Effects of soil sodicity on the germination, growth and productivity of Soybean (*Glycine max*)

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Abstract
Considering soybean potential for the inland irrigation and coastal areas where occurrence of surface and/or sub-surface soil sodicity impairs agricultural productivity, investigations were conducted on the two commercial paddocks in 1995/96 and 1996/97. Fifty plots of 3 m^2 size were marked at random locations based on their pre-determined surface (0-15 cm) soil exchangeable sodium percentage (ESP) variations (1.2-27.8). Composite samples were collected from each plot before sowing and after harvest of soybean for soil analysis. Experimental data showed significant reduction and delay in emergence of soybean seedlings due to increasing surface soil ESP. Soybean germination was comparatively less sensitive to soil ESP than its growth and yield. Surface soil ESP of 12.1 and 13.3 were found effective in reducing soybean yield to half whereas 50 per cent reduction in emergence of soybean seedlings occurred at ESP of 18 or more. Sub-soil ESP did not show high correlation with soybean growth and yield. Soybean grain yields had shown highly significant negative relationship with the surface soil ESP, with r^2 values of 0.979 and 0.989 in 1995/96 and 1996/97 respectively. Surface and sub-surface soil ESP were observed to reduce water infiltration rates and saturated hydraulic conductivity whereas clay dispersion and mechanical impedance of soil were found to increase with increasing ESP of the soils.

Key Words
Crop establishment, growth, crop yield, exchangeable sodium percentage, clay dispersion, infiltration.

Introduction

Prevalence of surface and sub-surface soil sodicity in irrigation areas of NSW is reported (Loveday 1974; McKenzie *et al.* 1993) to be an important constraint that reduces crop productivity as well as the productive performance of agricultural inputs and resources. Intensity of sodicity problems is generally quantified by measuring exchangeable sodium percentage (ESP) and relevant soil properties (Sumner 1993). Adverse effects of sodicity on crop growth mainly results in from the breakdown of soil structure through dispersion of aggregated particles (Loveday 1984; Rengasamy *et al.* 1991). Dispersive behavior of soils results in poor water use efficiency, reduced plant emergence and crop yields by promoting surface sealing, crusting and increasing mechanical impedance to plant roots (Abrol and Painuli 1986; Abrol *et al.* 1988; So and Aylmore 1993). Movement of air and water into the root zone is also reduced significantly. Plants, sometimes, face aeration stress due to prolonged water logging or impeded infiltration of irrigation and/or rain water.

Soybean crop holds considerable promise and potential for diversification of Australian farming systems of the inland irrigation areas and rain-fed coastal regions where surface and/or subsoil sodicity do occur commonly. Available information on response of soybean to sodicity in Australian soils under different climatic conditions is limited. Therefore, field investigations were carried out on the two commercial paddocks with spatial variations in surface and sub-surface soil sodicity.

Methods

Effects of the surface and sub-surface soil sodicity on establishment, growth and productivity of soybean were evaluated by investigations on the two commercial paddocks in 1995/96 and 1996/97. Irrigated lucerne (for hay) was grown on these paddocks during 1992-1995. High levels of variations in its patchy growth and establishment accompanied by morphological differences (crusting, water logging, seals, and poor water infiltration) in the surface soil were typical of sodicity effects. An intensive soil study was conducted on these paddocks previously. Experimental results from that study on important soil properties and apparent electrical conductivities (E_a) measured with EM-38 were used to utilize natural heterogeneity in surface and sub-surface sodicity rather than creating plots of variable sodicity by treating a sodic soil with variable amounts of gypsum.

To accomplish this study, 50 observation plots of 3 m^2 in size were marked in each of the two commercial grey soil (Grey Vertisol) paddocks at locations determined previously based on ESP variations. Composite soil samples were collected from each plot before the sowing and after the harvest of soybean (variety *Benjalong*). After their processing, these were analyzed for important soil properties and their variation range for different soil depths is shown in Table 1. Variation in each of these soil properties was more in the surface (0-15 cm) layer and it decreased with the depth.

Table 1. Variation ranges of important soil properties for different soil layers of the two paddocks.

Soil depth (cm)	$pH_{1:5}$ (H_2O)	$pH_{1:5}$ (0.01 M $CaCl_2$)	$EC_{1:5}$ (dS/m)	SOC (g/kg)	ESP	$CEC_{(+)}$ (cmol/kg)	Textural class
0-15	6.52-7.62	6.06-7.12	0.15-0.30	1.12-1.26	1.2-27.8	22.3-29.3	Clay loam
15-30	7.15-7.82	6.65-7.45	0.16-0.34	0.82-0.94	5.4-28.3	24.4-30.2	Silty clay
30-45	7.72-8.18	7.35-7.69	0.25-0.32	0.62-0.72	10.8-29.2	24.6-30.8	Clay
45-60	8.02-8.54	7.82-8.32	0.32-0.45	0.48-0.57	14.8-28.4	28.4-31.2	Clay
60-90	8.40-8.62	8.02-8.35	0.38-0.56	0.46-0.54	17.9-28.9	30.4-31.8	Clay
90-120	8.48-8.65	8.16-8.38	0.36-0.58	0.48-0.58	21.8-30.2	29.7-33.2	Clay

Establishment (germination) of soybean was assessed by recording emergence of plants on a 3 m^2 area of each plot daily for 20 days after sowing. Relative growth was evaluated by measuring dry biomass and leaf area index (LAI) at three growth stages (after 40, 70, and 100 days of sowing). At maturity, 2 m^2 area of each plot was harvested for determining grain and stubble yields. Plant and grain samples were also analyzed for their chemical composition. Selected agronomic parameters such as mass/100 seeds and pods/plant were also recorded for each plot during both the years. Soybean crop was commercially grown on flat (unlike the most preferred bed) layout under uniform agronomic management including the flood irrigation practices.

Infiltration rate of soil in each plot was measured after harvest of soybean crop for both the years. Bulk samples of surface (0-15 cm) soil were collected from all the plots before sowing soybean crop. After their air drying, these were grinded and sieved through a 2 mm sieve before using for laboratory measurements on hydraulic conductivity, clay dispersion, texture, EC, pH, exchangeable cations, CEC and SOC following standard methods (Rayment and Higginson 1992, Anderson and Ingram 1993). Statistical significance of data was tested following analysis of variance.

Results

Field observations showed significant effects of soil sodicity on germination (Figure 1). Per cent emergence of soybean was not only reduced but also delayed significantly with an increasing ESP of the soil. The soil ESP of 6 or less showed an average maximum 92 per cent emergence after 10 days of sowing. But it took 14, 16, 17, and 18 days for the mean maximum emergence of 82, 70, 50, and 30 in plots with ESP of 6-12, 12-18, 18-24, and ≥ 24, respectively. Soil sodicity was observed to inhibit early growth and vigor of seedlings. Data on biomass accumulation at 40, 70 and 100 days of sowing did indicate consistent effects of sodicity with almost linear decrease in growth. Irrigation was noticed to exacerbate impact of soil sodicity through surface crusting and prolonged flooding of surface soil.

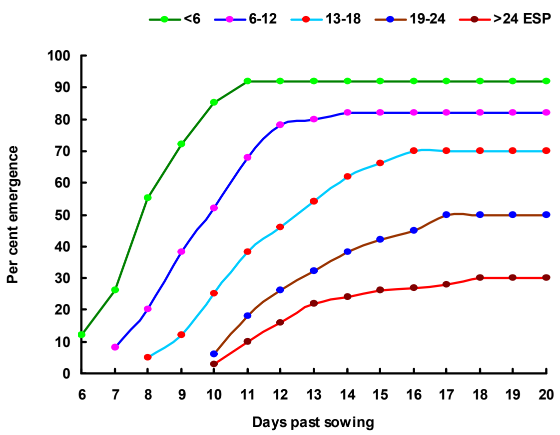

Figure 1. Effect of different soil ESP categories on the changes in average emergence of soybean seedlings during the 20 days past its sowing

Data on grain yield of soybean (Figure 2) illustrated adverse effects of surface soil ESP in both the years. In both years, surface soil (0-15 cm) ESP of 12.1 and 13.3 was found to cause grain yield reduction by 50 per cent. Highly significant relationships of grain yield with the dry biomass produced at 40, 70 and 100 days of sowing illustrated similarity in sodicity effects during growth periods of soybean in 1995/96 and 1996/97.

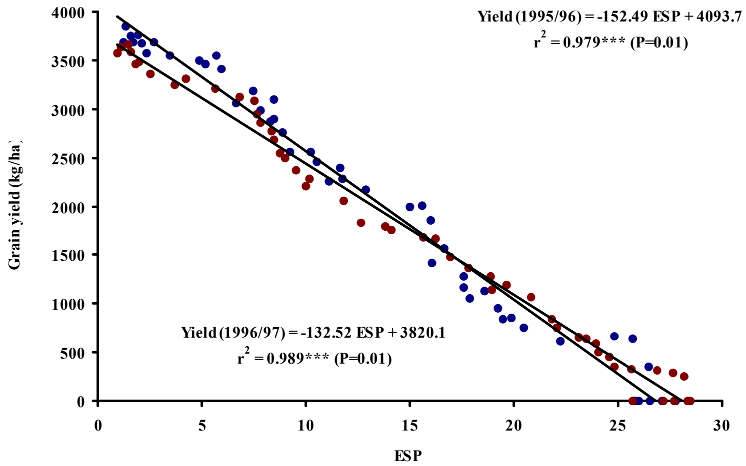

Figure 2. Relationships of ESP with grain yield of soybean crop grown in 1995/96 (blue) and 1996/97 (brown) on the two different paddocks

Soybean grain yield and ESP of 15-30 and 30- 45cm soil layers were also statistically highly significant. The ESP of soil layers beyond 45 cm depth did not show significant relationships with grain yield, indicating greater significance of surface than sub-surface soil sodicity for its adverse effects.

Experimental results of additional investigations in glasshouse indicate that germination of soybean is comparatively less sensitive to soil sodicity (ESP ~12) provided the maintenance of optimum moisture in the soil. Some plots with fairly high ESP (16-18) showed 75-90 per cent emergence. But growth of seedlings in those plots showed decline and significant mortality after post sowing irrigations and rain. This was mainly due to the dispersion induced sealing, crusting and water logging on sodic areas (Sumner 1993).

Field measurements of infiltration rates and penetration resistances of the surface (0-15 cm) soil (Table 2) provided sound support for explaining agronomic data on germination, growth and yield of soybean. Despite high variability, average penetration resistance (0.78 MPa) of non-sodic (ESP<6) was measured to increase by more than five times (4.26 MPa) in plots with ESP of ≥ 24. Average resistance values for plots with ESP of 6-12, 13-18 and 19-24 were 1.48, 2.95 and 3.84 MPa respectively. This was found associated with the impact of sodicity on reducing the amount of moisture in the soil, probably due to more evaporative losses from sodic surface soils.

Influence of surface soil sodicity did also show universally recognized adverse effect on water infiltration rate, a sharp decrease in average water intake rate of 16.26 mm/hr in non-sodic (ESP<6) plots to 6.84, 2.56, 1.65, and 0.84 mm/hr in plots of 6-12, 13-18, 19-24, and ≥ 24 respectively. Effects of rain and very low EC (0.115 dS/m) of available water for irrigation may have accelerated leaching of the surface soil. The irrigation water itself used to be highly turbid most times. Reduction in electrolytic concentration of irrigation water and/or soil solution is reported (Abrol *et al.* 1988, Rengasamy *et al.* 1991, Sumner 1993) to enhance adverse effects (surface sealing, crusting, oxygen diffusion rates, mechanical impedance, and infiltration rate) of sodicity or ESP by inducing clay dispersion.

Table 2. Averages of important soil physical properties in plots of different ESP categories. (Means with different letters are significantly different at P=0.05).

Soil property	Surface soil (0-15 cm) ESP				
	< 6	6-12	13-18	19-24	>24
Hydraulic conductivity[A] (cm/h)	1.56a	0.65b	0.28c	0.08d	0.06d
Dispersible clay[A] (per cent)	12.85a	34.85b	65.86c	74.62d	86.97e
Penetration resistance[B] (MPa)	0.78a	1.48b	2.95c	3.84d	4.26e
Infiltration rate[B] (mm/h)	16.26a	6.84b	2.56c	1.65d	0.84e

[A] and [B] denote measurements made on disturbed samples in the laboratory and *in situ* on undisturbed soil respectively.

The differences in saturated hydraulic conductivity and dispersible clay as measured in laboratory indicated the trends and their magnitudes similar to field measurements on penetration resistance and infiltration rate (Table 2) of water. A strong interaction between surface soil ESP and total electrolyte concentration, as measured by EC of the soil samples, was highly significant. This relationship was observed to weaken with soil depth. This may be due to the role of soil cementing agents other than electrolytic concentration.

Conclusion

Based on experimental results of these investigations, following conclusions can be made;

1. Variation in surface (0-15 cm) soil ESP affects establishment of soybean significantly. An increase in soil ESP was found effective in reducing and delaying the emergence of soybean seedlings.
2. Germination of soybean appeared relatively less sensitive to an increase in ESP than its adverse effect on the growth and productivity of soybean.
3. The surface soil (0-15 cm) ESP of 12.1 and 13.3 were found to reduce soybean yield by 50 per cent. Relationship between sub-surface soil ESP to soybean growth and productivity was not prominent.
4. Grain yields of soybean showed highly significant (P=0.01) negative relationships with the surface soil ESP in 1995/96 ($r^2 = 0.979$) and 1996/97 ($r^2 = 0.989$).
5. Surface and sub-surface soil ESP were observed to reduce water infiltration rates and saturated hydraulic conductivity and increase clay dispersion as well as mechanical dispersion of surface soil.

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