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Salinity Effects on the Growth of Corn at Different Stages of Development[1]

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SYNOPSIS. Tolerance of corn grown in field plots to salt was shown to be moderate and to increase with stage of development. Chlorides of Na, Ca, and Mg and sulfates of Na and Mg induced differential growth responses to corn seedlings. Contents of Ca, Mg, K, Na, and Cl in the seedling tops depended on kind and concentration of added salts, whereas total cations and N and P contents were little affected under the various treatments.

CORN is grown under irrigation in Egypt on 1.4 to 2.0 million acres which amount to one-fourth to one-third of the cultivable area. During the last 10 years the yields of corn ranged from 22 to 60 bushels per acre, with an average of about 33 bushels. Such relatively low yield under intensive agriculture might be attributed to various factors related to soil productivity and to infestation with pests, especially corn borers and cotton leaf worm in some years. Of the former factors, salinity, waterlogging, and lack of proper drainage as well as insufficient fertilization rates might be cited. No quantitative information is known concerning corn response to salinity under Egyptian conditions.

Corn is generally considered to be moderately tolerant to salt (3, 6, 8). According to Piruzyan (6) the yields of corn on slightly, medium, and highly saline (solonchak) gray-brown soil, were 62, 50, and 13%, respectively, of the yield on the nonsaline soil. The percentage solid residue[3] in the upper 40 cm. of the 3 saline soils ranged from 0.41 to 0.42, 0.35 to 0.97, and 1.23 to 1.97, respectively. This experiment represented one type of salt tolerance studies in which crops are grown in naturally saline soils and the salinity in the root zone determined during the development of the plant. In other studies saline irrigation waters are applied to water, sand, and soil cultures, or to field plots after the seedling stage (3), or in later stages of development shortly before the onset of the flowering stage (8). More information is needed to compare the effects of salinity when applied at various stages of growth.

The present work describes 3 experiments conducted during 1961 and 1962 and designed to study: (a) the response of corn to salinity applied at different stages of growth, and (b) the specific effects of salts on germination and seedling growth of corn.

EXPERIMENTAL PROCEDURE

Salinity Applied at Different Stages of Development

Two experiments were conducted during 1961 and 1962 in field plots 2.1 by 4.6 meters. The field plots are located in the laboratory site and represent reclaimed Lake Maryut beds. The upper 65 cm. consists of a nonsaline calcareous Nile alluvial deposit over-lying very coarse-textured deposits rich in marine shells. The texture of the soil ranges from clay loam (0–22 cm.), to clay (22 to 45 cm.), to sandy clay loam (45 to 65 cm.). The plots which were separated by field drains were arranged into two rows divided in the middle by a cement-lined ditch. Two side drain collectors were used to carry drainage water from the field ditches.

Each plot was divided into 3 ridges 70 cm. apart that ran the length of the plot. The seeds were planted in hills of 50 cm. apart halfway up the side of the ridges. Several seeds of 'American Early' or hybrid corn G.H. 67 were planted in each hill and later thinned to one plant per hill. American Early is the most common variety in Egypt. It is a white dent, long-season variety. American Early was introduced some 35 years ago from the U. S. and is believed to be the 'Boon County White' variety. Recent efforts have been taken to introduce hybrid corn into Egypt, and about one-seventh of the current acreage is planted to hybrid corn. In both 1961 and 1962 experiments, a randomized-block split-plot design was adopted in which the salinity levels represented the main plots and the corn type the subplots; each corn type occupied at random one-half of each plot. Fertilization, cultivation, and irrigation were conducted according to recommended procedures to produce maximum yields. Because of the relatively small size of the field plots, special care was taken to insure complete pollination by complementing natural pollination with manual operation in a manner similar to hybrid corn production. After harvesting, the dry weight yields of both grain and stover were determined.

In the 1961 experiment 4 salinity levels were applied and consisted of irrigation with tap water and with tap water to which was added 1,500, 3,000, and 6,000 ppm of 2:1 by weight of a salt mixture of NaCl and $CaCl_2$ respectively. The composition of

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[3] Soluble salts determined by evaporating the soil solution and weighing the oven-dried (105° C.) residue.

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Table 1. Composition of base nutrient solution.

Source of constituent	Constituent, me./liter								
	Ca	Mg	K	Na	NH_4	NO_3	SO_4	H_2PO_4	Cl
Hoagland	4	2	3	-	0.5	7	2	0.5	-
Tap water	1.5	1.0	0.09	1.5	-	-	0.3	tr.	1.0
Added HNO_3						2.3			
Total	5.5	3.0	3.09	1.5	0.5	9.3	2.3	0.5	1.0

tap water will be given in the experiment on specific salt effects. The salinity treatments were introduced with the 3 added salinities at seeding time, or 21 days after seeding with 3,000, and 6,000 ppm. added salinities. The treatments were replicated 3 times. Periodically soil samples were taken to a depth of 20 in. and the electrical conductivity of the saturation paste extract was determined. Plots were seeded on June 9, and harvested on September 22, 1961.

In the 1962 experiment 4 salinity levels of the added salt mixture consisting of 1,500, 3,000, 6,000, and 9,000 ppm. were applied in addition to the control treatment (tap water). The first 2 salinity treatments were applied at seeding time and the last two at the commencement of tassel emergence. The treatments were replicated 4 times. Seeding took place on April 17, 1962, and harvesting on August 11, 1962.

Specific Effects of Salts on Germination and Growth

Hybrid corn G. H. 67 was planted in clay bitumen-lined pots 322 cm. in diameteer and 29 cm. deep. The pots were filled with washed, coarse sand and 10 seeds were planted in each pot. The base nutrient solution consisted of one-half strength Hoagland solution No. 2 (4) dissolved in tap water and adjusted to pH 5.5 by the addition of HNO_3. Its composition is shown in Table 1.

The essential microelements were added to the base nutrient solution with special care to add sufficient Fe to overcome interveinal striping and chlorosis that often occur in corn leaves grown in sand culture. Five ppm Fe as ferric citrate was added every other day alternating with 1 ppm Fe as ferrous sulfate+tartaric acid.

To the base nutrient solution was added 1-, 2-, and 3-atmosphere osmotic concentrations of NaCl, $CaCl_2$, $MgCl_2$, 1:1:1 isosmotic mixture of the 3 chlorides, Na_2SO_4, $MgSO_4$, 1:1 isosmotic mixture of the sulfates, and a mixture of all the chlorides and sulfates at equal osmotic concentration of each constituent. The total treatments were thus 25 including the control treatment of the base nutrient solution. The treatments were replicated 5 times in a completely randomized block design. The seeds were planted on August 19, 1961, and the seedling shoots were harvested 22 days later. The pots were irrigated twice daily at the latter stages. At the termination of the experiment both fresh and dry weights of the seedling tops were determined.

The dry samples were ground in a Wiley mill, and Ca, Mg, K, Na, and P were determined after wet-ashing with nitric and perchloric acids. Ca + Mg, and Mg after Ca precipitation were determined by a modified versenate method (5), and Ca calculated by difference. K and Na were measured by direct measurement in a Kipp flame photometer, and P was determined colorimetrically as molybdovanadophosphoric acid. Total N and Cl were determined by the conventional Kjeldahl and Mohr methods respectively, Cl after wet-ashing by Ca acetate ignition.

RESULTS AND DISCUSSION

Salinity Applied at Different Stages of Development

Added salinity resulted in delayed germination but had no effect on final emergence of seedlings which was almost complete. Vegetative growth was very much reduced especially under 6,000 ppm salt introduced at seeding time as shown in Figure 1 for the 1961 experiment. The increased salinity resulted also in delayed tasseling and silking for a few days. Under high salinities applied at seeding time the cobs were generally smaller with fewer developed kernels. It remains to be seen whether the low seed set was caused by lower pollen viability, nonreceptive silks, or by other conditions not conducive to developing the fertilized seed.

Table 2 gives yields of grain for various treatments for the 1961 and 1962 seasons. In general the hybrid corn outyielded the American Early corn and exhibited somewhat more tolerance to salt as shown by their relative decreases in yields in comparison with their controls.

For the 1961 experiment increased salinity levels initiated at seeding time resulted in marked decrease in yield. Fifty percent of the yield of the control treatment for each variety

Figure 1. Response of hybrid corn G. H. 67 grown in field plots to irrigation with waters of different salinities (1961). Upper row, left to right: continuous irrigation with tap water, and irrigation with waters containing 3,000 and 6,000 ppm added salt respectively, starting 21 days after seeding. Lower row, left to right: irrigation with waters containing 1,500, 3,000 and 6,000 ppm added salt, respectively, starting at seeding time.

Table 2. Effect of salinity applied at different stages of growth on corn yield.

Salinity level ppm., and time of application*	Av. EC_e of sat'n. extr., mmho./cm. at 25° C. - 0-20 in. deep	Mean yield (kg.) of dry grain		
		American Early	Hybrid 67	Means
	1961 experiment			
000 (control)	2.0	2.962	4.502	3.732
1,500 (S)	3.8	1.921	3.515	2.718
3,000 (S)	5.5	1.240	1.979	1.610
6,000 (S)	8.2	0.207	0.513	0.360
3,000 (Sg)	4.7	1.958	3.313	2.636
6,000 (Sg)	7.4	1.138	2.775	1.957
	Variety means	1.571	2.766	
	1962 experiment			
000 (control)	not determined	3.194	3.327	3.261
1,500 (S)	"	2.264	2.685	2.475
3,000 (S)	"	0.785	1.504	1.145
6,000 (IT)	"	1.858	2.573	2.216
9,000 (IT)	"	1.362	2.037	1.699
	Variety means	1.893	2.425	

* 2:1 by weight mixture of NaCl and $CaCl_2$, respectively, added to tap water and applied at seeding (S), seedling stage, 21 days after seeding (Sg), and initial tasseling (IT). Effects of salinity level, time of application, and variety are significant at the 1% level. LSD (0.05) for 1961 and 1962 experiments were respectively: 0.733, 0.344 (salinity level means); 0.279, 0.162 (variety means); 0.731, 0.363 (variety means for 1 salinity level); and 0.896, 0.428 (salinity level means for 1 variety).

was obtained at salinity levels somewhere between added salinities of 1,500 and 3,000 ppm. It is reasonable to assume that such salinity level was close to 3,000 ppm added salinity since the yields under 1,500 and 3,000 ppm added salt as percent of the control yield for each variety were 78 and 44 for hybrid corn and 65 and 42 for American Early corn, respectively. Similar results occurred in 1962 growing season for hybrid corn. American Early, however, was affected relatively more by added salinity levels of 3,000 ppm.

When salinities were introduced 21 days after seeding the deleterious effects of salinity were greatly reduced. For both 'varieties' the yields under 1,500 ppm added salt applied at seeding time were not different from the respective yields under added salinity of 3,000 ppm applied 21 days after planting. The yields under 6,000 ppm added salt applied at the last application period were 62 and 38% of the yields of the control treatments for hybrid corn and American Early corn, respectively. When this last salinity level was introduced at seeding time the yields were almost negligible.

The yields under 6,000 ppm added salt applied at the commencement of visible tasseling were 77 and 58% of the respective control yields for hybrid corn and American Early. The corresponding values under 9,000 ppm added salt were 61 and 43%. These values did not reveal any specific sensitivity to salt at tasseling. The general trend of salinity effects applied at seeding time in the growing seasons of 1961 and 1962 were more or less of the same nature. The relative harmful effects of added salinity of 6,000 ppm applied 21 days after seeding during 1961 growing season were more pronounced than the corresponding effects when the same salinity level was applied at initial tasseling time during 1962 growing season.

It has been reported that subjection of corn during silking to soil moisture contents close to wilting point for only a few days resulted in severe reduction in yield (7). Bernstein and Pearson (1) drew attention to the possible lack of correlation between drought and salt tolerance of plants. In the former case the plants are subjected to severe moisture stresses whereas in the latter case the plants when properly irrigated are subjected to moderate stresses throughout the irrigation cycle.

In general, grain yields were much more sensitive to salt than were stover yields. For example in the 1961 experiment the yields of grain for American Early under added salinities of 1,500, 3,000, and 6,000 ppm when applied at planting time were 65, 42, and 7% of the yield of the control treatment, respectively. The corresponding values for stover yields were 91, 64, and 26%.

Table 3. Specific effects of different salts on yield and chemical composition of hybrid corn G. H. 67 seedlings.

Salt added to nutrient sol'n.	Osm. pres., atm.	Wt. of tops g.*	Elements in seedling tops-me./100 g. dry mat.							
			Cations					Cl	N as NO_3^-	P†
			Ca	Mg	K	Na	Tot.			
None	0	124.2	34	33	135	4	206	44	253	11
NaCl	1	78.7	29	32	137	13	211	94	258	12
	2	51.3	26	32	122	34	214	94	276	14
	3	38.6	25	29	106	61	221	102	301	16
$CaCl_2$	1	104.1	58	21	148	3	230	87	287	13
	2	52.3	76	18	147	4	245	105	289	14
	3	17.1	113	13	118	6	250	123	254	12
$MgCl_2$	1	117.9	19	66	146	3	234	87	274	14
	2	49.9	18	92	142	3	255	102	292	16
	3	12.6	18	143	97	3	261	128	248	12
NaCl, $CaCl_2$, $MgCl_2$‡	1	102.4	35	46	146	5	232	89	279	13
	2	87.0	36	48	151	4	239	102	282	15
	3	46.6	48	51	142	6	247	113	295	15
Na_2SO_4	1	65.2	20	30	133	25	208	43	272	13
	2	39.4	16	28	108	58	210	40	308	14
	3	16.4	15	25	86	99	225	30	323	16
$MgSO_4$	1	67.0	13	68	136	3	220	47	270	15
	2	19.4	11	121	104	3	239	35	288	12
	3	4.1	8	176	69	4	257	13	242	13
Na_2SO_4, $MgSO_4$	1	88.4	14	64	134	6	218	40	294	13
	2	46.3	12	78	133	13	236	38	310	15
	3	16.3	8	101	100	28	237	23	291	14
All salts‡	1	90.5	25	53	140	5	223	75	277	13
	2	73.1	25	63	138	6	232	87	298	14
	3	35.7	30	72	130	11	243	90	300	16

* Total of 5 replicates - LSD (0.05) for treatment totals = 12.5 g.
† As $H_2PO_4^-$. ‡ Isosmotic mixtures.

Specific Salt Effects on Germination, Seedling Growth and Composition of Hybrid Corn G. H. 67

Table 3 gives the yields and chemical composition of the seedling tops.

As salinity was increased germination was delayed without any effect on final germination which was almost complete. The moisture contents of the harvested tops ranged from 90.0 to 91.0, 88.5 to 90.8, and 85.5 to 90.2% for 1-, 2-, and 3-atm. osmotic pressure treatments, respectively. In general, there was a tendency for moisture contents to decrease with increasing salinity for any salt treatment, especially under $MgCl_2$ and the sulfate treatments.

As would be expected, increased salinity resulted in reduced growth of the seedlings which manifested more tolerance to chlorides than to sulfates at equal osmotic concentration. Different plant species exhibit variable responses to isosmotic concentrations of chlorides and sulfates. Eaton (2) found that the vegetative growth of both barley and dwarf milo was more tolerant of chloride than sulfate. Unpublished work in the authors' laboratory revealed that rice was more tolerant of sulfate than chloride during the seedling stage of growth.

Under NaCl, $CaCl_2$, and $MgCl_2$ treatments the yield under 1-atm. osmotic pressure of NaCl was significantly lower than the corresponding yields under $CaCl_2$ and $MgCl_2$ treatments with the former exhibiting more reduction in yield than the latter. Under 2-atm. osmotic pressure there were no differences among the 3 chlorides, and under 3-atm. the $MgCl_2$ and $CaCl_2$ treatments were significantly lower than the NaCl treatment. The mixture of the 3 salts resulted in higher yields than any of the single salts under 2- and 3-atm. osmotic pressure concentrations.

The yield response under 1 atm. of Na_2SO_4 and $MgSO_4$ was quite similar, and with increasing concentration $MgSO_4$ caused more depression in yield than Na_2SO_4. The yields of the sulfate mixtures were generally higher than the respective yields of the single components.

The beneficial effects of salt mixtures over single salts under high concentrations might be due to maintenance of proper balance among the essential elements in the plants (1). Increasing concentrations of chloride and sulfate solutions with the various cations showed that the yield depression was much greater with Ca and notably greater with Mg salts than with Na salts. Such response might be due to specific toxic effects of both Ca and Mg under high concentrations.

The addition of a single salt or a mixture of salts to the substrate resulted in increase in the contents of the respective added cation or cations in the seedling tops with concomitant reduction in one or more of the other cations. Such more or less compensating effects resulted in relatively small changes in the sum of the cations.

The reciprocal relationships between Ca and Mg were quite pronounced, with $MgSO_4$ causing more reduction in the contents of Ca than the reverse effect. Both NaCl and Na_2SO_4 induced some depression in Ca and Mg contents of tops; the sulfate reduced the Ca and Mg content more than did the chloride under equal osmotic concentrations, and Ca was generally more affected than Mg.

The concentration of K in tops depended on both kind and concentration of the added cations .Three-atmosphere concentrations of Na, Ca, Mg chlorides, Na, Mg sulfate and their mixtures, and 2-atm. concentrations of NaCl, Na, Mg sulfates reduced the K content in the tops, with the effects of sulfates being more marked than the effects of chlorides. One and 2 atm. of Mg, Ca chlorides as well as the 3 concentrations of the chloride mixture resulted in slight increase in K contents of the seedlings.

Sodium concentration in the seedling tops was generally of the order of 3 to 6 me./100 g. dry matter and showed very little change for treatments other than Na salts. Sodium sulfate treatments induced higher contents of Na in tops than NaCl treatments under equal osmotic concentrations.

The depressing effects of sulfates of Ca adsorption (1), as well as their effects when present in high concentrations on K adsorption, might have been the result of decreasing activity coefficients of the ions caused by the increased ionic strength of the substrate.

The first increment of Cl resulted in a relatively large increase in the Cl content of tops. The effects of subsequent increments of Cl were relatively less pronounced. Such response might be due to the low concentration of Cl in the base nutrient solution which amounted to 1 me./1; thus the first Cl increment constituted a very large relative increase in the Cl concentration of the substrate. Increasing sulfates depressed Cl contents of shoots especially under $MgSO_4$ treatments. Nitrogen and P contents of tops were in general little affected by increasing concentrations of the added cations and anions. Similar behaviour was reported in other plant species (1).

SUMMARY AND CONCLUSIONS

Two experiments were conducted in field plots on hybrid corn G. H. 67 and the open-pollinated corn, American Early. The plots were irrigated with tap water that contained about 370 ppm soluble salts, and with tap water that contained 1,500, 3,000, 6,000 and 9,000 ppm added salts. The salinity treatments were applied at three stages of development.

A third experiment was conducted with hybrid corn G. H. 67 in a sand culture. To the basal nutrient solution were added Na and Mg chlorides and sulfates and $CaCl_2$, singly and in combination at concentrations of 1-, 2-, and 3-atm. osmotic pressures. The experiment was conducted to study the effects of these salts on germination and seedling growth and composition. The experiments showed that:

(a) Corn is quite tolerant of salt during germination. Increasing salinity delayed germination but had no detrimental effect on percentage emergence.

(b) Hybrid corn G. H. 67 yielded more grain and exhibited somewhat more tolerance to salt than American Early. The tolerance of both corn types increased with the stage of development.

Stover yields were much less affected by salinity than were grain yields.

(c) Corn seedlings were more tolerant of chloride than sulfate at equal osmotic concentrations.

Under 1-atm. osmotic pressure, Na_2SO_4 resulted in seeding growth equal to $MgSO_4$, whereas NaCl depressed growth more than either $CaCl_2$ or $MgCl_2$. With increasing concentrations the reduction of growth was greater under Ca and Mg salts than under Na salts.

Mixtures of salts generally resulted in more seedling growth than single salts, especially under the high added concentrations of 2 and 3 atmospheres.

(d) The sum of total cation contents of seedling tops was not greatly affected by increasing salinity in the substrate since any increase in one or more cations was compensated to some extent by decrease in one or more other cations.

(e) The reciprocal relationships between Ca and Mg were quite pronounced. Sodium salts induced moderate lowering of both Ca and Mg in tops.

Potassium contents in tops depended on both kind and concentration of salt in the substrate. High salt concentrations generally decreased the K contents of the tops with the sulfates causing a greater reduction than the chlorides. Under low and sometimes moderate concentrations of Ca and Mg salts, K contents in tops were higher than in the control.

Sodium in tops was generally low and was little affected by addition of other salts.

Chloride in tops was increased by increasing chloride salts in the substrate and was depressed by increasing sulfates, especially $MgSO_4$. N and P contents were generally little affected by increasing concentrations of the added cations and anions.

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EFFECT OF SALINITY APPLIED AT DIFFERENT STAGES OF GROWTH ON DRY GRAIN CORN YIELD

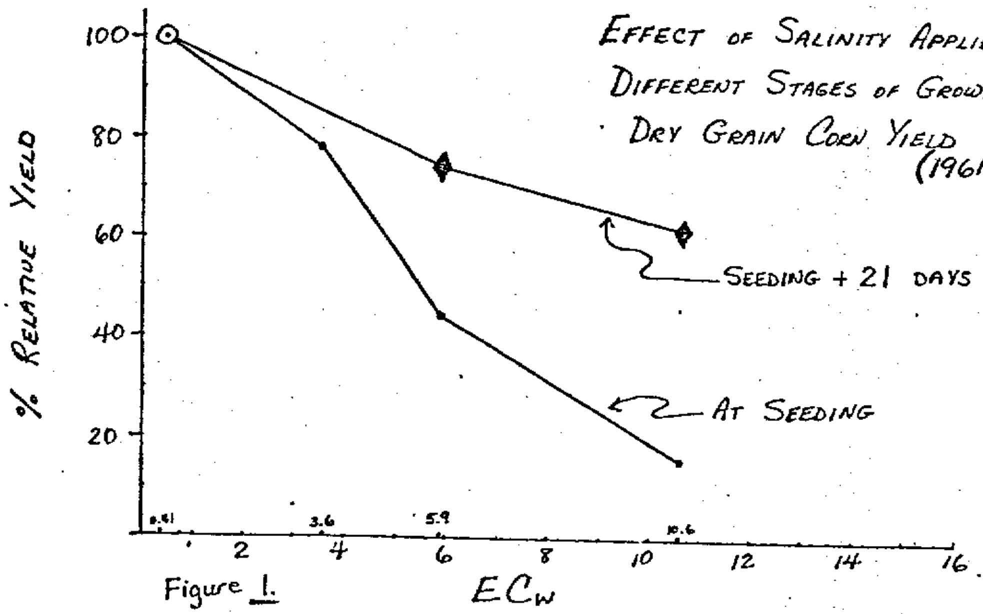

Figure 1.

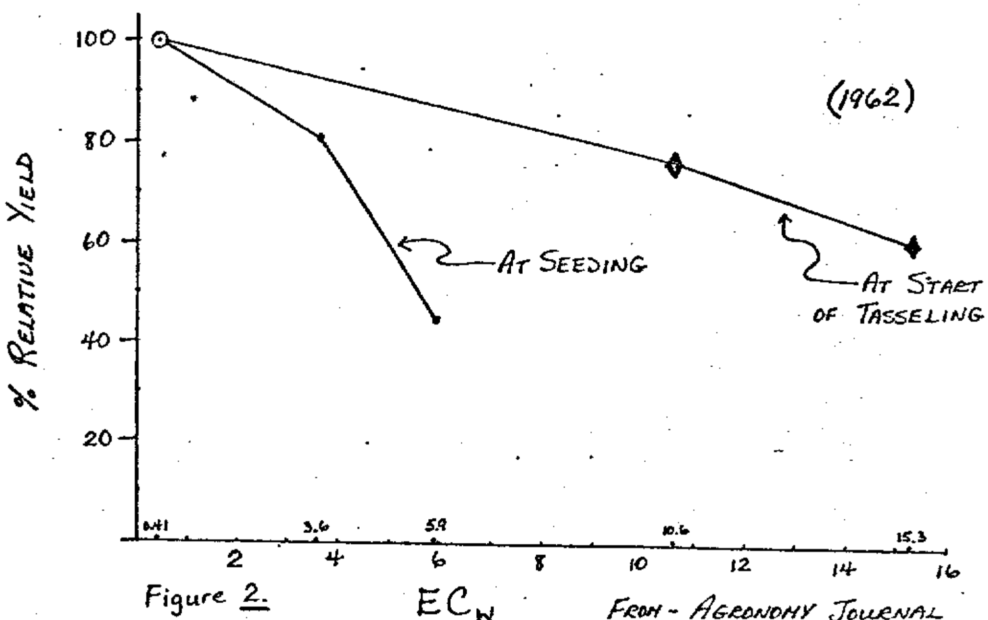

Figure 2.

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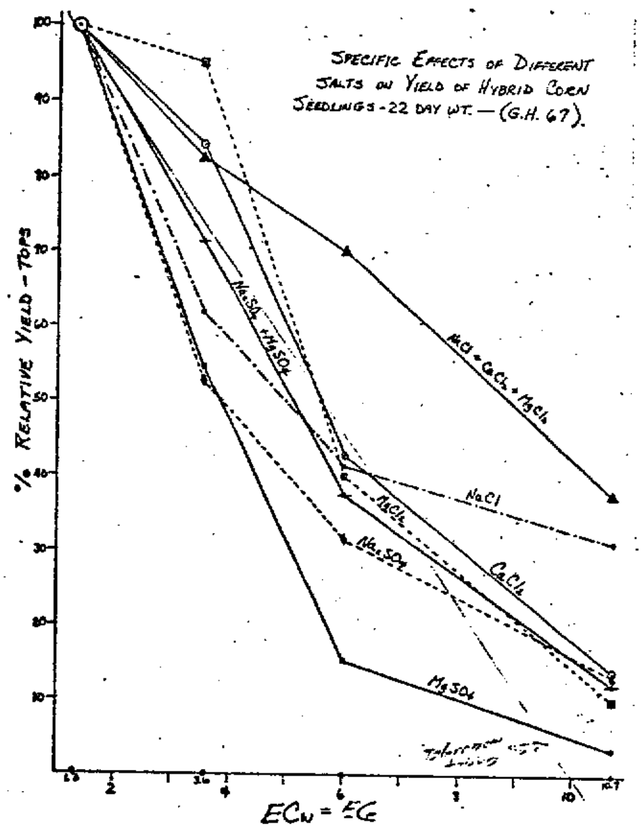

sand culture

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