World Academy of Science, Engineering and Technology
International Journal of Agricultural and Biosystems Engineering
Vol:5, No:3, 2011

Salinity on Survival and Early Development of Biofuel Feedstock Crops

Vincent M. Russo

***Abstract*—**Salinity level may affect early development of biofuel feedstock crops. The biofuel feedstock crops canola (*Brassica napus* L.), sorghum [*Sorghum bicolor* (L.) Moench], and sunflower (*Helianthus annuus* L.); and the potential feedstock crop sweet corn (*Zea mays* L.) were planted in media in pots and treated with aqueous solutions of 0, 0.1, 0.5 and 1.0 M NaCl once at: 1) planting; 2) 7-10 days after planting or 3) first true leaf expansion. An additional treatment (4) comprised of one-half strength of the 0.1, 0.5 and 1.0 M (concentrations 0.05, 0.25, 0.5 M at each application) was applied at first true leaf expansion and four days later. Survival of most crops decreased below 90% above 0.5 M; survival of canola decreased above 0.1 M. Application timing had little effect on crop survival. For canola root fresh and dry weights improved when application was at plant emergence; for sorghum top and root fresh weights improved when the split application was used. When application was at planting root dry weight was improved over most other applications. Sunflower top fresh weight was among the highest when saline solutions were split and top dry weight was among the highest when application was at plant emergence. Sweet corn root fresh weight was improved when the split application was used or application was at planting. Sweet corn root dry weight was highest when application was at planting or plant emergence. Even at high salinity rates survival rates greater than what might be expected occurred. Plants that survived appear to be able to adjust to saline during the early stages of development.

***Keywords*—**Canola, Development, Sorghum, Sunflower, Sweet corn, Survival

I. INTRODUCTION

SOIL salinity level can be affected by soil type, use of synthetic chemicals, and/or use of high salt content irrigation water. Water usage and cropping can change water table and soil salt contents [4]. Negative effects of high salinity levels, can affect seedling emergence, stand establishment, shoot, root and whole plant growth, leaf photosynthesis and stomatal conductance [2], [12], [13], [19]. Since roots are in closer contact than above ground plant parts they may be more apt to affected [11]. Seedling mortality may be due to hypocotly death caused by salt level [9], and crops can be detrimentally affected if other parts are exposed to salt [10].Several crops are used as biofuel feedstocks, and are being considered in locations, or for planting at times, not traditionally used in the past. Among these are canola (*Brassica napus* L.), sorghum [*Sorghum bicolor* (L.) Moench] and sunflower (*Helianthus annuus* L.). In addition sweet corn (*Zea mays* L.), which can contain significant amounts of readily accessible sugars in stalks [16], may play a role in biofuel biomass production.Under field conditions canola germination and plant development suffer above salt levels up to 6 $dS\cdot m^{-1}$ [18]. Puppala et al. [15] examined canola germination in Petri dishes and found as salt concentration increased (0 to 26.4 $dS\cdot m^{-1}$) germination decreased. As sorghum is exposed to increasing salinity levels (2 to 12 $dS\cdot m^{-1}$ biomass and soluble carbohydrate yields have been reported to decrease [1].

Responses to increased salt can be measured as yield and in plant response [5], [14]. Under laboratory conditions time to germination increased and percent germination decreased in sunflower as salinity level increased from 0 to 40 $dS\cdot m^{-1}$ [8]. Although seed yield of sunflower was unaffected by field irrigation with water with salinity up to 4.8 $dS\cdot m^{-1}$, yields decreased when salinity was higher [7]. When germinated in Petri dishes germination of sweet corn was reduced as salinity level increased [6]. Corn ear yields and tissue dry weights were decreased as irrigation water salinity level increased [3]. However, even if salinity level is increased salinity of irrigation at approx. 70% of potential evaporation could mitigate adverse effects on corn yield [17].

In various parts of the world it is necessary that agriculture practitioners deal with high levels of salt in soil and/or irrigation water. In soils that are not inherently high in salt content salinity can be introduced from the irrigation source. As a result this may provide a way of managing effects of salinity with application at growth stages that are less susceptible. It is necessary to determine if application timing of water containing various levels of salt can affect germination and early plant development of biofuel feedstock crops.

II. MATERIALS AND METHODS

Canola, var. Wichita; sorghum, var. Della; sunflower, small, black seeded, Perdovik oil type, and sweet corn, cv. Incredible, se endosperm genotype, were used. Prior to the start of the experiment the nutrient content for the potting medium and irrigation water were determined (Tables I and II). Potting mix, Sunshine CV1 (SunGro, Bellevue, Wash.), was placed in 1.5 L pots and moistened with water. Plants were irrigated twice daily for 3 min at each application with water delivered in a fine mist from an overhead irrigation system. No additional nutrition was provided to plants.

Three seed of each crop were placed in individual pots. Solutions of NaCl (0, 0.1, 0.5 and 1.0 M) were applied once to the potting mix at: 1) planting; 2) plant emergence [7-10 days after planting depending on crop] or 3) first true leaf expansion. An additional treatment (4) was comprised of a

Vincent M. Russo is with the United States Department of Agriculture, Agricultural Research Service, Wes Watkins Agricultural Research Laboratory, 911 Highway 3W, POB 159, Lane, OK 74555 USA (phone: 580-889-7395; Fax: 580-889-5783 e-mail: vincent.russo@ars.usda.gov).

split application in which 0.05, 0.25, or 0.5 M [each treatment adding to the 0.1, 0.5 or 1.0 M levels applied once] was added to the potting mix at first true leaf expansion and again four days later. In all treatments 80 mL of each solution was applied to the medium in pots assigned to each treatment. After plants emerged care was taken to assure that addition of NaCl solutions did not touch plants during application.

TABLE I
VALUES FOR CONSTITUENTS [a] OF THE WATER USED FOR IRRIGATION IN THE GREENHOUSE

pH	Nitrate nitrogen	K	B	Ca	Cl	Na	Calcium carbonate	Alkalinity (as $CaCO_3$)	Mg	SO_4	Hardness
7.5	<1	2	0.01	11	12	10	39	32	2	11	35 [b]

[a] Analyses performed by the Oklahoma State University Soil, Water & Forage Analytical Laboratory, Stillwater, Okla.

TABLE II
VALUES FOR CONSTITUENTS [a] OF THE SUNSHINE POTTING MEDIUM

pH	Ammonium nitrate	Nitrate nitrogen	P	K	B	Ca	Cu	Fe	Na	Mg	SO_4	Zn
						$\mu g \cdot g^{-1}$						
6.4	6.6	11	0.2	4	– [b]	31	–	–	7	24	24	-

[a] Analyses performed by the Oklahoma State University Soil, Water & Forage Analytical Laboratory, Stillwater, Okla.
[b] "–" not analyzed.

Numbers of emerged plants were determined and plant final population was one per pot. After emergence plants were maintained for approximately one month and then harvested. Tops and roots were separated. Potting medium was gently washed from roots. Tissues were blot dried. Fresh weights of tops and roots were determined. Plant parts were individually placed in paper bags at 66°C for 72 hr.

The experiment was arranged in a randomized complete block design. There were 4 application times, 4 total NaCl concentrations (0, 0.1, 0.5, 1.0 M; split treatments were 0.05, 0.25 or 0.5 M which equaled the 0.1, 0.25 or 1 M single treatments), 5 replications per treatment with the entire experiment repeated 5 times. Data were subjected to ANOVA and tested for significance due to main effects or due to the interaction in SAS (SAS Inc., Cary, NC). If the interaction was significant it was used to explain results. If the interaction was not significant means were separated with the Ryan-Einot-Gabriel-Welsch multiple F test in SAS. Pearson Product Moment correlation analysis was performed in SAS for plant development criteria for each crop.

The electrical conductivity (EC) values of the irrigation water and the NaCl solutions were determined with a Hanna EC meter (model HI98331, Perlis, Malaysia). Changes in EC values in treated potting medium were determined with the same meter. The same size pots were filled with the same amount of the same potting medium and moistened with the water used for irrigation. No seeds were planted in the moistened medium. There were three pots for each treatment, and EC values of the moistened potting medium were obtained before treatment with the saline solutions on day 0. After treatment with 0, 0.05, 0.1, 0.25, 0.5 or 1.0 M solutions EC values were again determined. Measurements were taken daily for the next four days. After the measurement on day 4 the 0.05, 0.25 and 0.5 M solutions were again applied and measurements obtained after treatment. A final measurement was recorded on day 7 after initiation of treatment. The experiment was arranged in a randomized complete block design. Data were subjected to ANOVA and tested for significance due to the main effect of treatment in SAS (ver. 9.1, SAS, Inc., Cary, NC). Means were separated with the Ryan-Einot-Gabriel-Welsch multiple F test in SAS.

III. Results

A. EC Values

Values for solutions ranged from 0 (irrigation water) to 1,406 $dS \cdot m^{-1}$ (1 M NaCl) concentration (Table III). For each salinity level, EC values of the moistened, treated, medium were lower prior to the first treatment time than after 7 days (Table IV). Values did not increase consistently over time.

B. *Plant response to treatment*

Crops responded differently to application time, NaCl concentration and their interaction.

C. *Canola*

Application time affected all variables and NaCl concentration affected survival; interaction affected survival and top

TABLE III
EC VALUES OF VARIOUS MOLAR CONCENTRATION SOLUTIONS PRIOR TO TREATMENTOF THE MEDIUM

Treatment solution, NaCl Molar concentration	$mg \cdot L^{-1}$	Corresponding EC value ($dS \cdot m^{-1}$)
0 [a]	0	0
0.05 [b]	2,925	33.8
0.1	5,850	66.4
0.25	14,625	121.6
0.5	26,250	134.5
1	58,500	140.6

[a] non-replicated readings, all solutions diluted in water, Table I.
[b] the 0.05 and 0.25 levels represent the split application of the 0.1 and 0.5 M levels; the 0.5 M is a treatment level and also represents the split application of the 1 M level.

TABLE IV
EC VALUES FOR MEDIUM TREATED WITH SOLUTIONS WITH VARIOUS MOLAR CONCENTRATIONS OF NaCl

Day	NaCl solution Molar concentration 0	0.05 [a]	0.1	0.25 [a]	0.5	0.5 [a]	1.0
				$dS \cdot m^{-1}$			
0 pre-application	8(2) [b]	8(1.7)	10(1.3)	9(1.2)	10(1.7)	8(4.2)	10(1.4)
0 post-application	10(0.6)	9(1.3)	11(1.6)	13(1.1)	13(1.4)	10(3.1)	15(1.3)
1	10(0.6)	9(2)	11(1.2)	14(2.7)	16(2.4)	25(8.9)	26(1.5)
2	10(0.6)	9(3.5)	12(1.2)	14(5.0)	19(4.3)	27(7.0)	36(2.2)
3	12(0.6)	12(1.3)	15(2.9)	19(2.1)	26(3.7)	23(2.8)	52(7.6)
4 pre-application	10(0.6)	9(3.5)	12(1.2)	14(5.0)	19(4.3)	21(3.6)	36(2.2)
4 post-application	13(0.6)	12(1.3)	15(2.9)	19(2.1)	26(3.7)	31(1.9)	53(7.6)
7	12(0.8)	12(1.9)	14(2.9)	24(9.0)	27(8.8)	16(3.5)	35(5.8)

[a] Split application of the 0.1, 0.5 and 1.0 M treatments.
[b] Values in parentheses are standard error of the mean of EC values.

fresh weights (Table V). Regardless of time of application survival was better than 95% for concentrations up to 0.1M; for the 0.5 and 1 M concentrations survival was reduced to 75 and 44%, respectively. The interaction affected top fresh weight. When application was at planting top fresh weight was unchanged through 0.5 M (avg. 5.4 g) and decreased with application at 1 M (1.58). When application was at plant emergence top fresh weight was unchanged through 0.5 M (avg. 3.61 g) and increased with application at 1 M to 5.44 g. When application was at emergence of the first true leaves top fresh weight was unchanged (avg. 3.36 g) regardless of NaCl solution concentration. When application was split the top fresh weight declined from 6.07 g at 0 M and was less (avg. 3.84 g) unchanged thereafter.Some weight components were affected by time of application (Table VI). For plants treated at planting top dry weights were higher than when treated at first true leaf expansion, and plants treated at the other times were intermediate. When treated at plant emergence root fresh weights were greater than for plants treated at planting or at first true leaf expansion. Plants treated with the split application had root fresh weights that were intermediate. Root dry weights were highest on plants treated at plant emergence. Top fresh and dry weights were positively correlated with root fresh and dry weights (Table XI). Correlation values ranged from 0.4986 (top dry and root dry weights) to 0.8953 (root fresh and dry weights).

D. *Sorghum*

Application time affected all but top dry weight; NaCl concentration affected all but top fresh and dry weights, and the interaction affected survival, and top fresh weight; the interaction affected survival (Table V). Averaged over concentrations plant top dry weight averaged 0.64 g. Regardless of time of application survival was better than 95% for concentrations up to 0.5; for the 1M concentration survival was reduced to 75%. Some weight components were affected by time of application and concentration of NaCl solution (Table VII). When treated with the split application top fresh weight was higher than when application was at all other times. When treated with the control (0 M) top fresh weights were higher than plants treated once with 0.5 and 1 M; all others values were intermediate. When application was at planting and when application was split root dry weight was higher than when application was at emergence of first true leaves; when application was at plant emergence root dry weight was intermediate. When the 1 M application was split root fresh weight was higher than for the single application of 0.1, 0.5 and 1 M applications; all others were intermediate. When the 0.5 M application was split root dry weight was higher than for the 0 M application, and all others were intermediate. When application was split root fresh weights were highest (Table IX). Top fresh and dry weights were positively correlated with root fresh and dry weights (Table XI). Correlation values were from 0.5524 (top dry and root fresh weights) to 0.9225 (root fresh and dry weights).

TABLE V
ANOVA RESULTS FOR EFFECTS OF TIME OF APPLICATION AND NaCl CONCENTRATION ON SURVIVAL AND EARLY DEVELOPMENT OF BIOFUEL FEEDSTOCK CROPS

Crop	Source	Percent survival	Top weight fresh	Top weight dry	Root weight fresh	Root weight dry
Canola	Application time	*	*		**	**
	NaCl conc. (C)	**	NS	NS	NS	NS
	Interaction A × C	**	**	NS	NS	NS
Sorghum	Application time	**	**	NS	**	**
	NaCl conc. (C)	**	NS	NS	**	**
	Interaction A × C	**	**	NS	NS	NS
Sunflower	Application time	**	**	**	*	NS
	NaCl conc. (C)	**	**	NS	**	**
	Interaction A × C	NS	NS	NS	**	**
Sweet corn	Application time	NS	NS	NS	**	**
	NaCl conc. (C)	**	*	NS	NS	NS
	Interaction A × C	**	NS	NS	NS	NS

NS, *, ** not significant or significant at $P \leq 0.01$ or $P \leq 0.05$, ANOVA

TABLE VI
AFFECT OF TIME OF APPLICATION OF NaCl SOLUTION ON EARLY DEVELOPMENT TOP AND ROOT WEIGHTS OF CANOLA

Time of application	Top dry weight (g)	Roots fresh weight (g)	Roots dry weight (g)
Planting	0.57a[a]	1.31b	0.40b
Plant emergence	0.42ab	2.00a	0.78a
First true leaf expansion	0.28b	1.10b	0.20b
Split application at first true leaf expansion and 4 days later	0.36ab	1.53ab	0.28b

[a] values in a column followed by the same letter are not significantly different, $P \leq 0.05$, Ryan-Einot-Gabriel-Welsch multiple F test.

E. *Sunflower*

Application time affected all but root dry weight; NaCl concentration affected all but top dry weight; the interaction affected root fresh and dry weights (Table V). Top dry weight averaged 0.88 g. Survival was affected by time of application and concentration of the NaCl solution (Table VIII). Plants treated at planting and with the split application had higher survival than plants treated at plant emergence or first true leaf expansion. Plants treated with the 1 M NaCl solution had the lowest survival. Plants treated with the split application had higher top fresh weights than those treated at planting and at the first true leaf expansion; those treated at plant emergence were intermediate. Plants treated with 0.05 M (split application of 0.1 M) had higher top fresh weights than those treated with 0.1, 0.5, being the 1 M split, and 1 M. Plants treated with 0 M and 0.25 M (split of 0.5 M) were intermediate. Top dry weights for plants treated at

TABLE VII
AFFECT OF TIME OF APPLICATION AND NaCl CONCENTRATION ON EARLY DEVELOPMENT ROOT FRESH AND DRY WEIGHTS OF SORGHUM

Source	Top fresh weight (g)	Root weight (g) fresh	Root weight (g) dry
Time of application			
Planting	5.92b[a]	6.78b	1.48a
Plant emergence	6.21b	6.12b	1.29ab
First true leaf expansion	5.13b	5.94b	0.99b
Split application at first true leaf expansion and 4 days later	7.43a	8.80a	1.44a
Concentration (M)			
0	9.48a	6.54bc	0.91b
0.05[b]	6.19bc	8.17abc	1.22ab
0.1	6.31bc	6.62bc	1.41ab
0.25[b]	8.34ab	9.60ab	1.74a
0.5	5.40c	6.03c	1.14ab
0.5[b]	7.40abc	10.44a	1.66ab
1	4.77c	6.77bc	1.29ab

[a] values in a column followed by the same letter are not significantly different, $P \leq 0.05$, Ryan-Einot-Gabriel-Welsch multiple F test.
[b] solutions of NaCl concentrations represent split applications of the 0.1, 0.5 and 1.0 M concentrations.

plant emergence higher than for those treated at planting or at first true leaf emergence; plants treated with the split treatments were intermediate. The interaction affected root fresh and dry weights (Table X). Root fresh weight for plants treated at planting or plant emergence were not affected. Plants treated at first true leaf expansion had higher root fresh weights when treated with 0.1 M than plants treated with the other concentrations. When plants were treated with the split application those provided 0.05 M (split of 0.1 0.1 M) had the highest root fresh weight. Root dry weight for plants treated at plant emergence or with the split applications were not affected. Plants treated at planting or at the first true leaf emergence had lower root dry weights as NaCl solution concentration increased.Top fresh and dry weights were positively correlated with root fresh and dry weights (Table XI). Correlation values were from 0.7195 (top dry and root dry weights) to 0.9260 (root fresh and dry weights).

F. *Sweet Corn*

Application time affected root fresh and dry weights; NaCl concentration affected survival and top fresh weight; the interaction affected survival (Table V). Regardless of time of application survival was better than 95% for concentrations up to

TABLE VIII
AFFECT OF TIME OF APPLICATION AND NaCl CONCENTRATION ON PERCENT SURVIVAL AND EARLY DEVELOPMENT OF TOP FRESH AND DRY WEIGHTS OF SUNFLOWER

Source	Percent survival	Top weight (g) fresh	Top weight (g) dry
Time of application			
Planting	85a [a]	5.83b	0.74c
Plant emergence	77b	6.58ab	0.95a
First true leaf expansion	83b	6.37b	0.82bc
Split application at first true leaf expansion and 4 days later	94a	7.34a	0.91ab
Concentration (M)			
0	100a	8.12ab	
0.05 [b]	100a	8.67a	
0.1	91ab	6.67b	
0.25 [b]	100a	7.44ab	
0.5	88ab	6.12b	
0.5 [b]	76b	6.10b	
1	57c	6.01b	

[a] values in a column followed by the same letter are not significantly different, $P\leq0.05$, Ryan-Einot-Gabriel-Welsch multiple F test; effect on "Top dry weight" explained by an interaction.

[b] solutions of NaCl concentrations in this group represent split applications of the 0.1, 0.5 and 1.0 M concentrations.

0.5 M; for the 1 M concentrations survival was significantly reduced to 71%. For plants treated with the 0.05 M concentration (split of the 0.1 M) top fresh weight was greater than for the plants treated with the 1 M concentration; all others were intermediate (Table X). Top dry weight averaged 1.12 g. Roots treated at planting and with the split applications had higher root fresh weights than plants treated at plant emergence or emergence of the first true leaf. Plants treated at planting and plant emergence had root dry weights that were higher than plants treated at first true leaf expansion. Plants treated with the split application had intermediate values.Top fresh and dry weights were positively correlated with root fresh and dry weights (Table XI). Correlation values were from 0.4878 (top dry and root fresh weights) to 0.8738 (top fresh and dry weights).

TABLE IX
INTERACTION EFFECT OF TIME OF APPLICATION AND NaCl SOLUTION CONCENTRATION ON EARLY DEVELOPMENT OF ROOT FRESH AND DRY WEIGHTS OF SUNFLOWER

Time of application ×	*Concentration (M))*	Root weight (g) fresh	Root weight (g) dry
Planting	0	3.84	1.44
	0.1	3.91ns	1.54ns
	0.5	3.02ns	0.83**
	1	3.81ns	1.08ns
Plant emergence	0	3.13	0.92
	0.1	2.81ns	0.90ns
	0.5	3.90ns	1.25ns
	1	3.14ns	0.87ns
First true leaf expansion	0	3.55	1.04
	0.1	5.27**	1.51ns
	0.5	2.27**	0.48**
	1	1.24ns	0.24**
Split application at first true leaf expansion and 4 days later	0	3.94	1.30
	0.05[a]	5.88**	1.32ns
	0.25	4.01**	1.30ns
	0.5	3.94ns	0.80ns

ns, *, ** non-significant or significant at P<0.05 or P<0.01, respectively, Least Squares Means analysis. In this analysis values in groups are compared to the one immediately below it.

[a] solutions of NaCl concentrations in this group represent split applications of the 0.1, 0.5 and 1.0 M concentrations.

IV. DISCUSSION

High water salinity levels can be problematic to development of some crops. Average salinity of sea water is about 3.5% (35,000 $mg{\cdot}L^{-1}$). In California the Salton Sea, a source of irrigation water, has a salinity of 4.5%. Other major sources of irrigation water range between 650-800 $mg{\cdot}L^{-1}$, Colorado River and Red River (border of Texas and Oklahoma). The 1 M NaCl treatment approximated about 58,500 $mg{\cdot}L^{-1}$, the salinity in the 0.1 M treatment approximated about 5,850 $mg{\cdot}L^{-1}$, and the 0.05 M treatment represented about 2,921 $mg{\cdot}L^{-1}$.In part plant responses to salinity are due to the amount of salt that remains in the region of the roots. In a greenhouse irrigation is generally under better control than under field conditions. In the system employed amounts of irrigation water used kept the medium moist but without significant flow through drains in pots. The size of the pot and the length of time of the experiment insured that the salt in solution remained in the root zone. Since no additional nutrients were supplied plants were exposed only to those salts in the medium, the irrigation water and the NaCl solution and it was to those that plants were responding. The EC values for the medium taken over time indicate buildup of salt. However, the salt solution was likely diluted over the volume of the medium in a pot reducing the salt concentrations to below those recorded for the solution alone. Although there appears to be beneficial and detrimental responses in development of plants due to treatment, overall there was no consistent pattern of responses to salinity level or to the timing of application of treatments.The closest universal response to salinity was that at above 0.5 M NaCl survival declined for crops tested. For plants that survived treatment the response to concentration indicated benefits due to the most part for time of application, i.e., for canola increased root dry weight; for sorghum increased top and root fresh weights; increased top fresh weight in sunflower, and increased root fresh weight in sweet corn. There were instances of increases in measured variables due to specific concentrations of the NaCl solution, i.e., increased top and root fresh weights in sorghum, at the split application of 0.5 M for the former and the split application of 1 M for the latter. In general differences in response to NaCl concentration were associated with time of application in interactions. If the plants can survive they appeared to be able to adjust to either a single application of saline levels, above 0.1 M for canola and above 0.5 M for sorghum, sunflower, and sweet corn, or a split application of NaCl solutions during the early stages of development. Under the test conditions the crops seemed to be more tolerant to salt levels used than reported previously, and more so than under field conditions. However, exposure for a short time under greenhouse conditions is not equivalent to exposure to soils in the field receiving salts of fertilizers or with salty irrigation water. It remains to be determined if repeated irrigation with relatively high saline content water will affect plant development and yield under field conditions.

TABLE X
AFFECT OF TIME OF APPLICATION AND NaCl CONCENTRATION ON ROOT DRY WEIGHT AND NaCl SOLUTION CONCENTRATION ON EARLY DEVELOPMENT TOP FRESH WEIGHT OF SWEET CORN

		Root weight (g)	
Source	Top fresh weight (g)	fresh	dry
Time of application			
Planting		9.80a [a]	2.06a
Plant emergence		9.83b	2.08a
First true leaf expansion		7.59b	1.41b
Split application at first true leaf expansion and 4 days later		10.76a	1.82ab
Concentration (M)			
0	14.16ab		
0.05 [b]	15.60a		
0.1	13.20ab		
0.25 [b]	13.31ab		
0.5	10.83ab		
0.5 [b]	9.82ab		
1	8.12b		

[a] values in a column followed by the same letter are not significantly different, $P \leq 0.05$, Ryan-Einot-Gabriel-Welsch multiple F test.
[b] solutions of NaCl concentrations in this group represent split applications of the 0.1, 0.5 and 1.0 M concentrations.

TABLE XI
PEARSON PRODUCT MOMENT CORRELATIONS FOR PLANT DEVELOPMENT CRITERIA BY CROP

	Prob > |r| under HO: Rho = 0		
	Canola		
	Top dry weight	Root fresh weight	Root dry weight
Top fresh Weight	0.6122 <0.0001	0.6714 <0.0001	0.5775 <0.0001
Top dry Weight		0.5325 <0.0001	0.4986 <0.0001
Root fresh weight			0.8653 <0.0001
	Sorghum		
Top fresh Weight	0.8446 <0.0001	0.6138 <0.0001	0.6519 <0.0001
Top dry Weight		0.5524 <0.0001	0.6109 <0.0001
Root fresh weight			0.9225 <0.0001
	Sunflower		
Top fresh Weight	0.9230 <0.0001	0.7650 <0.0001	0.7195 <0.0001
Top dry Weight		0.8634 <0.0001	0.8316 <0.0001
Root fresh weight			0.9260 <0.0001
	Sweet corn		
Top fresh Weight	0.8938 <0.0001	0.5236 <0.0001	0.6156 <0.0001
Top dry Weight		0.4878 <0.0001	0.5965 <0.0001
Root fresh weight			0.8768 <0.0001

REFERENCES

[1] M. Almodares, M.R. Hadi, and H. Ahmadpour, “Sorghum stem yield and soluble carbohydrates under different salinity levels”, Africa J. Biotechnol., vol. 7, pp. 4051-4055, 2008.
[2] L. Berstein, “Effects of salinity and sodicity on plant growth”, Ann. Rev. Phytopathol., vol. 13, pp. 295-312, 1975.
[3] F.F. Blanco, M.V. Folegatti, H.R. Gheyi, and P.D. Fernandes, “Growth and yield of corn irrigated with saline water”, Sci. Agric., vol. 65, pp. 574-580, 2008.
[4] G.E. Cardon, J.G. Davis, T.A. Bauder, T.A., and R.M. Waskom, “Managing saline soils”, Extension Publ. 0.503, Colorado State Univ., Ft. Collins, CO. available on-line at: http://www.ext.colostate.edu/pubs/crop/00503.html, 2007.
[5] C.F. de Lacerda, J. Cambraia, M.A. Oliva, and H.A. Ruiz, “Osmotic adjustment in roots and leaves of two sorghum genotypes under NaCl stress”, Brazilian J. Plant Physiol., vol. 15, pp. 113-118, 2003.
[6] A. Farsiani and M.E. Ghobadi, “Effects of PEG and NaCl stress on two cultivars of corn (Zea mays L.) at germination and early seedling stages”, World Acad. Sci. Engineer. Technol., vol. 57, pp. 382-385, 2009.
[7] L.E. Francois, “Salinity effects of four sunflower hybrids”, Agron. J. vol. 88, pp. 215-219, 1996.
[8] M.D. Kaya, “The role of hull in germination and salinity tolerance in some sunflower (Helianthus annuus L.) cultivars”, African J. Biotechnol., vol. 8, pp. 597-600, 2009.
[9] S. Miyamoto, K. Piela, and J. Pettigrew, “Salt effects on germination and seedling emergence of several vegetable crops and guayule”, Irrig. Sci., vol. 6, pp. 159-170, 1985.
[10] S. Miyamoto, K. Piela, and J. Pettigrew, “Seedling mortality of several crops induced by root, stem or leaf exposure to salts”, Irrig. Sci., vol. 7, pp. 97-106, 1986.
[11] D. Morales-Garcia, K.A. Stewart, and P. Seguin, “Effects of saline water on growth and physiology of bell pepper seedlings”, Int. J. Veg. Sci., vol. 14, pp. 121-138, 2008.

[12] R. Munns, "Comparative physiology of salt and water stress", Plant Cell Environ., vol. 25, pp. 239-250, 2002.
[13] R. Munns, and M. Tester, "Mechanisms of salinity tolerance", Annu. Rev. Plant Biol., vol. 59, pp. 651-681, 2008.
[14] G.W. Netondo, J.C. Onyango, and E. Beck, "Sorghum and salinity: II. Gas exchange and chlorophyll fluorescence of Sorghum under salt stress", Crop Sci., vol. 44, pp. 806-811, 2004.
[15] N. Puppala, J.L. Fowler, L. Poindexter, and H.L. Bhardwaj, "Evaluation of salinity tolerance of Canola germination", in Perspectives on New Crops and Uses, J. Janick Ed. Alexandria, Va.: ASHS Press, 1999, pp. 251-253.
[16] V.M. Russo, J. Williamson, K. Roberts, J.R. Wright, and N. Maness, "13C-nmr spectroscopy to monitor sugars in pith of internodes of a sh2 corn at developmental stages", HortScience, vol. 33, pp. 980-983, 1998.
[17] U. Shani, and L.M. Dudley, "Field studies of crop response to water and salt stress", Soil Sci. Soc. Am. J., vol. 65, pp. 1522-1528, 2001.
[18] P. Thomas, "Chapter 6 – acidity, salinity solonetzic. Canola response to acidity, salinity and solonetzic soil", Canola growers manual. available on-line at: http://www.canola council.org, 2010.
[19] N. Zollinger, R. Koenig, T. Cerny-Koenig, and R. Kjelgren, "Relative salinity tolerance of intermountain western United States native herbaceous perennials", HortScience, vol. 42, pp. 529-534, 2007.