crop gets exposed to such condition. Waterlogging condition was maintained through continuous water supply or whenever needed for 90 days where crop was standing in water depth of 1 m.

2.6. Assessment of morphological parameters

Following morphological parameters were evaluated in water stressed canes:

2.6.1. Leaf length and leaf width

Leaf length and leaf width of last transverse mark (LTM) leaves was measured while number of internodes present in the stalk of cane was also counted at harvesting in each treatment. Besides, cane height was measured of three randomly selected canes in each clump of treatment.

2.6.2. Leaf surface area

Leaf surface area was calculated by the formula: Leaf surface area = Leaf width × Leaf length × 0.623.

2.6.3. Internodes distance

Internodal distance of each internode was measured by measuring scale and its mean was calculated by adding up all the lengths and dividing it with total number of internodes.

2.6.4. Stalk diameter

Vernier calipers were used for measuring the stalk diameter of mother shoot of three randomly selected sugarcane clumps. Stem diameter of top, middle and bottom parts of stalk were measured and its mean was calculated for considering it to be actual stem diameter of the plant. The cane diameter was expressed in centimeters (cm).

2.6.5. Fresh and dry weight of sugarcane plant (sheath, stalk and leaves)

The harvested canes were separated into stalk, sheath, leaves and roots. The fresh weight of sheath, stalk and leaves were recorded. For dry weight analysis, 100 g (g) of fresh weight of the plant component (or the one available) was kept in the hot air oven at 102 °C for two hours and then dried at 85 °C to a constant weight. The mean dry matter of the plant was expressed in grams per plant (g $plant^{-1}$) and recorded.

2.6.6. Fresh and dry root weight (g $plant^{-1}$)

The treated plants were carefully uprooted. The roots were washed in running tap water to remove all the soil and dirt particles that were adhered to the plant. The fresh root weight of the plant was taken and then total root weight was kept for drying for measuring its dry weight.

2.6.7. Fresh and dry weight of aerial and stilt roots (Specific features in waterlogging)

The plants were carefully uprooted and from harvested sugarcane clumps, aerial roots and stilt roots were properly separated. Washing of roots were performed in running tap water so as to remove all the soil and dirt particles that were adhered to the plant. The fresh weight of aerial roots and stilt roots of the plant were taken and then respective roots were kept for drying for measuring its dry weight. Dry weight analysis of aerial and stilt root was performed as stated earlier in dry weight analysis of total root weight.

2.7. Statistical analysis

The experiment was planned in randomized block design having three replications. Analysis of variance (ANNOVA) was performed using statistical software, CropStats 7.2 (IRRI, 2009).

3. Results and discussion

3.1. Leaf length, leaf width and leaf surface area of water stressed sugarcane

There was an increase of 2.75% and 11.61% in leaf length in drought and waterlogging affected canes, respectively, as compared to normal grown canes. This implies that canes exposed to drought had lower increase in leaf length as compared to waterlogging ones. In leaf width, drought affected canes showed decrease by 31.11% and waterlogging affected canes with 23.17% in comparison to normal grown canes. This difference in leaf width in drought and waterlogging canes were statistically significant (CV = 2.86; CD = 0.183; SE = ±0.04) while in leaf length no statistical significance was obtained (Fig. 1 a, b). The result indicated that though leaf length increase was superior in waterlogging affected canes but leaf width decrease was superior in drought affected canes. The results obtained are contrasting to obtain by Endres et al. (2018) which showed that in water stress condition occurring during tillering and intense growth phase of cane leaf length of SP 79-1011 and RB 855536 decreased by 29.7% and 27%, respectively. Pincelli and Silva (2012) had revealed that variation in leaf width pattern in water deficit condition is an important parameter for tolerance, however, this could be seen when such conditions occur for prolonged time (Holanda et al., 2014). As in our study, water deficit condition is for prolonged time, changes in leaf width have also been observed, suggesting that plant is tolerant to such condition.

Leaf surface area data showed decreased in drought affected canes by 29.17% and by 34.95% in waterlogging affected canes as compared to normally growing (unstressed) canes (Fig. 1c). This showed that leaf area decreased more in case of waterlogged canes than drought affected ones. Data indicated that leaf surface area between drought and waterlogging grown canes was statistically significant (CV = 10.00; CD = 30.54; SE = ±7.77). Study has shown that impinging drought gave such results of decreasing leaf area index. However, no significant difference in leaf area and leaf weight had been showed in irrigated or drought conditions (Singh and Reddy, 1980). Reduction in leaf area and leaf area index has been reported in waterlogged conditions (Gomathi and Chandran, 2009; Gomathi et al., 2010). Hughes et al. (1964) had also revealed that contribution of leaves to its area in waterlogged canes decreased by 26.5% which is lesser than the decrease seen in our result in such condition. This decrease in leaf area could be due to prior recognition of mother shoots from other tillers in waterlogging condition and contribution of its various parts like leaves, total area of leaves and its weight to cane yield was comparatively more under such conditions (Gomathi et al., 2014).

3.2. Number of Internodes, internodal length and stalk diameter

The number of internodes on drought affected canes was decreased by 43.51% while in waterlogged affected ones, it was increased by 10.67% as compared to normally growing (unstressed) canes (Fig. 2). Number of internodes in drought affected canes was relatively lesser but it was *vice-versa* in case of waterlogged ones in comparison to canes grown under normal conditions. Statistical analysis showed that internode number between drought and waterlogging conditions were statistically significant

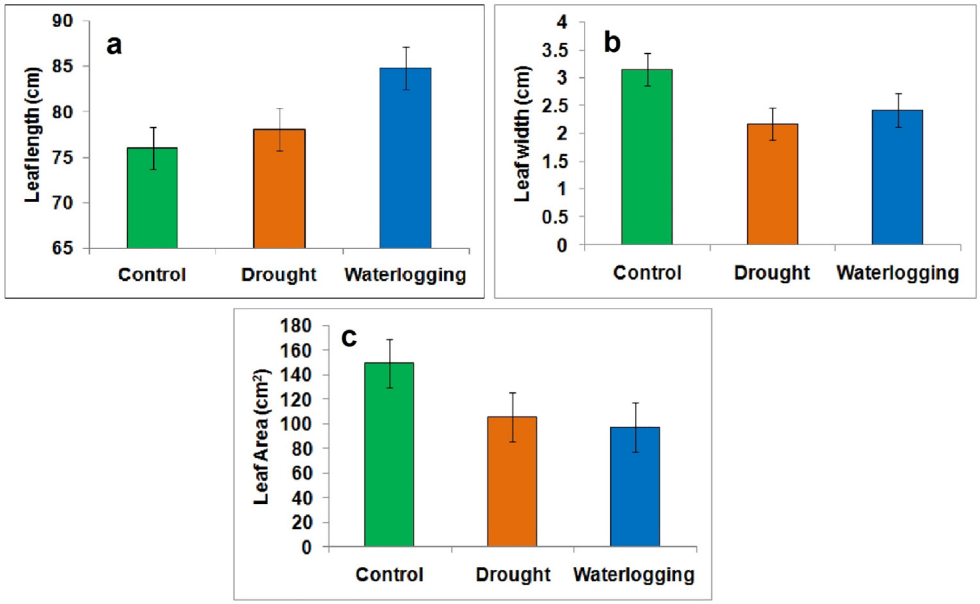

Fig. 1. Effect of drought and waterlogging on (a) Leaf length: Increase in leaf length was observed in both stresses, drought and waterlogging in comparison to control (b) Leaf width: Decrease in leaf width was observed in drought and waterlogging as compared to control, wherein higher decrease in drought canes than from waterlogging canes (c) Leaf area: Decreased in both drought and waterlogging affected canes in comparison to control whereas marginal difference between decrease of drought and waterlogging canes.

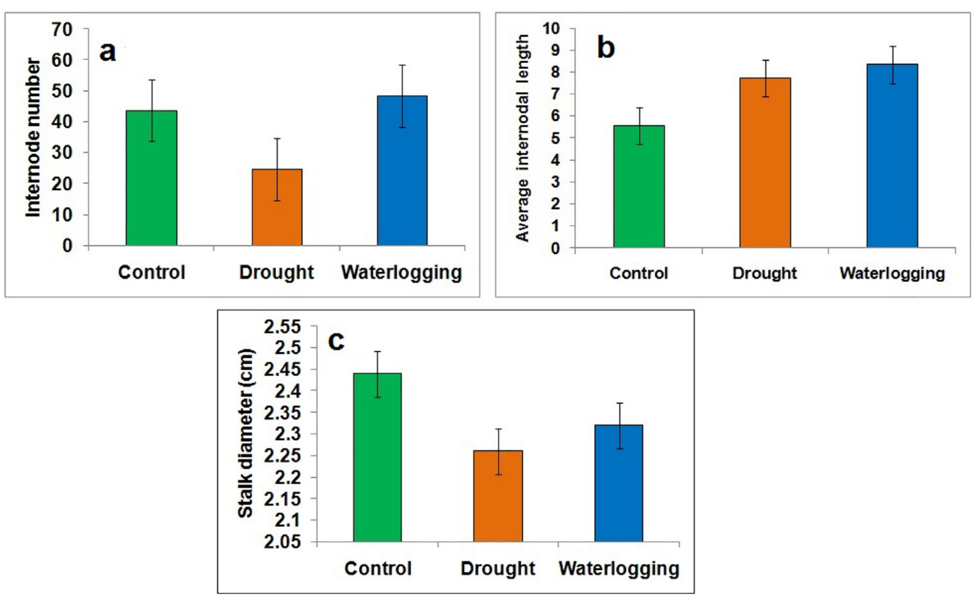

Fig. 2. Effect of drought and waterlogging on (a) Internode number: Internode number was decreased in drought canes while increase in waterlogging affected canes was seen in comparison to control (b) Inter-nodal length: Average internode length was increased in both drought and water logging affected canes in comparison to control (c) Stalk diameter: Stalk diameter was decreased in drought and waterlogging canes in comparison to control with more loss in drought canes than in waterlogging ones.

(CD = 3.02; CV = 3.45; SE = ±0.76). Similarly, Hemaprabha et al. (2012) had also showed that in water deficit conditions, there is decrease in internode number in most of the varieties like Co 99008 (33.35%), Co 86032 (45.76%) while in few increase in internode number was also seen.

Average internodal length data showed that there was increase in average internodal length in drought and waterlogging affected canes in comparison to normal grown canes. This increase was revealed to be of 39.02% in drought affected canes whereas in waterlogging, this increase was of 50.17% with respect to normal grown canes (Fig. 2b) indicating tolerance to waterlogging and drought condition. Data indicated that there was higher increase in average internodal length in waterlogged canes than in drought affected canes. Statistical analysis showed that internodal length between drought and waterlogging canes were statistically significant (CV = 0.108; CD = 0.017; SE = ±0.0045). Anitha et al. (2016) had revealed that in variety CoC24, waterlogging causes increase in internodal length by 17.65% and number of nodes by 14.8% which is much less than the increase observed in our study. Gomathi and Chandran (2009) had suggested that the canes having increase in internodal length under waterlogging condition or flooding had better capability to survive under such condition as the oxygen supply is maintained even when such condition occurs which would otherwise be restricted.

In stalk diameter, both sorts of canes (drought and waterlogging) showed a decreasing pattern against normal grown canes. In drought affected canes, the decrease in stalk diameter was of 7.37% whereas in waterlogging, decrease of 4.91% in comparison to normal grown canes has been observed (Fig. 2c). The data revealed that stalk diameter was statistically non-significant between drought and waterlogging canes. This indicated that under drought condition, canes are relatively thinner than under waterlogging condition. Silva et al. (2008) had showed that effect on stalk diameter is dependent on genotype under drought stress. Lal et al. (1968) had revealed that varieties possessing thinner stalks may flourish relatively better than the ones with thicker stalks in water deficient stress. In waterlogging condition, Gomathi and Chandran (2009) had also observed decrease in stalk thickness in waterlogged canes.

Association of stalk diameter and internodal length has also been observed in studies (Gilbert et al., 2007; Anitha et al., 2016). Gilbert et al. (2007) had showed that rise in internodal length and decline in cane diameter was observed when canes were exposed to waterlogging condition for a long period. It has been reported that under such situation it is one of the characteristic features of shoot tolerance as it contributes to proper oxygen supply to the plant when usual route of oxygen supply is blocked (Anitha et al., 2016; Gilbert et al., 2007). This is similar to the results obtained in our study.

3.3. Cane height and cane weight

There was a decrease in cane height in drought (by 18.25%) and waterlogged affected canes (by 7.11%) as compared to normally grown canes. The difference in decrease in cane height in waterlogged affected canes was higher than the decrease in cane height in drought affected canes (Fig. 3a). Similar results were also obtained by Khaled et al. (2018) in canes exposed to drought stress. However, disparity lies that canes exposed to drought had reduced cane height but increase diameter which was not so in our study. Furthermore, Silva et al. (2008) and Inman-Bamber and Smith (2005) had illustrated that cane height might be affected under drought condition.

Furthermore in cane weight, it was decreased in drought affected canes by 21.33% in comparison to normal grown canes while in waterlogging canes, increase was of 65.43% in comparison to normal grown canes (Fig. 3b). The data revealed that cane height and cane weight between drought and waterlogging canes were statistically significant (CD = 4.30; CV = 0.66; SE = ±1.09; CD = 0.0881; CV = 1.25; SE = ±0.02). Our results were found to be similar with results of Gomathi and Chandran (2009) in waterlogged canes but contrast to results of Kumar et al. (2015) which showed CoLk 94184 variety to be least waterlogging affected variety. Manoharan et al. (1990) had reported that waterlogging causes reduction in many important parameters such as growth of shoots and roots, dry matter production and total crop yield. When waterlogging was of 15–60 days, about 5–30% loss in yield has been reported but when waterlogging conditions prevails for 2 months, loss in cane yield has been found to be 26–36% in different varieties (Manoharan et al., 1990). More et al. (2010) and Singh (2013) had also revealed heavy loss in yield and quality deterioration in sugarcane exposed to waterlogging condition. Reduction in cane weight was alike to that observed by Khaled et al. (2018) in drought affected canes as compared to normal ones (28.6%).

3.4. Total root weight of water stressed sugarcane

There was a decrease in total root weight of sugarcane affected by drought affected canes by 16.99% while there was increase by 4.02% in waterlogging affected canes in comparison to normal grown canes (unstressed canes) (Fig. 4). One important distinguishing feature of waterlogging grown canes and drought/normal grown canes is the presence of aerial roots which grows on water surface of sugarcane due to low oxygen supply under such a condition (Gomathi et al., 2014). In waterlogging condition, our study also showed that total root weight is contributed by aerial roots too besides stilt roots. In respect to number of stilt roots, there was decrease in number of stilt roots in drought and waterlogged canes compared to canes grown under normal conditions. The data showed that total root weight between drought grown canes and waterlogging canes were statistically significant (CD = 0.00; CV = 1.73; SE = ±0.00), however, aerial roots were statistically

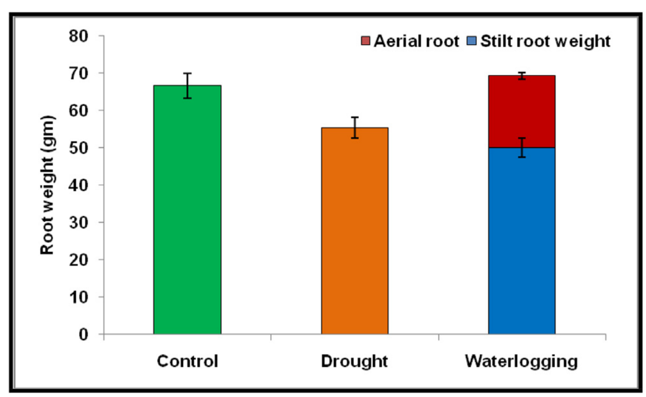

Fig. 4. Effect of drought and waterlogging on total root weight. Reduction in total root weight of drought canes was seen in comparison to control. In waterlogging canes, total root weight was marginally increased in comparison to control due to presence of aerial roots as adaptation.

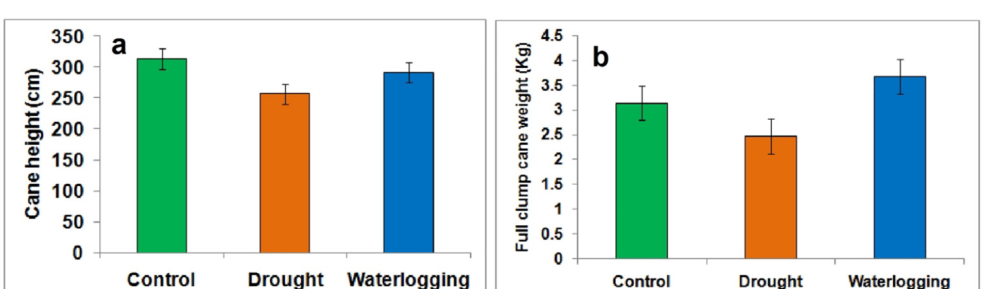

Fig. 3. Effect of drought and water logging on (a) Cane height: Cane height was decreased in drought as well as waterlogging canes in comparison to control, with higher losses in drought as compared to waterlogging canes (b) Cane weight: Full clump cane weight was increased in waterlogging canes while in drought canes, it was reduced in comparison to control.

significant (CD = 0.01; CV = 0.10; SE = ±0.003) with respect to normal grown canes.

Characteristics of roots are one of the important features that help in calculating the adaptive ability of plants in water stress conditions (Songsri et al., 2008; Wang et al., 2009). Growth and development of deep and enhanced roots is used as one of the selection criteria for drought tolerance (Smith et al., 2005). Furthermore, it has been reported that higher root length density causes better and improved water uptake efficiency under water stress conditions (Tardieu et al. 1992; Blum, 2005; Tardieu, 2012). Roots under drought conditions do not extend in dry soil and thus nutrient uptake gets reduced (Shrivastava and Srivastava, 2006). However, in case of waterlogged canes, due to the anaerobic conditions in water, death of root hairs leading to blackening and rotting of roots. As a result, the choking of root system takes place with impairment in respiration of roots (Gomathi et al., 2014).

3.5. Weight of the aerial roots (in waterlogged sugarcane) and stilt roots

Aerial roots are a specific feature for a crop grown under waterlogging conditions (Fig. 5). 68% of the roots in waterlogged condition were aerial roots whereas under normal conditions, there was no aerial root produced. In case of drought conditions, there is no aerial roots produced rather it possess all stilt roots.

Generally for adapting the waterlogged condition, emergence of aerial roots has been observed. Avivi et al. (2016) and Gilbert et al. (2007) had illustrated that in certain varieties, higher aerial root formation occurs in waterlogging condition for supplying oxygen and maintains the root activity. This may appear due to imbalance of hormones which is caused by hypoxia and decrease in oxygen content. These roots are found on the water surface possibly due to high oxygen content in it (Gomathi et al., 2014). In canes growing well under such conditions were found to have aerenchyma extended from shoots up to the tips of roots. This is being observed in most of the species of canes (Justin and Armstrong, 1987). These roots are much more adaptive in comparison to stilt roots under such condition due to the presence of intercellular spaces (Kovar and Kuchenbuh, 1994; Van der Heyden et al., 1998). Adventitious roots were grown in sugarcane in waterlogged conditions which were formed may be due to disproportion of hormones which is created by hypoxia and even decreased supply of oxygen to the submerged tissues. Generally these roots remain in the upper layers of water that were most probably rich in oxygen content. As soon as flood retreat, normal roots play into function that helps in growth of the plant. Under such waterlogging conditions the rate of root growth in sugarcane, extent of branching and fibrous root growth varied, *viz*., BO3 (resistant water logged variety) had maximum root density per unit area (Hughes et al.,1964). A Japanese variety, NiF 8 had showed three different kinds of roots that were grown under waterlogged conditions (1 month) in pots: aerial roots (above water surface) which were reddish black in color, from per existing roots (under water) and whitish in color, newly developed roots, pinkish in color and were grown against gravity (upwards) (Hidaka and Karim, 2007a,b). Generally, the loss in strength of roots under such conditions reduce anchorage of the plant besides affecting nutrient uptake and water, resulting into crop vulnerability due to lodging and uprooting if strong winds accompanied watelogging (Raid, 1992). Regarding soil oxygen content and development of root under such conditions, it has been observed that for adequate growth of root and its development

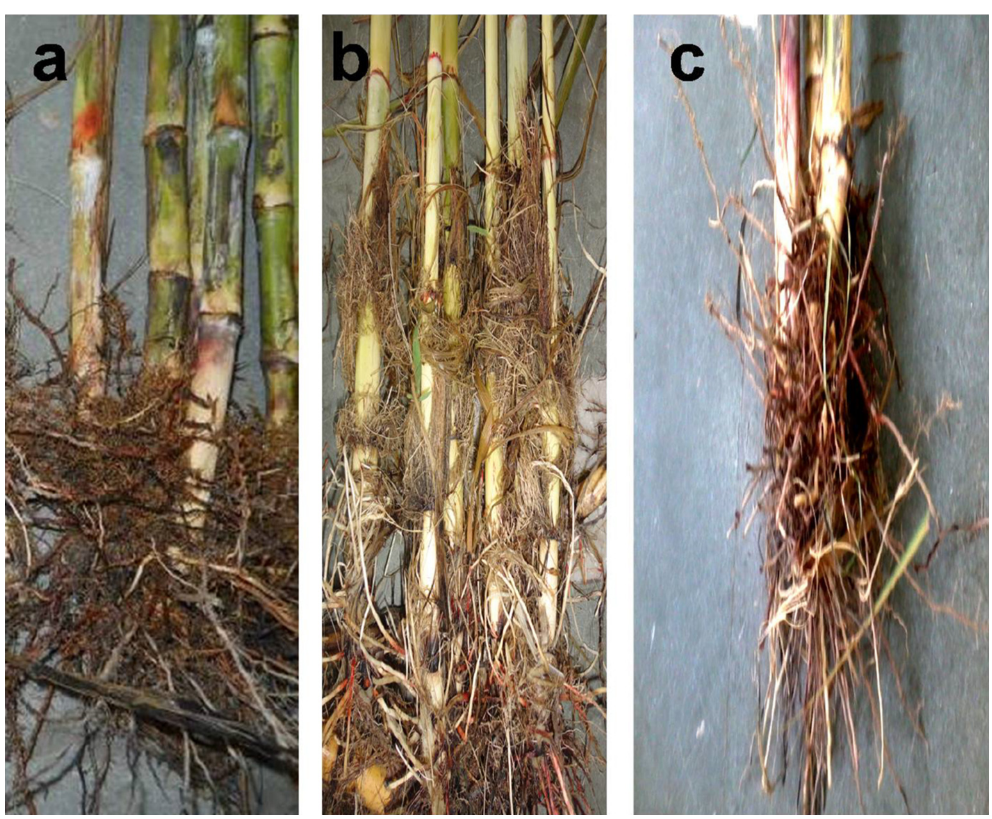

Fig. 5. Comparison of sugarcane roots grown under normal, waterlogged and drought conditions. a. Roots of control canes (stilt roots) b. Prominent aerial roots was seen in waterlogging conditions along with stilt roots c. Stilt roots was reduced and longer in length in comparison to control.

good aeration in top 60 cm of soil was necessary and that too during early growing season. It has been also reported that at lower depths, adequate aeration was comparatively less important (Gardner et al., 1984).

3.6. Per cent partitioning of dry matter of water stressed sugarcane

Per cent partitioning of dry matter of leaf laminae, leaf sheath and roots was observed to be increased in drought affected canes (17.48%, 27.44%, 25.35%, respectively) while it was *vice-versa* in waterlogged ones in comparison to normal grown canes (37.82%, 52.43%, 77.42%, respectively) (Fig. 6). However, in per cent partitioning of dry matter of shoots, decrease was observed in drought ones (31.96%) but increase in case of waterlogged ones (62.67%) on comparing with normally grown canes. Data revealed that per cent partitioning of dry matter of leaf laminae (CD = 0.16; CV = 0.26; SE = ±0.04), leaf sheath (CD = 0.009; CV = 0.01; SE = ±0.002), shoot (CD = 0.02; CV = 0.02; SE = ±0.006) and roots (CD = 0.013; CV = 0.089; SE = ±0.00) were statistically significant. Gomathi et al. (2014) had revealed that reduction in growth of shoots and roots as well as dry matter production and total crop yield occurs in waterlogged affected canes. The loss in cane yield in waterlogged canes depends on the period of waterlogging, the stage of cane growth where it happens and before and after practices of mangement in waterlogging. In drought stress, Lawlor (2013) had found that the growth and development of the plant under such condition is greatly hampered. Similiar trend of reduction in dry mass production of shoots and roots in drought condition as observed in CoLk 94184 variety in this study was also seen by Medeiros et al. (2013) in water stressed plants of variety RB867515. Higher biomass production in drought affected canes causes high tolerance towards such condition due to overexpression of Scdr 2 genes (Begcy et al., 2019). In case of waterlogging, reduction in dry root weight by 35% and 48% had also reported in other studies (Morris, 2005; Gilbert et al., 2007) which is much less than reported in this study (77.42%). This difference in reduction is may be due to longer duration of waterlogging causing higher primary root anoxia condition.

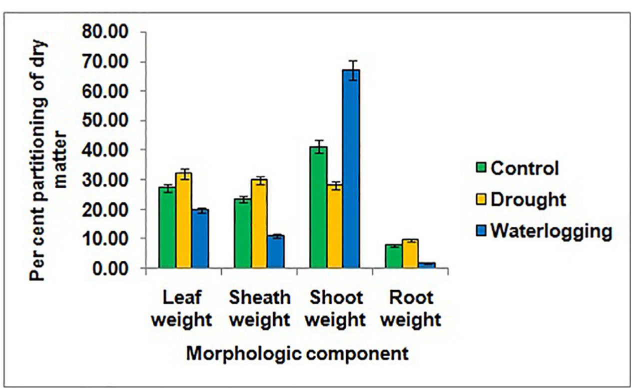

Fig. 6. Effect of drought and waterlogging on Per cent partitioning of dry matter. In comparison to control, dry matter partitioning of leaf weight showed increase in drought and decrease in waterlogging canes, sheath weight was highly reduced in waterlogging canes while increase in drought canes. Similarly in dry matter partitioning of root weight. In shoot weight, dry matter partitioning was highly increased in waterlogging canes and it was reduced in drought canes in comparison to control.

3.7. Cane weight per unit plant, Root weight per unit plant and Leaf weight per unit plant in water stressed sugarcane

Cane weight per unit plant decreased in drought affected sugarcane while there was an increase in waterlogging affected ones. The decrease in drought affected canes was reduced relatively to a lesser extent as compared to the increase in waterlogged ones (Fig. 7a). In root weight per unit plant was decreased while leaf weight per unit plant was increased in case of drought affected sugarcane. In sugarcane grown under waterlogging conditions, root weight per unit plant was almost same while leaf weight per unit plant was decreased in waterlogging affected sugarcane (Fig. 7b). Contrastingly, root weight dry mass in waterlogging condition increased in certain varieties due to higher aerial root formation (Avivi et al., 2016) that helps in oxygen supply to the plant through roots (Hidaka and Karim, 2007a,b).

4. Conclusion

Abiotic stresses are commonly been seen in sugarcane just like in other crops. Drought and waterlogging are amongst the most important ones. Our study concluded that under drought conditions, number of green leaves was affected more than waterlogging conditions. For coping up the problem of drought and waterlogging condition, leaf length was marginally increased in drought condition but decreased in waterlogging condition along with more decrease in leaf width in drought condition (31.11%) than in waterlogging condition (23.17%). Cane height and total root weight was also relatively highly affected more in drought condition (18.25%, 16.99%, respectively) than in waterlogging conditions (7.11%, 4.02%, respectively). Internodes number and internodal length was also hampered more in drought conditions (43.51%, 39.02%, respectively) than in waterlogging conditions (10.67%, 50.17%, respectively). This implies that there are more morphological losses in canes exposed to drought condition than in canes exposed to waterlogging condition. This will contribute to more losses in production, productivity and yield of sugarcane grown under drought conditions than ones grown under waterlogging condi-

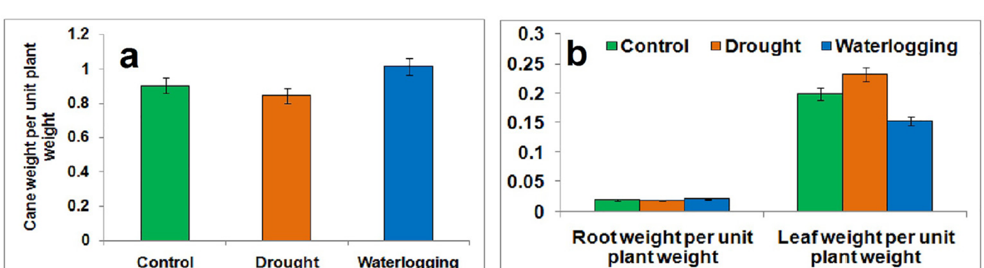

Fig. 7. Effect of drought and water logging on (a) Cane weight per unit plant weight: Marginal increase in waterlogging in cane weight per unit plant weight but in drought it was decreased in comparison to control (b) Root weight per unit plant and leaf weight per unit plant: Marginal difference was seen in root weight per unit plant while in leaf weight per unit plant was highly reduced in waterlogging and increase in drought canes in comparison to control.

tions. Thus, there is a need of developing such cane varieties which are tolerant to such frequent occurring abiotic stresses.

Declaration of Competing Interest

The authors declared that there is no conflict of interest.

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