



Emergence and seedling growth of soybean cultivars and maturity groups under salinity

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Abstract

Soybean is an important agricultural crop and has, among its genotypes, a relatively wide variation in salt tolerance. As measured by vegetative growth and yield, however, the achievement or failure of a high emergence ratio and seedling establishment in saline soils can have significant economic implications in areas where soil salinity is a potential problem for soybean. This study was conducted to determine the effects of salinity, variety and maturation rate on soybean emergence and seedling growth. Included in the study were the variety 'Manokin'; four near-isogenic sibling lines of the variety 'Lee' belonging to maturity groups IV, V, VI and VII; and the variety 'Essex' and two of its near-isogenic related lines representing maturity groups V, VI and VII, respectively. Field plots were salinized with sodium chloride and calcium chloride salts prior to planting. The soybeans were irrigated with furrow irrigation which redistributed the salts towards the tail ends of the field plots. Elevated soil salinity near the tail ends of the field significantly reduced soybean emergence rate, shoot height and root length. No significant reduction was found for emergence or seedling growth of variety 'Manokin' when the electrical conductivity of soil solution extract (ECe) was less than 3 dS m⁻¹. Soybean emergence and seedling growth was significantly reduced when soil ECe reached about 11 dS m⁻¹. Maturity groups V and VII of variety 'Lee' or V and VI of 'Essex' appeared to be more sensitive to salinity stress than other maturity groups. Salt tolerance of different genotypes and maturity groups should be considered, among other limiting factors, in minimizing salinity effects on soybean growth.

Introduction

High levels of soil salinity can significantly inhibit seed germination and seedling growth, not only of glycophytes but also of halophytes, due to the combined effects of high osmotic potential and specific ion toxicity (Grieve and Suarez, 1997; Katembe et al., 1998; Khan and Ungar, 1998). Among salt sensitive glycophytes, a wide variation in salt tolerance has been reported for different genotypes of the same plant species. In soybean, El-Samad and Shaddad (1997) found that cultivar 'Clark' was more sensitive to sodium chloride salinity than cultivar 'Forest', followed by cultivar 'Kint'. An earlier study by Abel

and MacKenzie (1964) indicated that seed germination of the soybean varieties 'B54-842', 'N53-505', 'N53-509', 'Improved Pelican', 'Lee' and 'Jackson' was reduced by a variable degree of sodium chloride salinity. Variability among soybean varieties in response to salinity is often attributed to the degree of chloride toxicity. Severe leaf scorch was blamed on high concentrations of soil chloride from applications of potassium chloride fertilizer (Parker et al., 1983). Yang and Blanchard (1993) found that the degree of soybean chloride toxicity from potassium chloride fertilizer application was significantly different among chloride accumulator and excluder cultivars. Lauchli and Wieneke (1979) reported an increase in plant uptake of Na⁺ and Cl⁻ in soybean varieties 'Lee' and 'Jackson' when increasing NaCl concentrations in the nutrient solution. The severity of soybean leaf injury

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from chloride can also be increased with high levels of solution phosphate (Grattan and Maas, 1988). As indicated in Pantalone et al. (1997), the wide differential responses to salinity, especially in perennial Glycine accessions, may be used to develop new soybean cultivars with enhanced salt tolerance.

Differences in time of flowering and maturity in soybeans, reflected as maturity groups, are attributed to genetic differences (Palmer and Kilen, 1987). Significant correlation ($r=0.55$) was found, among 20 cultivars of soybean, between maturity groups and their genome sizes (Graham et al., 1994). However, there are no studies that explore whether the genes unique to specific maturity groups may also have implications for salt tolerance, or the potential effect of salinity on the emergence and seedling development of different soybean maturity groups. From a plant physiological standpoint, the long growing time for the late maturing groups would make the plants subject to more cumulative salt stress, therefore, may suffer more salinity damages than the early maturity groups. Furthermore, salinity stress was found to increase plant ethylene production (Lutts et al., 1996). Depending on the plant species, the increased ethylene concentration could either shorten or prolong the growing time to maturity. No matter what the plant species are, this would likely impact the late more than the early maturity groups because of the longer growing time.

Most of the soybean salt tolerance studies reported in the literature have been conducted in the laboratory or greenhouse under artificial environmental conditions. Under such conditions, the ambient environment can be better controlled to maximize the salinity effect and reduce variation between treatments. However, salinity problems occur naturally in uncontrolled field conditions as a consequence of irrigation management and the natural salinity in soil and water. Other than salinity, environmental variables such as soil hydraulic properties, air temperature, wind speed, radiation, atmospheric CO₂ and ozone levels are difficult to duplicate in the laboratory. However, these variables can directly affect plant growth, and may have an indirect effect on plant salt tolerance (Shannon, 1997). Therefore, the eventual resolution of any salinity problem must also be achieved in the field, and direct field experimentation on crop salt tolerance should be an important integral part of salinity research.

Since, in many places, soil salinization in agriculture is derived from mismanaged long-term irrigation of farmlands, research in crop salt tolerance should

consider the processes that contribute to the accumulation of soil salts. For example, the surface water flow in furrow irrigation can pick up soluble salts from the surface soils and either gradually deposit them towards the tail end of the irrigated fields or carry them off the field in the runoff water. Because of this mechanism of salt redistribution, Rhoades et al. (1997) found that the level of soil salinity doubled from the head to the tail ends of furrow-irrigated fields.

To help bridge the gaps of our understanding of soybean salt tolerance, a field experiment was conducted to determine the effect of salinity on emergence and seedling growth of three soybean cultivars ('Manokin', 'Lee' and 'Essex') and four maturity groups (IV, V, VI and VII) under furrow irrigation. 'Manokin' is a late maturity group IV cultivar. The 'Lee' consisted of four maturity groups IV, V, VI and VII, whereas the 'Essex' soybeans were from maturity groups V, VI and VII. The specific objectives of the study were 1. to determine emergence and seedling growth of cultivar 'Manokin' under different levels of salinity along the irrigation furrows, 2. to compare varietal differences in response to soil salinity, and 3. to characterize salinity effects on seed germination and seedling development among different maturity groups of cultivars 'Lee' and 'Essex'.

Materials and methods

To simulate salt redistribution from furrow irrigation and its effects on soybean emergence and seedling growth, two strip plots (16 rows, each 76 m long; 0.75 m row spacing) were selected for the field experiment. Prior to planting, half of each plot (8 rows) was salinized with sodium chloride and calcium chloride salts (1:1 weight ratio). The remaining halves of each plot (8 rows) were used as controls with no salt application. The low salt treatment received 42 kg of NaCl and CaCl₂ mixture, which was calculated to raise the soil salinity to about 3 dS m⁻¹ in the surface 30 cm soil. The high salt plot received 84 kg salts, which was expected to bring the salinity to about 6 dS m⁻¹. Salt solutions were dissolved in 225 l of water, then injected into a sprinkler system that further diluted and applied the salt solutions to the salt treatment plots. A total of 48 mm solution was applied to each plot. To create similar initial soil moisture conditions between the salinized and the control plots, a total of 48 mm water was applied, with the same sprinkler system, to the two control plots (the remaining 8 rows of the

strip plots). The irrigation source water used during the experiment had a low bulk electrical conductivity ($EC_{iw}=0.5 \text{ dS m}^{-1}$). This water (nonsalinized) was used to irrigate both the salt and the control plots after soybean planting and throughout the experiment.

Because the action of furrow irrigation would move salts from the head to the tail end of the field, soil salinity levels would be higher near the tail than the head end. The magnitude of salt accumulation near the tail ends could be so large that substantial yield loss was expected for even salt-tolerant crops such as sugar beet (Rhoades et al., 1997). However, no data could be found in the literature to illustrate the adverse effect of furrow-irrigation-induced salinity problems on crop development. One of the goals of this field study, therefore, was to verify such a salt redistribution effect on soybean growth. For this, soybean variety 'Manokin' was selected to determine its response to different salinity levels along the field furrows, i.e. at the head, middle and tail end. 'Manokin' is a late maturity group IV determinate cultivar recently developed for its superior yield and resistance to soybean cyst nematode (Kenworthy et al., 1996). It is genetically related to cultivar 'Lee', but no information was found in the literature on its potential for salt tolerance.

To compare responses to salinity of different varieties and maturity groups, near-isogenic sibling lines of the cultivars 'Lee' and 'Essex' were grown. The 'Lee' isolines belonged to maturity groups IV, V, VI and VII; and the 'Essex' lines represented maturity groups V, VI and VII. The two cultivars were selected because the 'Lee'-related soybeans are reported to be salt tolerant (Abel and MacKenzie, 1964), whereas 'Essex' lines are considered relatively sensitive to salinity stress (Yang and Blanchar, 1993). Seeds of 'Lee' and 'Essex' were planted on 32 subplots located 12 m from the tail ends of the 'Manokin' furrow plots (the low salt, high salt and two associated control plots). Each subplot consisted of four rows of 3-m long sections. The seven cultivar-maturity group combinations were randomly assigned to eight subplots within each of the four furrow plots, with 'Essex' maturity group V replicated once as the eighth treatment but not sampled for statistical analyses.

Because of differences in plot size, 'Manokin' was planted using a soybean planter mounted behind a tractor, whereas 'Lee' and 'Essex' were planted with a hand-operated and planter. All seeds were planted at a rate of 32.8 seeds per m and at depths between 3 and 5 cm from the soil surface. To stimulate nodule formation for nitrogen fixation, a commercial inoculant

NITRAGIN¹ (LiphaTech[®] Inc., Milwaukee, WI) was mixed with the seeds immediately before planting.

For 'Manokin', the emergence rate was measured by counting the number of visible seedlings in three randomly selected 2 m sections from each furrow plot at 5, 38 and 71 m from the head end of the field. The three locations are thereafter called Head, Middle and Tail. During the emergence measurement, seedling height and tap root length were also recorded from six randomly selected seedlings from every 2 m section selected for the emergence survey. For the different maturity groups of 'Lee' and 'Essex', the emergence rate was measured by counting the total number of soybean seedlings from the 3-m section of all four rows. Because of the destructive sampling of root length, only seedling heights, from 20 randomly selected soybeans, were recorded for each cultivar-maturity group combination. ANOVA and mean comparison procedures from SAS (SAS Institute Inc., 1985) were used to compare differences of the measured parameters among varieties, maturity groups, and salinity levels.

Prior to the soybean emergence and seedling growth measurements, replicated soil samples were taken from each furrow plot at the Head, Middle, and Tail locations of the 'Manokin', and the 'Lee' and 'Essex' subplots. Five samples were obtained by separating each soil core at 0–5, 5–10, 10–20, 20–30 and 30–50 cm increments. Three replicated cores were taken at each location per treatment with a hand-operated auger at the center of the soybean row. Soil samples from the two control plots (associated with the high and low salt treatments) were composited to produce a common control for the three furrow locations of the 'Manokin' plot. A common control was also produced for the 'Lee' and 'Essex' subplots. To determine soil salinity, soil solution was extracted from a mixture of 100 g of field moist soil and 100 g of de-ionized water after equilibrating for 24 h. The extract was collected under vacuum after placing the soil-water slurry over a filter paper fitted in Buchner funnels. Bulk electrical conductivity of the solution extract (EC_e) was measured and corrected for the conductivity under field saturation. The soil water content of each sample was also determined for correction of the EC_e calculations. The estimated soil EC_e data were used to interpret the soybean emergence and seedling growth measurement among different locations (or salinity levels), cultivars and maturity groups.

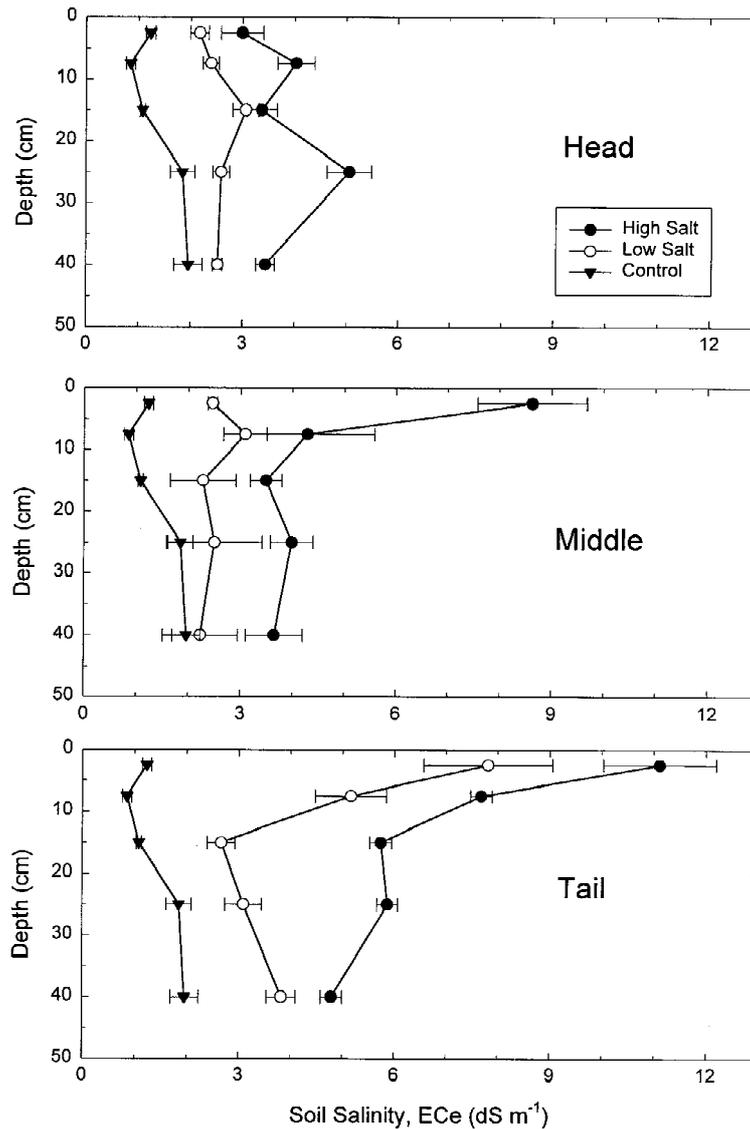


Figure 1. Soil salinity distribution over depth at three locations (Head, Middle, Tail) relative to the water inlet in furrow-irrigated field plots presalinized to two levels (High Salt and Low Salt) of sodium chloride and calcium chloride salts. Soybean variety 'Manokin' was planted in each plot. Error bars represent standard errors.

Results and discussion

At the time of soil sampling, furrow irrigation had redistributed salinity levels in the salinized plots from the head to the tail ends of the field. Significantly higher levels of soil salinity were found in the tail than in the head ends of the field in both the high salt and low salt treatments (Figure 1). A relatively uniform salt distribution was observed through the 50 cm soil profile at the head end of the field. This was expected because longer leaching time at the head end

would increase the vertical transport of soluble salts to lower depths of the soil profile. Water flowing along the irrigation furrows transported the salts to the lower sections of the field. Because of the salt remobilization and transportation at the head ends, the ECe for the surface 5 cm soil, after correction for field saturation, was only at 2.2 and 3.0 dS m⁻¹ for the low and high salt treatments, respectively.

Near the middle of the field, the electrical conductivity of surface soil extracts remained low for the low salt treatment (ECe=2.5 dS m⁻¹), but reached 8.6

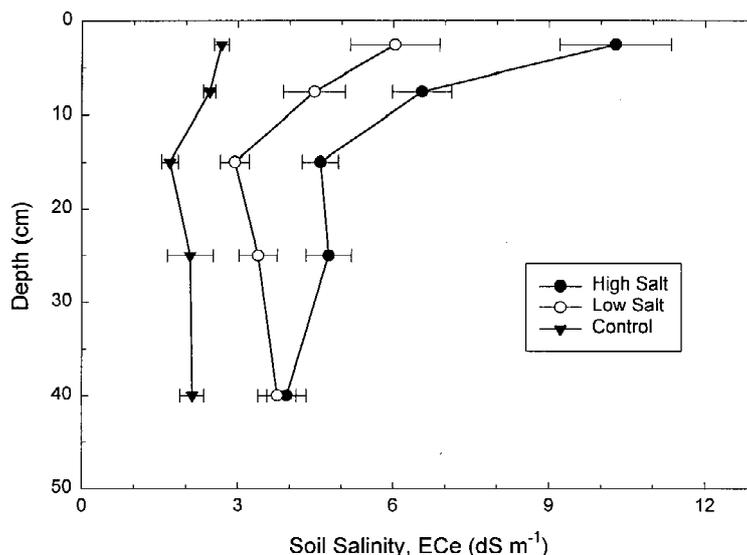


Figure 2. Soil salinity distribution in field plots presalinized to two levels (High Salt and Low Salt) of sodium chloride and calcium chloride salts, and planted with soybean varieties 'Lee' and 'Essex' of different maturity groups. Error bars are standard errors.

dS m^{-1} for the high salinity treatment. Substantially more salt accumulation occurred at the tail end of the field, especially for the low salt treatment where the electrical conductivity of surface 5 cm soil was 7.8 dS m^{-1} . In the high salinity plot, the ECe further increased to 11.1 dS m^{-1} . The substantial increase in soil salinity was directly attributed to furrow irrigation on a saline soil, or more specifically to the effect of salt redistribution by the irrigation water.

In addition to the increased surface ECe, electrical conductivity of the subsurface soils was also significantly higher at the tail than at the head or middle of the field. This may be attributed to the reduced leaching and increased salt concentrations in irrigation water transported from upper streams of the furrow irrigation. The differences in surface-soil salinity among the three locations provided a comparison of responses of 'Manokin' to different levels of salinity stress.

Soil salinity in the 'Lee' and 'Essex' subplots decreased over depth following a pattern similar to that at the tail end of the field plots (Figure 2). This was expected since the sample locations for the 'Lee' and 'Essex' subplots were only 8–18 m from the tail end sample locations of the 'Manokin' soybeans. The electrical conductivity of the surface 5 cm soil averaged 6.0 and 10.3 dS m^{-1} for the low and high salt treatment, respectively. The ECe for the low salt treatment was 3.4 dS m^{-1} higher than that in the control plot.

The emergence ratio and growth parameters of 'Manokin' appeared to have been affected by the dif-

ferential soil salinity levels at the head, middle and tail ends of the field (Table 1). Comparison within each salinity treatment indicated that the measured plant parameters were significantly ($P=0.05$) smaller at the tail than the head or middle of the field when under high salt. This is consistent with the soil salinity measurement (Figure 1), since the soil ECe had increased, from relatively lower values at the head and middle sections of the field, to 11.1 dS m^{-1} at the tail end. No statistically significance was found between the three sample locations for the low salt and control plots. Analysis of variance indicated that soybean emergence, shoot height and root length varied significantly ($P=0.05$) among the three furrow locations (i.e. head, middle and tail; Table 2). The test also showed that the shoot height and root length varied among the salt treatments. Root length was the only parameter that was significant for the interactive effect of location and salt treatment. Probably because of its genetic relationship with 'Lee' (Kenworthy et al., 1996), it appears that the 'Manokin' soybean has some degree of salt tolerance. However, salinity effects on emergence and seedling growth became significant when the soil ECe reached about 11 dS m^{-1} . Deleterious effects of salinity on soybeans can be attributed to a combination of both osmotic and specific ion effects, and a possible inhibitory effect on nodulation (Bernstein and Ogata, 1966; Velagaleti and Marsh, 1989). During our destructive root measurement, no nodules

Table 1. Emergence and early growth parameters of soybean 'Manokin' under salinity*

Salinity Treatment	Furrow Location	Emergence		Shoot height (cm)	Root Length (cm)
		(no. m ⁻¹)	(%)		
High Salt	Head	17.0 (2.4)a	51.8 (7.3)a	4.1 (1.5)a	5.7 (0.9)a
	Middle	13.3 (4.1)a	40.5 (12.5)a	2.7 (1.1)a	6.2 (1.1)a
	Tail	1.0 (0.7)b	3.0 (2.1)b	0.4 (0.3)b	0.3 (0.3)b
Low Salt	Head	21.0 (3.4)a	64.0 (10.4)a	5.2 (2.4)a	5.3 (1.1)a
	Middle	19.7 (8.1)a	60.1 (24.4)a	5.9 (2.3)a	5.4 (0.9)a
	Tail	12.8 (1.7)a	39.0 (5.2)a	4.6 (1.6)a	5.5 (0.8)a
Control	Head	19.8 (1.9)a	60.2 (5.8)a	4.2 (1.4)a	5.6 (1.0)a
	Middle	17.1 (4.6)a	52.1 (13.9)a	5.5 (2.0)a	6.0 (0.8)a
	Tail	15.0 (4.2)a	45.6 (12.8)a	4.6 (1.5)a	5.7 (1.0)a

*Values are the means (SE) of three replicates of emergence, and 18 replicates of root height and root length measurements. Different letters indicate statistical significance at $P=0.05$ level using the Tukey test.

were found for soybeans at the tail end of the salinized field plots.

Compared to their controls, maturity groups V and VII of the soybean variety 'Lee' were relatively more sensitive to salinity than groups IV and VI (Table 3). Emergence for maturity groups V and VII were reduced by about 50% by the salt treatments, whereas similar emergence was found between the salt and control for maturity groups IV and VI. Seedling height was also significantly ($P=0.05$) reduced by the salinity treatments for maturity groups V and VII (Table 3). It also appeared that, compared to the control plots, saline soil would reduce seedling growth even though a reasonable emergence was achieved such as in the low salt treatment of maturity groups IV and V. Compared to the controls for cultivar 'Essex', emergence was significantly ($P=0.05$) reduced by the high salt treatment for maturity groups V and VI (Table 4). Shoot height was also lower in the salinity than in the control treatment. For maturity group VII, however, the high salt treatment appeared to have stimulated shoot development. Maturity groups V and VII of 'Lee' had significantly ($P=0.05$) higher emergence rates in the control plots than that of the 'Essex' soybeans. This would numerically indicate a stronger adverse effect of salinity on these two than other maturity groups. While it is likely that other environmental variations such as soil properties may contribute to soybean emergence and seedling growth, a systematic difference in salinity response among maturity groups may be caused by the genetic variations among maturity groups. Some of the gene pairs unique to a

Table 2. Significance of ANOVA ($Pr > F$) showing effects of location and salt treatment on emergence, shoot height and root length of soybean 'Manokin'

	Emergence	Shoot	Root
Location	0.0300	0.0273	0.0001
Salt treatment	0.0719	0.0001	0.0001
Interaction	0.5515	0.0543	0.0001

particular group such as IV or VI may also affect salt tolerance. From a developmental standpoint, earlier maturing groups may have a faster growth rate than the late maturity groups. This may affect the seedling vigor for tolerance of environmental stresses such as salinity.

The ANOVA test for cultivars 'Lee' and 'Essex' indicated that soybean emergence was significantly reduced with salt application ($Pr > F=0.0004$). The four maturity groups also responded differently to the salt treatment ($Pr > F=0.0001$) in terms of emergence. Seedling height, however, responded to the salt treatment ($Pr > F=0.0001$), but not to differences in maturity groups. Soybean emergence rate for maturity group IV was significantly lower than values for the other three maturity groups (Table 5). The comparison also indicated a significant difference between groups V and VII in terms of emergence. No significant difference was found for other maturity groups or for shoot development. Information on differential responses to salinity among soybean maturity groups should be useful for seed or maturity group selection

Table 3. Emergence and seedling height of soybean 'Lee' of different maturity groups under salinity*

Maturity group	Salinity treatment	Emergence		Shoot height (cm)
		(no. m ⁻¹)	(%)	
IV	High Salt	11.9 (0.6)a	36.3 (1.8)a	7.7 (0.3)a
IV	Low Salt	7.1 (3.2)a	21.6 (9.8)a	4.2 (0.5)b
IV	Control	10.6 (1.4)a	32.4 (4.2)a	10.3 (0.6)a
V	High Salt	8.8 (1.3)a	26.8 (4.0)a	4.6 (0.4)a
V	Low Salt	12.4 (1.8)a	37.8 (5.5)a	6.1 (0.5)b
V	Control	24.7 (2.3)b	75.3 (7.2)b	11.2 (0.4)c
VI	High Salt	14.0 (2.3)a	42.7 (7.0)a	7.5 (0.4)a
VI	Low Salt	20.8 (3.9)a	63.4 (11.9)a	7.5 (0.4)a
VI	Control	20.3 (3.3)a	61.0 (10.1)a	8.6 (0.6)a
VII	High Salt	13.3 (1.9)a	40.5 (5.8)a	5.2 (0.4)a
VII	Low Salt	15.9 (5.1)a	48.5 (15.5)a	5.5 (0.6)a
VII	Control	31.1 (7.2)b	94.7 (22.1)b	10.6 (1.6)b

*Values are the means (SE). $N=4$ and 20 for emergence and shoot height measurement, respectively. Different letters indicate statistical significance at $P=0.05$ level using the Tukey test.

Table 4. Emergence and seedling height of soybean 'Essex' of different maturity groups under salinity*

Maturity group	Salinity treatment	Emergence rate		Shoot height (cm)
		(no. m ⁻¹)	(%)	
V	High Salt	10.8 (1.4)a	32.9 (4.3)a	6.1 (0.4)a
V	Low Salt	15.5 (1.9)b	47.3 (5.8)b	7.3 (0.4)a
V	Control	18.0 (1.3)b	54.7 (4.0)b	10.8 (1.9)b
VI	High Salt	14.1 (2.9)a	43.0 (8.8)a	5.8 (0.5)a
VI	Low Salt	22.9 (2.7)b	69.8 (8.2)b	8.3 (0.4)a
VI	Control	21.1 (1.3)b	64.2 (4.3)b	12.8 (2.5)b
VII	High Salt	24.9 (4.1)a	75.9 (12.5)a	10.5 (0.4)a
VII	Low Salt	21.2 (1.2)a	64.6 (3.7)a	8.5 (0.5)b
VII	Control	24.2 (3.0)a	73.8 (9.2)a	7.7 (0.5)b

*Values are the means (SE). $N=4$ and 20 for emergence and shoot height measurement, respectively. Different letters indicate statistical significance at $P=0.05$ level using the Tukey test.

in areas where salinity may be a potential problem in certain times of the growing season.

Our results indicate that furrow irrigation can significantly redistribute soil salts towards lower ends of the field. Elevated levels of soil salinity near the tail ends of the field can significantly reduce soybean emergence, shoot height and root length, compared to the head end or the middle of the field. A salinity level of $E_{ce}=3$ dS m⁻¹ probably would not affect the emergence and seedling growth of soybean variety 'Manokin'. While it is generally believed that a

soil E_{ce} of 5 dS m⁻¹ or above would inhibit soybean growth (Maas and Hoffman, 1977), this study indicates that significant reduction in emergence and seedling growth occurs when soil E_{ce} reaches 11 dS m⁻¹ for soybean variety 'Manokin'. For variety 'Lee', maturity groups V and VII were more sensitive to salinity than groups IV and VI in terms of emergence and seedling growth. Maturity groups V and VI of cultivar 'Essex' were relatively more sensitive to soil salinity than group VII. The variability in salt sensitivity between different genotypes and

Table 5. Effects of maturity groups on the emergence of soybean variety 'Lee' and 'Essex' under salinity. Symbols '***', 'NS', and 'NA' indicate significant, not significant at $P=0.05$ level, and not apply

Maturity group	IV	V	VI	VII
IV	NA	***	***	***
V	***	NA	NS	***
VI	***	NS	NA	NS
VII	***	***	NS	NA

maturity groups presents a potential for increasing soybean salt tolerance by selective breeding programs (Yeo and Flowers, 1989). In addition to other limiting factors, such as duration of growing season or resistance to specific pathogens, selection for salt tolerance of soybean genotypes and maturity groups should be considered in locations where salinity may become a problem.

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