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Title: Performance of Maize and Sunflower to Abiotic Stresses: Excess Water during Emergence and Salinity during Reproductive Stage

Authors: Md. Enamul Kabir*, Bidhan Chandro Sarker and S.M. Hasibur Rahman
Agrotechnology Discipline, Khulna University, Khulna-9208, Bangladesh
*Corresponding Author: Md. Enamul Kabir Email: ekabir73@ku.ac.bd

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ABSTRACT

Excess of wetness and salinity in soil are the two major constraints of cropping during the winter season in southwestern (SW) Bangladesh. Seed sowing and crop establishment in the saturated soil might utilize the soil profile water (non-saline) in the early stage of growth and irrigation with natural canal water (low salinity) may open up opportunities of cropping in the winter season. The current pot study (two separate experiments) was conducted with sunflower and maize by sowing seeds in excessively wet field soil (collected, soil moisture was more than field capacity, 42% v/v) in small pots for their performance of emergence to evaluate grain yield. After emergence in small pots, the plants were transferred to large pots and allowed to grow till maturity. The source of irrigation water with cumulative electrical conductivity (EC) was the treatment as fresh water, canal water or NaCl solution. The strength (dS m^{-1}) of NaCl solution was made equal to that of canal water during each of the irrigation. The number of irrigation was four and the ECs were 3.2, 3.9, 4.6 and 5.4 dS m^{-1} on 30 January, 15 and 28 February, and 15 March, respectively. In both crops, all irrigations were completed by 74 days after sowing (DAS) and the plants were harvested at 75 DAS for dry matter (DM) measurement and 110 DAS for DM, yield and yield attributes. The emergence of seeds decreased significantly when seeds were sown in wet soil which caused the closing of seed-holes from the surface of wet soil. Decreased grain yield recorded for both of the crops (28% in sunflower and 40% in maize compared to that by freshwater irrigation) due to irrigation by canal water or NaCl solution. The yield and yield attributes were numerically lower in NaCl solution irrigation in both of the crops though the ECs of both canal water and NaCl solution maintained as same. The crops established successfully in excessive wet soil, but the yield loss was due to irrigation water salinity (irrespective of source). The yield loss would have been decreased if the crops were sown early (in late December or early January instead of early February in the current study) and completing the irrigations by February. The findings of the current study suggest that sunflower and maize might be grown in the field by using the canal water as a potential irrigation source in the SW Bangladesh.

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INTRODUCTION

In southwestern (SW) Bangladesh, transplanted (T) *aman* rice in the monsoon (mid-July to mid-November) is the only crop, the rest of the time of the year, a vast area of land (about 1,23,000 ha) remains fallow (Krupnik et al., 2017). Salinity of soil and irrigation water is considered traditionally as one of the major constraints to cultivate crops during winter and/or *Kharif*-1 seasons in this region (Karim et al., 1990). Where fresh surface or ground water for irrigation is available, some *rabi* cereals like wheat (Kabir et al., 2019) and new crops for this region, maize and sunflower, can be grown (Paul et al., 2020; Bell et al., 2019; Krupnik et al., 2015). While groundwater access is challenging, SW Bangladesh is known for its dense network of rivers and natural canals that comprise part of a tidal ecosystem that conveys fresh surface water proximal to the farmlands. Also, tidal backflow of oceanic salt water intrusion makes the canal water saline (salinity less than the river water) during the dry season (Krupnik et al., 2017). The river water is not suitable for irrigation for its high salinity. From a consecutive 3-year field study, Kabir and Jahan (2016) observed that the water salinity of the canal became a constraint (electrical conductivity, EC, ~6 dS m^{-1}) after March. They also reported that the saline water of the canals may be used for irrigation during dry season maize production with yield sacrifice (~30% of control). Maize grain yield reduced when irrigation water salinity exceeded 5 dS m^{-1} as reported by Maruf and Ahahad (2017). However, canal water remains safe for irrigation till March and if the crops (maize and also sunflower in the current study) are sown early (by early and mid-January), at least two irrigations could be applied with canal water (Krupnik et al., 2017) instead of three (BARI, 2014). Reduction of number of irrigation could facilitate fitting of both maize and sunflower after T. *aman* in this scarce fresh-water condition.

In Fallow-Fallow-T. *aman* cropping system in SW region of Bangladesh, sunflower is a new crop and its yield performance to canal water irrigation and early establishment in the excess soil water need to be tested. According to Kabir et al., (2019), wheat and other winter crops including sunflower and maize can be cultivated by irrigation with confined canal water (canal disconnected from river during early December, EC remains <3 dS m^{-1}). However, the water of the confined canal gets finished due to excessive use for irrigation as it remains low in EC (1–3 dS m^{-1}) (Bell et al., 2019). These circumstances demand the testing of the suitability of open canal water (connected to the river) for irrigation.

Apart from the effect of saline water irrigation on the yield of a crop, excess water after rice harvest delays the sowing of winter crops. The issue of such waterlogging has been given less emphasis for a long time than that of salinity constraint (Kabir et al. 2019; Kabir and Jahan, 2016). A soil is said to be waterlogged if the water table remains below 0.3 meter from the surface (Bennett et al., 2009; Wesseling, 1974). The fine-textured soils become saturated to relatively greater heights above this water table than coarse-textured soils (Grable, 1966). In the SW region, the water table remains within 0.3 m till the end of January (Paul et al., 2020). Our preliminary study in this waterlogged soil showed that dibbling maize seed in fully saturated soil and closing the seed-hole from the top, reduces maize emergence (Kabir and Jahan, 2016). Thus, in this current study, seed emergence trial, keeping the seed-hole open or closed was also included. The evaluation of the combined effects of stresses as early sowing in the saturated soil and irrigation by canal water would justify the cultivation of winter crops like maize and sunflower in these situations. Such justifications would primarily be satisfied from the proposed study in the pot which could lead further field trials. Therefore, the current study was conducted to investigate the early establishment of maize and sunflower in saturated soil after T. *aman* rice harvest. An evaluation was also made for dry matter and grain yield of the crops (maize and sunflower) in response to irrigation with saline canal water.

MATERIALS AND METHODS

Two separate pot experiments (each for maize and sunflower) in the plastic shed (transparent) were conducted at Dr. Purnendu Gain Field Laboratory in Khulna University Campus.

The treatments were the source of irrigation water with cumulative EC. For each of maize and sunflower experiment the salinity levels were the same:

i. Control (Fresh water, EC, 0 dS m^{-1})
ii. Canal water (EC was measured at each time of irrigation throughout the growing period of maize and sunflower)
iii. Saline solution made by table salt (NaCl) keeping the exact EC to that of canal water at each irrigation.

***Justification of including saline water of NaCl*:** Usually we conduct experiment with saline water made by NaCl only to observe the crop response. But, in natural saline water, salts of Ca, Mg, etc. are also present. For the presence of these salts, the growth performance of plants sometimes inhibited or very rarely enhanced (Marschner, 1995). For a better understanding of the response of maize and sunflower under the (semi) controlled condition, the NaCl solution with the same EC of canal water at each of the irrigation was included.

There were 3 replications of each treatment. The crops were harvested during flowering stage (to compare between data of two harvests) and at maturity. Thus the treatment combination for each crop was: 3 salinities X 2 harvests X 3 replications = 18 pots, and total pots for two crops were 36; each pot contained two plants. Each experiment was laid out in a completely randomized design (CRD).

***Soil, preparation of pot, treatment imposition, growing and harvesting of plants*:** Soil was collected from a typical coastal cropland, Hogladanga, Batiaghata, Khulna (22°73' N latitude and 89°52' E longitude). Top (0–10 cm) and saturated soil was collected after harvest of T. *aman*. For initial emergence of the selected crops, the saturated topsoil was kept in a 1-kg pot (12 cm in diameter, 6 cm high, small pot) then four seeds of maize or sunflower in separate pot were sown on 3 January 2018. After emergence (~14 days), thinning was done and two healthy seedlings were kept in each of the small pot and the plants from small pot were transferred in a 10-kg pot (17-cm high, 20 cm diameter, large pot) containing dry soil collected from the same place (Hogladanga, Batiaghata, Khulna). The small pots were used for emergence of the seed that could mimic the field wetness of the soil after T. *aman* rice harvest.

After transfer of the plant from small pot to the large one (perforated in the bottom for draining out of excess water), a light irrigation with fresh water was done for adaptation of the plants in large pot. The treatment irrigation with saline or fresh water was started after two weeks of transferring the plants to bigger pot, ~one month after sowing. Canal water for irrigation was collected from the canal nearby the field (from which the pot-soil was collected) and carried to Khulna University. The salinities of canal water during irrigations were 3.2, 3.9, 4.6 and 5.4 dS m^{-1} on 30 January, 15 and 28 February, and 15 March, respectively. The NaCl solution was made at par the EC of canal water at each of the irrigations by adding table salt with reverse osmosis (RO) water. In control, the crops were irrigated with the RO water and the EC was maintained as zero at each of the irrigation. The irrigation was applied according to the water holding capacity of the used soil. The water holding capacity was measured following Asher et al., (2002). The saline solution of the respective concentration was applied to pots according to the water holding capacity which we have termed as field capacity (FC) water in the subsequent sections. Total four irrigations were applied by 74 days after sowing (DAS). Treatment irrigation was not applied during emergence (it was applied one month after sowing and 15 days after transfer of seedlings to the large pots).

Data collection: Data were collected following standard procedures on soil moisture and salinity, water EC at every irrigation, crop phenological data, dry matter, seed yield and biological yield of both crops.

Statistical analysis: The collected data were analyzed for each of the crops by one-way ANOVA by Statistix 10. The treatment means were compared by the Least Significant Difference (LSD) test at 5% level of significance.

RESULTS AND DISCUSSION

Emergence in the small pot and survival in the large pot

Almost all seeds of both sunflower and maize were emerged (in small pot) when the seed-hole was kept open (Figure 1) from the top after dibbling despite the soil moisture was 42% (v/v) which was excess of the field capacity (~32% v/v and ~28% w/w) of the experimental soil (clay loam). On the other hand, only ~25% seeds of both crops were emerged when the seed-hole was closed from the top. The low emergence (~25%) in closed seed-hole might be due to the poor aeration through the wet soil that restricts the oxygen supply to the seed. Since, oxygen is the essential requirement (other two requirements are temperature and moisture) for seed germination (Copeland and McDonald, 2001). Moreover, the soil was muddy with almost no structure due to water stagnation from previous rice cultivation. In a preliminary study, we compared emergence of seeds of maize by wetting of the same dry soil in pot to the same water holding capacity and found better emergence might be due to the presence of larger granules of soil (which was collected, dried, broken clods and then made wet in the pot) that facilitated aeration. The emergence in the wet field soil (above field capacity) suggests that the seed-hole need to be kept open after dibbling.

After transferring from the small pot to the large one, almost all plants (sunflower and maize) survived (data not shown). This was might be due to the presence of lump of soil (total soil that was in the small pot) with the root.

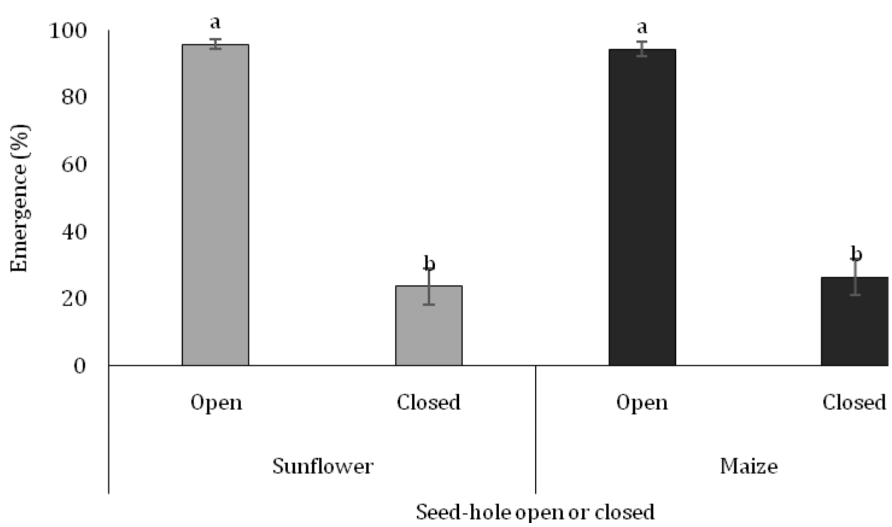

Figure 1. Seed emergence of sunflower and maize under open or closed seed-holes after seed dibbling in saturated clay loam soil. Different letters on the bars of a specific crop signify that the means are statistically different. Bars represent ± standard error (n=3)

Plant height and dry matter (DM) at flowering and physiological maturity

Plant height: After 15 days of transfer to the large pots (one month after sowing), plants were irrigated according to the treatments. The plant height was measured (at 75 and at 110 DAS) after application of all irrigation treatments. Plant height was maximum at 75 DAS in both crops in the control treatment (Figure 2 and 3). When irrigated with canal water or NaCl solution, the plant height of both sunflower and maize decreased. At 75 DAS, for both sunflower and maize, plant height was reduced by 14% (compared to that of control) due to canal water or NaCl solution irrigation. At 110 DAS, this reduction was 15% for sunflower and 20% for maize when irrigated with canal water and 24% for both crops when irrigated with NaCl solution. The results showed that at the later stage of growth irrigation with NaCl solution affected the plant height more than that of canal water in both crops even though the EC of both canal water and NaCl solutions were similar.

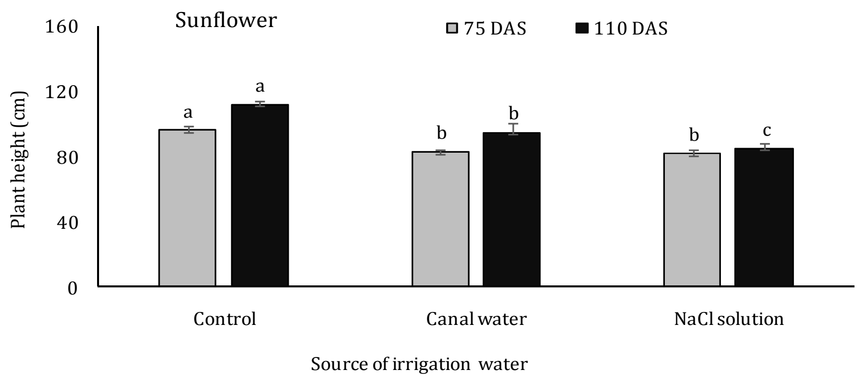

Figure 2. Plant height of pot-grown sunflower as affected by different sources of irrigation water at 75 and 110 days after sowing (DAS). The EC of canal water or NaCl solution were 3.2, 3.9, 4.6 and 5.4 dS m^{-1} on 30 January, 15 and 28 February, and 15 March, respectively, in four irrigations. Different letters on the bars at a specific measuring date signify that the means are statistically different. Bars represent ± standard error (n=3)

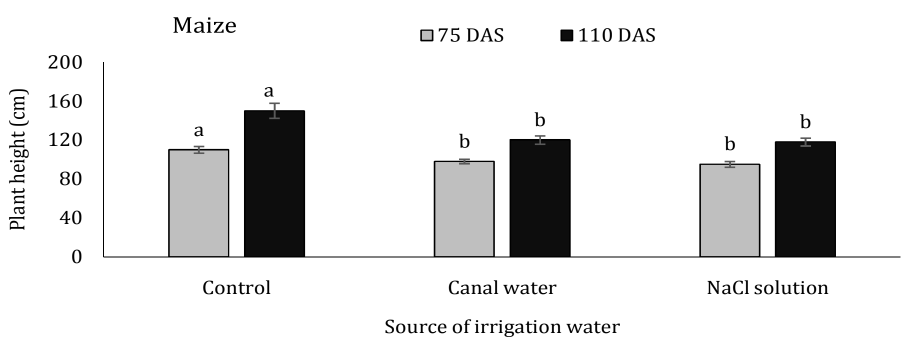

Figure 3. Plant height of pot-grown maize as affected by different sources of irrigation water at 75 and 110 days after sowing (DAS). The number of irrigation and the ECs of irrigation water were similar as detailed in Figure 2. Different letters on the bars at a specific measuring date signify that the means are statistically different. Bars represent ± standard error (n=3)

***Dry matter*:** The trend of dry matter production in both crops was similar at both 75 and 110 DAS. The saline water irrigation either from canal or NaCl reduced DM production at approximately in an equal rate (Figure 4 and 5). However, in sunflower, the rate of reduction was 22% at the flowering stage and 13% during maturity (Figure 4). In maize, the rate of reduction in both silking and maturity was ~20% (Figure 5). As expected the fresh water irrigation produced the highest DM in both crops in both stages of growth.

All irrigations (four) we applied by 74 DAS and the plant height and DM were recorded after all irrigations, at 75 and 110 DAS. The reduction of plant height of sunflower at 110 DAS under NaCl solution (compared to that of canal water) might be due to the solution contained only Na^+ as cation. Presence of other cations (e.g., Ca^{++}, Mg^{++}) in mildly saline water sometimes enhance growth (Marschner, 1995). Moreover, both the canal or NaCl irrigation source was saline, it is well established that saline irrigation reduces photosynthesis, DM and thus the plant height. Salinity reduces the physiological water availability to plants such water deficits exert their effect directly on cell extension and/or division, i.e., any reductions in photosynthesis would merely be secondary effects of reduced growth including height (Greenway and Munns, 1980).

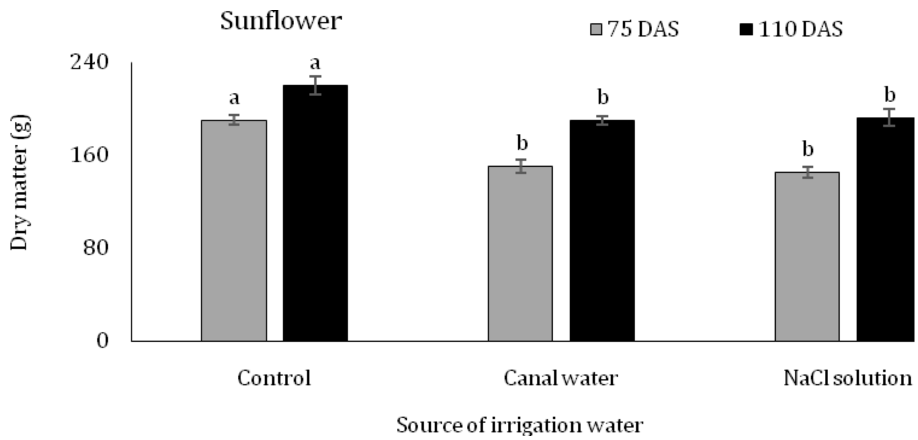

Figure 4. Shoot dry matter of pot-grown sunflower under different sources of irrigation water at 75 and 110 days after sowing (DAS). The number of irrigation and the ECs of irrigation water were similar as detailed in Figure 2. Different letters on the bars at a specific measuring date signify that the means are statistically different. Bars represent ± standard error (n=3)

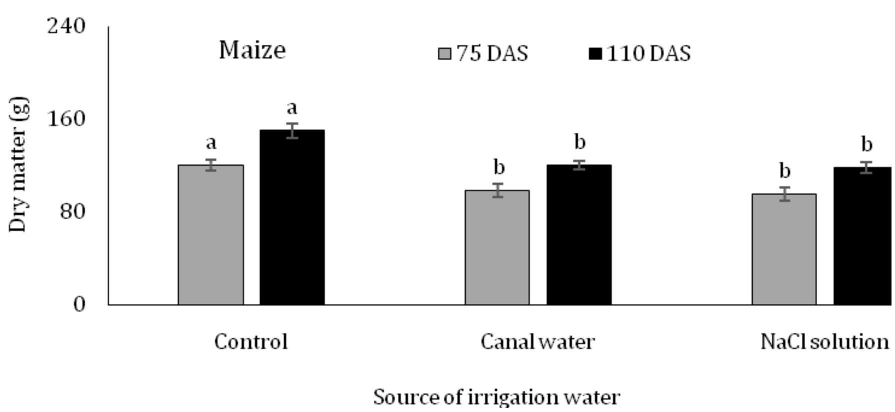

Figure 5. Shoot dry matter of pot-grown maize under different sources of irrigation water at 75 and 110 days after sowing (DAS). The number of irrigation and the ECs of irrigation water were similar as detailed in Figure 2. Different letters on the bars at a specific measuring date signify that the means are statistically different. Bars represent ± standard error (n=3)

Yield attributes and yield

In sunflower, head diameter, head circumference, seed per head were significantly decreased due to saline water irrigation (Table 1) and thus the seed yield per plant was decreased: 28% reduction compared to that of control. Although there was no significant difference in yield attributes and seed yield between canal water and NaCl solution irrigation, all parameters gave numerically lower value when the plant was irrigated with NaCl solution.

Table 1. Yield attributes and seed weight per plant of pot-grown sunflower under different sources of irrigation

Irrigation water	Head diameter (cm)	Head circumference (cm)	Seed head^{-1}	100-seed weight (g)	Seed yield plant^{-1} (g)
Control	10.5a	33.3a	680a	5.8	40a
Canal water	8.9b	28.2b	590b	5.1	30b
NaCl solution	8.5b	26.3b	520b	4.9	26b
CV (%)	9.6	11.3	8.7	9.6	9.4
$LSD_{0.05}$	1.5	4.9	83.3	NS	6.6

[Note: The number of irrigation and the ECs of irrigation water were similar as detailed in Figure 2. Different letters in a column signify that the means are statistically different. NS signifies that the means are not statistically different.]

In maize, almost similar responses (as in sunflower) of yield attributes (number of grain cob^{-1}, number of row ear^{-1}, number of grain row^{-1} and 100-grain weight) and grain yield (40% decreased compared to that of fresh water irrigation) to irrigation water sources were found (Table 2). The values of yield attributes and yield were also lower in NaCl solution irrigation compared to that of canal water.

Table 2. Yield attributes and seed weight per plant of pot-grown maize under different sources of irrigation water

Irrigation water	Number of grain cob^{-1}	Number of row ear^{-1}	Number of grain row^{-1}	100-grain weight (g)	Grain yield plant^{-1} (g)
Control	408a	24a	17a	24a	98a
Canal water	334b	18b	13b	19b	64b
NaCl solution	304b	17b	12b	18b	55b
CV (%)	11.3	7.2	6.6	8.5	10.3
$LSD_{0.05}$	74.5	3.0	2.0	3.5	15.0

[Note: The number of irrigation and the ECs of irrigation water were similar as detailed in Figure 2. Different letters in a column signify that the means are statistically different.]

The reduction of DM and yield attributes of both crops might be due to the 3rd (EC 4.6 dS m^{-1}) and 4th (EC 5.4 dS m^{-1}) irrigations. Kabir et al., (2017) showed that maize DM and grain yield was reduced when irrigated with saline water with EC more than 5 dS m^{-1}. Recent studies in the SW Bangladesh on sunflower showed that this crop can be grown in field with ~3.5 t ha^{-1} seed yield by irrigating from confined canal water (EC ~2 to 3 dS m^{-1}, canal disconnected from saline river in early December) (Sarker et al., 2019; Paul et al., 2020; Bell et al., 2019). The current study suggests that irrigation water EC over 4 dS m^{-1} reduces the dry matter and crop yield. If these crops could have been sown approximately one month earlier (early December, seed dibbled in the current study was in early January), the EC of the canal water would have been less than 4 dS m^{-1}, thus the DM and yield reduction could be decreased. Kabir et at. (2019) showed that sowing wheat in early December is possible by early harvest of T. *aman* and draining out the excess water from the field in typical SW coastal soil.

CONCLUSIONS

From the study it could be concluded that (i) the early establishment of sunflower and maize in excessive wet soil is possible by dibbling the seed and keeping the seed-hole open; (ii) the production of DM reduced due to saline water irrigation (either canal water or NaCl solution) might happen as an effect of applying irrigation water with EC over 4 dS m^{-1} at later stage of crop growth. The results need to be tested in the field by irrigating the winter crops from natural canal water where EC increases with the progress of winter (dry) season or confined canal water where water EC remains low (safe for irrigation). Early establishment of winter crops in saturated soil after T. *aman* could open up the opportunity of cropping and lessen the effect of salinity on crops in the SW Bangladesh.

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Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this article.

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