Bangladesh J. Sugarcane, ***33 & 34*** : *130-139* *August, 2013*

SHORT COMMUNICATION

Performance of Different Sugarcane Genotypes under Flood Stress Condition

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Key words: Dry and green leaves, Adventitious root (AR), Growth rate, Juice quality

Flooding is a natural disturbance affecting crop and forage production worldwide due to the detrimental effects that it provokes on most terrestrial plants (Bailey-Serres & Voesenek, 2008; Colmer & Vosenek, 2009). Among abiotic stresses, flood is an important stress for sugarcane cultivation in Bangladesh. It is because of increased cultivation of sugarcane in low lying char areas prone to periodic inundation by flood water.

The effects of excess water stress from temporary or continuous flooding has been studied extensively (Scott *et. al.*, 1989; Jackson *et. al.*, 1978). Sugarcane root density is greatest near the soil surface with 60% in the 0-30cm depth, but roots may penetrate to 180 cm in well-drained soils (Gascho and Shih, 1983; Paz-vergara *et. al.*,1980). One morphological change in sugarcane roots growing under high water tables is a greater proportion of fibrous to thick roots in the soil layer above the water. The reason is probably an adaptation to lower O_2 levels. A thin root has a smaller path-length for O_2 diffusion to respiring tissue than a thicker root. Presence of root aerenchyma is a key requisite for sustained root activity in flooded soil.The roots of all of 40 sugarcane genotypes examined contained aerenchyma (Ray et. al., 1996; Van Der Heyden et. al., 1998). In species that are flood tolerant, aerenchyma formation is usually constitutive, meaning that it requires no external stimulus, such as flood (Drew, 1997). Glaz et. al., (2002) grew nine sugarcane cultivars under 15 and 38 cm water table depths. They reported a mean yield reduction of 8.3% at the 15-cm water table, but two cultivars had similar yields at both water tables, and the yield of one cultivar was reduced by 25% at 15 cm water table. Generally, sugarcane is not considered a flood tolerant species, but when it exposed to flood sugarcane produces adventitious roots which contains aerenchyma. These adaptations allow some sugarcane genotypes to sustain growth under flood stress. In previous studies, germination and early seedling growth stages were found most susceptible to flood (Miah and Rahman, 2002). In Bangladesh, sugarcane is not planted before November, December which reduces the possibility of flood stress during early growth. Some morphological traits associated with tolerance under flood, however are yet to be identified. Main objective of this experiment was to find out suitable varieties for cultivation in low lying areas of Bangladesh.

An experiment was carried out to screen flood tolerant genotypes during 2009-2010 cropping season. BSRI produced sugarcane genotypes I 124-00, I 112-01, I 7-03, I 78-03, I 111-03, I 137-03, I 139-03, I 231-03, Isd 34, Isd 39 and Isd 40 were grown in plastic pots (2 pots per clone). One pre-germinated seed cutting was transplanted in each pot. Irrigations and other cultural practices were done as and when required to all plant in pot for natural growth. Six months after transplanting two pots of each clone were placed in a concrete tank and inundated in running water (30cm deep above pot soil), while the remaining five pots per clone were kept as non-flooded controls. Green and dry leaf counts were taken after 60, 90 and 120 d of inundation. Data on fresh and dry weight of adventitious roots as well as volume of adventitious roots (ARs) were taken at harvest. ARs were collected and taken in paper bags of known weight and oven dried at 85°C until constant weight. Tolerance rating scale was recorded on greenness of leaves and other factors recorded. Data were recorded on growth rate at 60, 90, 120 d floods.

Laboratory analysis of cane juice was done after 11 months of growth. The cane samples were crushed in a three-roller mill (power crusher). Brix was determined by Brix hydrometer standardized at 20°C and Horne's dry lead method was used for sucrose determination using an automatic polarimeter (Bellingham and Stanley ADP-220®). Juice purity was calculated as the ratio of the sucrose content and corrected Brix reading. Reducing sugars were determined by the method described in Queensland Laboratory Manual [Bureau Sugar Experiment Stations (BSES), 1970]. Statistical analysis was performed and mean values were compared using LSD at 5% level of significance (Gomez and Gomez, 1984).

Plants develop a suite of anatomical, morphological and physiological responses in order to deal with partial submergence imposed by flooding (Striker et al., 2005; Colmer & Voesenek, 2009). The most common anatomical response is the generation of aerenchyma in tissues (Seago et al., 2005), which facilitates the transport of oxygen from shoots to roots (Colmer, 2003a). At morphological level, usual responses to flooding include adventitious rooting and increases in plant height and consequently, in the proportion of biomass above water level (Naidoo & Mundree, 1993; Grimoldi et al., 1999). This also helps to facilitate the oxygenation of submerged tissues through aerenchyma tissue (Colmer, 2003a). At physiological level, flooding modifies water relations and plants carbon fixation. Closing of stomata, with or without leaf dehydration, reduction of transpiration and inhibition of photosynthesis, are responses that can occur in hours or days, depending on the tolerance to flooding of each plant species (Insausti et al., 2001; Striker et al., 2005; Mollard et al., 2008 & 2010). The following sections show the main plant responses at those levels associated with tolerance to flooding.

Partitioning to dry and green leaves

Genotypes have significant effects on dry leaf, green leaf and genotypes. Genotype Isd 39 produced the highest no of green leaf (62.2 %) followed by I 124-00 (57.4 %). The highest growth rate was recorded in the genotype Isd 39 (1.44 cm/ d) followed by I 231-03 (1.30 cm/d). Flood and control condition has significant effect on dry leaf, green leaf and growth rate. Different days after initiation of stress showed significant effects on dry leaf, green leaf and no significant effects on growth rate. Interaction of factor A (variety) and factor B (Flood, Control), factor A & factor C (Different days after

initiation of flood), factor B & factor C, factor A, factor B & factor C has significant effect on dry leaf, green leaf and growth rate. All the genotypes produced more green leaf showed better growth in flood stress condition than in control condition except in the genotypes I 7-03, I 78-03, I 137-03 and Isd 34 which showed comparatively less growth rate in flood condition than in control condition. All the genotypes showed highest growth rate at 60 d after stress period. Our findings are in agreement with Hidaka Tetsushi and Md. Abdul Karim (2007) who found that plant height of the flooded plants was noticeably higher than that of the control plants. It is possible because sugarcane has constitutive aerenchyma. For this reason when it falls under stress it can easily survive by using oxyzen which is preserved by aerenchyma cell. Aerenchyma formation in the root cortex is the most studied plastic response to flooding (Visser *et al.*, 2000; McDonald *et al.*, 2002; Evans, 2003; Grimoldi *et al.*, 2005; Seago et al., 2005; Striker *et al.*, 2007a). This aerenchyma tissue provides a continuous system of interconnected aerial spaces (aerenchyma lacunae) of lower resistance for oxygen transport from aerial shoots to submerged roots, allowing root growth and soil exploration under anaerobic conditions (Colmer & Greenway, 2005). It is predictable that stress from soil flooding on roots also alters shoot morphology because of close functional interdependence between both of them. In this way, flooded plants of tolerant species are often taller than their non-flooded counterparts as a result of increases in the insertion angles and length of their aerial organs. These responses were well characterized in the dicotyledonous *Rumex palustris* by Cox et al. (2003; 2004) and Heydarian *et al.* (2010) among others.

Adventitious Root

There were significant differences in adventitious roots of various genotypes under stress condition. (Table.2). It was found that the genotype Isd 39 produced higher adventitious roots (836.0 g/plant) followed by I 231-03 (566.7g/plant), Isd 34 (380.0 g/plant), Isd 40 (315.0 g/plant) and I 124-00 (220.0 g/plant). Flooding induces morphological changes in roots and shoots. In roots, formation of adventitious roots is highlighted as a common response of flood-tolerant species. These adventitious roots, which have high porosity, help plants to continue with water and nutrient uptake under flooding conditions, replacing in some way the functions of older root system (Kozlowski & Pallardy, 1984). It is frequent that these adventitious roots are positioned near the better-aerated soil surface. Following review by Jackson (2004), there are three mechanisms for generating these 'replacement' root systems: (i) stimulation of the outgrowth of pre-existing root primordia in the shoot base (Jackson *et al.*, 1981), (ii) induction of a new root system that involves initiation of root primordia and their subsequent outgrowth (Jackson & Armstrong, 1999; Shimamura *et al.*, 2007;) and (iii) placing roots at the soil surface involving the re-orientation of the root extension as seen for woody species by Pereira & Kozlowski (1977) and for herbaceous species by Gibberd *et al.* (2001). The two first mechanisms appear to be triggered by ethylene, which is thought to increase the sensitivity of plant tissues to auxin (Bertell *et al.*, 1990; Liu & Reid, 1992).

Table 1: Effects of flood on dry leaf, green leaf and growth rate of sugarcane genotypes

Treatments	Dry leaf	Green leaf	Growth rate
Factor A (Genotypes)			
I 124-00 (V_1)	40.6 f	57.4b	0.96 ef
I 112-01 (V_2)	51.4 c	48.6 e	0.92 f
I 7-03 (V_3)	45.8 e	54.4 c	0.89 f
I 78-03 (V_4)	54.8 b	45.6 g	1.01 e
I 111-03 (V_5)	55.1 a	44.9 g	1.10 d
I 137-03(V_6)	51.4 c	47.7 f	0.91 f
I 139-03(V_7)	50.9 c	49.1 e	1.21 c
I 231-03 (V_8)	46.8 d	53.3 d	1.30 b
lsd 34 (V_9)	51.2 c	48.8 e	1.14 d
lsd 39 (V_{10})	37.8 g	62.2 a	1.44 a
lsd 40 (V_{11})	45.8 e	49.3 e	1.27 bc
LSD (0.05)	0.7446	0.8569	0.07046
Factor B			
Flood (F)	40.0 b	60.01 a	1.22 a
Control (C)	56.6 a	42.02 b	0.99 b
LSD (0.05)			
Factor C (Days)			
60 days (D_1)	38.6 c	59.8 a	1.22 a
90 days (D_2)	49.7 b	50.0 b	1.08 b
120 days (D_3)	56.6 a	43.2 c	1.01 b
LSD (0.05)	0.7509		0.07106
Factor Ax Factor B			
V_1F	31.3 o	68.7 b	1.06 ghi
V_1C	49.9 h	46.1 j	0.86 jk
V_2F	36.4 n	63.6 c	1.25 e
V_2C	66.4 a	33.6 p	0.59 l
V_3F	43.1 kl	56.9 ef	.80 k
V_3C	48.5 i	51.8 h	0.98 hi
V_4F	51.5 g	48.5 i	0.99 hi
V_4C	57.3 e	42.7 k	1.04 ghi
V_5F	47.4 j	52.7 gh	1.13 fg
V_5C	62.9 b	37.1 n	1.07 gh
V_6F	43.9 k	56.1 f	0.86 jk
V_6C	58.9 d	39.2 m	0.96 ij
V_7F	42.5 lm	57.5 de	1.37 cd
V_7C	59.3 d	40.7 l	1.05 ghi
V_8F	36.6 n	63.5 c	1.54 b
V_8C	57.0 e	43.0 k	1.06 ghi
V_9F	41.8 m	58.2 d	0.29 de
V_9C	60.5 c	39.5 m	0.98 hi
$V_{10}F$	28.9 p	71.1 a	1.67 a
$V_{10}C$	46.7 j	53.3 g	1.20 ef
$V_{11}F$	36.6 n	63.4 c	1.42 c
$V_{11}C$	54.9 f	35.1 o	1.13 fg
LSD (0.05)	1.053	1.110	0.09965

Treatments	Dry leaf	Green leaf	Growth rate
Factor Ax Factor C			
V_1D_1	34.7 s	63.3 b	1.06 hijkl
V_1D_2	42.8 no	54.1 g	0.95 klmno
V_1D_3	44.5 lm	54.8 g	0.87 no
V_2D_1	41.7 op	58.3 de	0.98 jklmn
V_2D_2	51.5 ij	48.5 ij	0.85 o
V_2D_3	61.1 c	39.0 n	0.94 lmno
V_3D_1	29.8 t	70.7 a	0.93 lmno
V_3D_2	48.6 k	51.4 h	0.87 no
V_3D_3	59.0 d	41.0 m	0.87 no
V_4D_1	44.7 l	55.3 g	1.17 fgh
V_4D_2	56.0 e	44.1 l	0.96 klmno
V_4D_3	62.5 b	37.50 o	0.92 mno
V_5D_1	43.4 mn	56.7 f	1.08 hijk
V_5D_2	55.1 ef	44.9 l	1.17 fgh
V_5D_3	67.0 a	33.1 p	1.06 hijkl
V_6D_1	42.2 nop	57.2 ef	0.90 mno
V_6D_2	54.2 fg	44.8 l	0.92 mno
V_6D_3	57.8 d	41.1 m	0.91 mno
V_7D_1	38.4 q	61.6 c	1.40 bcd
V_7D_2	53.6 gh	46.5 k	1.22 fg
V_7D_3	60.7 c	39.3 n	1.03 ijklm
V_8D_1	41.1 p	58.9 d	1.46 bc
V_8D_2	48.2 k	51.8 h	1.29 def
V_8D_3	51.1 j	49.1 i	1.15 ghi
V_9D_1	43.1 n	56.9 f	1.34 cde
V_9D_2	52.6 hi	47.5 jk	1.08 hijk
V_9D_3	57.9 d	42.2 m	0.99 jklmn
$V_{10}D_1$	29.2 t	70.8 a	1.65 a
$V_{10}D_2$	35.8 rs	64.3 b	1.37 cd
$V_{10}D_3$	48.4 k	51.6 h	1.29 def
$V_{11}D_1$	36.5 r	48.5 ij	1.50 b
$V_{11}D_2$	47.9 k	52.1 h	1.22 efg
$V_{11}D_3$	52.9 h	47.2 jk	1.10ghij
LSD (0.05)	1.207	1.272	0.1143
Factor B x Factor C			
FD_1	29.0 f	71.0 a	1.45 a
FD_2	41.2 e	58.8 b	1.13 b
FD_3	49.8 c	50.2 c	1.07 bc
CD_1	48.2 d	48.6 d	1.00 cd
CD_2	58.1 b	41.2 e	1.03 cd
CD_3	63.4 a	36.3 f	0.95 d
LSD (0.05)	1.062	1.119	0.1005

Treatments	Dry leaf	Green leaf	Growth rate
Factor A x Factor B x Factor C			
V_1FD_1	25.1 l	74.9 c	1.20 fghijklm
V_1FD_2	34.3 y	65.7 g	1.04 lmnopqrs
V_1FD_3	34.6 y	65.4 g	0.93 pqrstuv
V_1CD_1	44.2 qrs	51.6 pq	0.91 qrstuv
V_1CD_2	51.3 mno	42.5 xyz	0.87 rstuvw
V_1CD_3	54.3 kl	44.1 vwx	0.81 uvwxy
V_2FD_1	24.2	75.8 bc	1.60 cd
V_2FD_2	37.3 vwx	62.7 hij	0.94 opqrstuv
V_2FD_3	47.8 p	52.2 p	1.22 fghijkl
V_2CD_1	59.2 ef	40.8 z	0.36 z
V_2CD_2	65.7 c	34.3	0.75 vwxy
V_2CD_3	74.3 a	25.7 b	0.65 y
V_3FD_1	23.0	77.0 b	1.02 mnopqrst
V_3FD_2	44.6 qrs	55.4 mno	0.70 wxy
V_3FD_3	61.6 d	38.4	0.68 xy
V_3CD_1	36.6 x	64.4 gh	0.85 stuvwx
V_3CD_2	52.6 lm	47.4 t	1.03 lmnpqrs
V_3CD_3	56.4 ij	43.6 vwx	1.05 klmnopqr
V_4FD_1	39.4 u	60.6 k	1.130 ijklmno
V_4FD_2	54.9 jk	45.1 uv	0.93 pqrstuv
V_4FD_3	60.2 de	39.8	0.91 qrstuv
V_4CD_1	50.0 o	50.0 qr	1.21 fghijkl
V_4CD_2	57.0 hi	43 0 wxy	0.98 nopqrstu
V_4CD_3	64.8 c	35.2	0.92 pqrstuv
V_5FD_1	36.7 wx	63.4 hi	1.26 fghij
V_5FD_2	46.0 q	54.0 o	1.10 jklmnopq
V_5FD_3	59.4 e	40.6	1.03 lmnopqrs
V_5CD_1	50.0 o	50.0 qr	0.89 rstuvw
V_5CD_2	64.2 c	35.8	1.24 fghijk
V_5CD_3	74.5 a	25.5	1.09 jklmnopq
V_6FD_1	32.2 z	67.8 f	0.93 pqrstuv
V_6FD_2	42.9 st	57.1 lm	0.81 uvwxy
V_6FD_3	56.5 ij	43.5 vwxy	0.83 tuvwxy
V_6CD_1	52.1 mn	46.6 tu	0.86 rstuvwx
V_6CD_2	65.5 c	32.5	1.03 lmnopqrs
V_6CD_3	59.0 efg	38.7	0.99 nopqrstu
V_7FD_1	30.9 z	69.1 ef	1.65 cd
V_7FD_2	45.0 qr	55.0 no	1.33 efgh
V_7FD_3	51.6 mno	48.4 rst	1.14 ijklmn
V_7CD_1	45.9 q	54.1 o	1.15 hijklmn
V_7CD_2	62.1 d	37.9	1.10 jklmnopq
V_7CD_3	69.8 b	30.2	0.91 qrstuv
V_8FD_1	30.1	69.9 e	1.82 b
V_8FD_2	37.9 uvwx	62.2 ijk	1.48 de
V_8FD_3	41.8 t	58.4 l	1.31 efghi

Treatments	Dry leaf	Green leaf	Growth rate
V_8CD_1	52.1 mn	47.9 st	1.10 jklmnopq
V_8CD_2	58.5 efgh	41.5 yz	1.09 jklmnopq
V_8CD_3	60.3 de	39.7	0.99 nopqrstu
V_9FD_1	31.1 z	68.9 ef	1.58 cd
V_9FD_2	43.8 rs	56.2 mn	1.19 fghijklm
V_9FD_3	50.6 no	49.4 rs	1.10 jklmnopq
V_9CD_1	55.1 jk	44.9 uvw	1.11 jklmnop
V_9CD_2	61.3 d	38.7	0.97 nopqrstu
V_9CD_3	65.1 c	34.9	0.88 rstuvw
$V_{10}FD_1$	19.3	80.7 a	2.067 a
$V_{10}FD_2$	28.0	72.0 d	1.58 cd
$V_{10}FD_3$	39.3 u	60.7 k	1.37 ef
$V_{10}CD_1$	39.1 uv	60.9 jk	1.23 fghijk
$V_{10}CD_2$	43.5 rst	56.5 mn	1.16 ghijklmn
$V_{10}CD_3$	57.5 fghi	42.5 xyz	1.21 fghijkl
$V_{11}FD_1$	26.9	73.1 d	1.7 bc
$V_{11}FD_2$	38.5 uvw	61.5 ijk	1.34 efg
$V_{11}FD_3$	44.4 qrs	55.6 mno	1.22 fghijkl
$V_{11}CD_1$	46.1 pq	23.9	1.30 efghi
$V_{11}CD_2$	57.3 ghi	42.7	1.10 jklmnopq
$V_{11}CD_3$	61.3 d	38.7	0.98 nopqrstu
LSD (0.05)	1.707	1.799	0.1616

Different letter indicates significance difference as per LSD at 5% level

Table 2. Adventitious Roots (AR) of BSRI bred sugarcane genotypes under induced flood stress condition (pot experiment).

Varieties/ Genotypes	Fresh weight of AR/Plant (g)	Air dry weight of AR/Plant (g)	Volume of AR/Plant (ml)
I 124-00	220.4 e	73.3 d	278.6 e
I 112-01	30.2 h	21.9 f	64.0 f
I 7-03	27.0 h	4.8 h	40.8 h
I 78-03	41.9 g	9.8 g	67.1 f
I 111-03	50.4 f	10.3 g	57.1 g
I 137-03	17.3 i	5.1 h	21.7 i
I 139-03	48.6 f	9.3 g	66.4 f
I 231-03	566.7 b	116.7 b	640.0 b
Isd 34	380.0 c	89.5 c	570.0 c
Isd 39	836.0 a	133.1 a	894.0 a
Isd 40	315.5 d	55.1 e	338.6 d
Lsd (0.05)	4.544	2.395	4.817

Different letter indicates significance difference as per LSD at 5% level

Table 3. Effects of flood on Brix, pol, purity and rs of sugarcane genotypes.

Treatments Factor A (Genotypes)	Brix (%)	Pol (%)	Purity (%)
I 124-00	18.2 ab	12.3 ab	86.9 abc
I 112-01	18.6 ab	12.8 ab	87.6 ab
I 7-03	18.8 ab	12.6 ab	86.0 c
I 78-03	17.6 bc	12.0 abc	87.3 abc
I 111-03	17.5 bc	11.7 bc	86.0 c
I 137-03	16.5 c	10.7 c	80.6 d
I 139-03	18.4 ab	12.4 ab	86.0 c
I 231-03	19.4 a	13.3 a	88.1 ab
Isd 34	17.9 bc	11.8 bc	86.8 bc
Isd 39	18.2 ab	12.5 ab	88.0 aab
Isd 40	18.9 ab	13.1 ab	88.3 a
LSD (0.05)	1.286	1.286	1.286
Factor B			
Flood (F)	18.3 a	12.3	86.265
Control (C)	18.1 b	12.3	86.736
LSD (0.05)	NS	NS	NS
Factor Ax Factor B			
V_1F	18.5 bcd	12.6 abc	87.4 bcde
V_1C	17.9 bcd	12.1 bc	86.5 def
V_2F	19.4 ab	13.4 ab	84.6 ab
V_2C	17.8 bcd	12.1 bc	86.6 def
V_3F	18.6 bc	12.5 bc	85.8 ef
V_3C	19.0 abc	12.7 abc	86.2 def
V_4F	18.0 bcd	12.4 bc	88.1 abcd
V_4C	17.2 cd	11.6 bcd	86.6 def
V_5F	17.8 bcd	12.0 bcd	86.1 def
V_5C	17.2 cd	11.5 bcd	85.9 ef
V_6F	16.5 d	10.0 d	77.7 h
V_6C	16.5 d	11.3 cd	83.5 g
V_7F	17.3 cd	11.4 bcd	84.6 fg
V_7C	19.5 ab	13.4 ab	87.3 bcde
V_8F	20.8 a	14.6 a	90.0 a
V_8C	18.0 bcd	12.1 bc	86.2 def
V_9F	17.3 cd	11.6 bcd	86.3 def
V_9C	18.4 bcd	12.0 bcd	87.3 cde
$V_{10}F$	17.5 bcd	11.8 bcd	86.6 def
$V_{10}C$	18.8 bc	13.2 abc	89.3 a
$V_{11}F$	19.0 abc	13.0 abc	87.8 bcde
$V_{11}C$	18.8 abc	13.1 abc	88.8 abc
LSD (0.05)	1.819	1.819	1.819

Different letter indicates significance difference as per LSD at 5% level

Juice quality

Juice quality of sugarcane which was indicated by Brix%, Purity%, Pol% and Reducing Sugar (Table 3). Genotypes showed significant difference on Brix, pol, purity and reducing sugar. Genotype I 231-03 produced the highest Brix per centage (19.4) the highest pol per centage (13.3) and the highest purity per centage (88.1) followed by Isd 40 (Brix 18.9, pol 13.1, purity 88.3). Flood and control condition showed no significant difference on Brix, pol and purity per cent. All genotypes showed no significant difference Brix, pol and purity per cent under flood and control condition except in the genotypes I 112-01, I 139-03 and I 231-03. Among them genotypes I 139-03 produced less Brix, pol and purity per cent under flood condition than in control condition. So, it is not fit for cultivation under flood condition. On the other hand, I 112-01 and I 231-03 produced more Brix, pol and purity per cent under flood condition than in control which are in agreement with Hasan et. al., (2003) who grew some sugarcane genotypes under waterloging condition and found that all genotypes produced higher Brix, pol, purity per cent and lower RS in waterloging condition than normal condition.

It may be concluded that the genotypes which showed better performance under flood stress condition may be selected as tolerant genotypes for flood stress. The genotypes I 112-01, I 7-03, I 231-03, Isd 39 and Isd 40 showed better performance under flood stress than in control condition compare to other genotypes in respect of juice quality because it is an important parameter for selecting a sugarcane variety. So, we can say that the genotypes genotypes I 112-01, I 7-03, I 231-03, Isd 39 and Isd 40 are better for cultivation under flood stress condition. All these information would help to develop strategies for identifying flood tolerant species.

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