Spatial pattern of the effect of soil salinity on crop physiological parameters, soil water content and yield of wheat

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Abstract
In the Birchip region of western Victoria, Australia (35.98°S and 142.92°E), subsoil constraints are considered to be the most important factors determining crop growth and yield. Salinity, alkalinity, and boron toxicity occur in many soils in this region and current crop simulation models have shown to perform poorly in this region, particularly due to their inability to account for multiple subsoil constraints and their interactions with the seasonal conditions. The objective of this work was to study the impact of subsoil constraints on crop physiological parameters, growth and yield of a wheat crop to help develop algorithms that could be used to improve the performance of existing crop simulation models. From a calibrated electromagnetic (EM 38) survey over an area 13m wide by 100m long, we identified three points of low, medium and high salinity levels. During the cropping season crop samples were taken around each selected point, and canopy interception, radiation use efficiency, growth rate of different organs, biomass and yield was calculated. Above ground dry weight, canopy light interception, radiation use efficiency, plant water uptake and grain yield, were all reduced by increasing salinity levels. Relative to low salinity site, medium and high salinity levels reduced the above ground dry weight of the crop at harvest by 40% and 68%, accumulated intercepted radiation by 23% and 37% and radiation use efficiency by 25% and 52%, respectively. The final grain yield was 4.53, 2.69 and 2.36 t/ha, at the low, medium and high salinity sites and crop harvest index was reduced by 3.6% and 18%, at medium and high salinity levels, respectively.

Key words
Spatial variability, salinity, water use, wheat yield

Introduction
In Victoria as well as in most of Australia wheat yields are highly spatially and temporally variable (Potgieter *et al.* 2002). Factors contributing to this variability include seasonal climate variability and spatial variability in the soil properties such as: soil type, soil texture, and nutrients supply (Whelan *et al.* 2003). Yield maps from wheat crops grown in western Victoria clearly show high spatial variability, with areas of consistent high and low yields across seasons. A field survey conducted in the western Victoria or southern Mallee region showed large spatial variability in soil chemical characteristics (Nuttall *et al.* 2001a&b). Spatially variable wheat yields in western Victoria could be related to, subsoil constraints notably soil salinity (ABARE 2004). High soil salinity in the deeper subsoil restricts crop growth by reducing the osmotic potential and adsorption of water (Sadras *et al.* 2002), reducing grain yield in Victorian Mallee (Sadras *et al.* 2002; Nuttall *et al.* 2003a&b; Rodriguez *et al.* 2003). The inherent variability of soil characteristics leads to large variability in response to fertiliser inputs (Pedler *et al.* 2003), resulting in areas been over and underfertilised due to different achievable grain yields in different areas within the paddock (Cahn *et al.* 1994).

Hence spatial variability in soil properties is one of the most important factors determining the spatial variability in grain yield in the southern Victorian Mallee. The need for sustainable grain production in an environment of high spatially variable soil properties prompted us to conduct this study to observe the effect of within field spatial variability in soil properties, mainly salinity, on crop physiological parameters, water use, biomass and yield of wheat.

Materials and Methods
EM maps are a powerful tool in mapping soil variation across fields and apparent electrical conductivity (ECa) readings, obtained from EM survey, can be used to locate soil sample sites and to create management zones within the field, allowing management of the inputs to a crop in the field (Beecher 2002). An EM survey was conducted by towing a Geonics EM38 combined with a DGPS over the field.

The EM 38 soil electrical conductivity maps were obtained to represent soil salinity in order to identify different zones of low, medium and high salinity. The benefit in measuring and mapping ECa is that with targeted soil sampling it can be correlated with soil physical and chemical properties that are highly related to crop productivity. The ECa readings are directly and positively related to each of soil clay content, soil salt content and soil water content. So that light textured, non-saline, well-drained soils will give relatively low EM readings whilst heavy textured, saline, poorly drained soils will give relatively high readings.

We studied the impact of different soil properties, *i.e.* electrical conductivity, exchangeable sodium percentage, boron and chloride, on wheat yield, and found that subsoil salinity was the most important factor driving crop growth and yield.

In a 13m x 100m plot, three points were identified to represent low, medium and high salinity, as derived from EM survey and wheat was sown on 13th May 2003. At these points lab tested soil salinity averaged for the depth 0-0.7m were 0.25, 1.14 and 1.63 dS/m, respectively. Intercepted solar radiations at top and bottom of the plants were recorded at five different stages of crop growth. Crop samples were taken at tillering, anthesis and harvest along a 2x50cm linear distance to calculate different physiological parameters e.g., dry weight of different organs, leaf area index, radiation use efficiency, above ground biomass and yield. Crop was hand harvested from a linear distance of 2x50 cm around the selected points on 30th November 2003. Leaf area was measured by leaf area meter and then leaves and stems were oven dried at 70°C for 3 days to obtain dry weight of leaves and stems. Time course of soil water content at each point was obtained by neutron probes that have already been installed at those points.

Results and Discussion

Leaf and stem development

Leaf production and expansion are critical developmental processes for plants to establish photosynthetic competency and growth. Variation in growth and productivity of plants is caused largely by the variable rates at which leaves are formed, expand and develop into canopies. They are the primary sites of photosynthesis, and the product of their metabolism fuel the growth of the stems roots, flower, fruits and seeds (Volkenburgh *et al.* 1998).

Figure 1 a,b&c show the leaf dry weight per plant, leaf area per plant and stem dry weight per plant at tillering and around anthesis. Evidently it shows the effects of salinity on leaf dry weight, leaf area and stem dry weight. Leaf dry weight is about 47% and 77% lower for medium and high salinity in compare to low salinity at tillering and about 38% lower at around anthesis for both, medium and high salinity level. The rate of growth of leaf dry weight from tillering to anthesis is 0.017, 0.011 and 0.013 g/day at low, medium and high salinity levels respectively. It shows that the rate of growth of leaf dry weight was about 35% and 24% lower for medium and high salinity levels respectively. For medium and high salinity the leaf dry weight is not much different indicating crop was sensitive to salinity when salinity increased from 0.25 to 1.14 dS/m but it was not affected much when salinity increased from 1.14 to 1.63 dS/m.

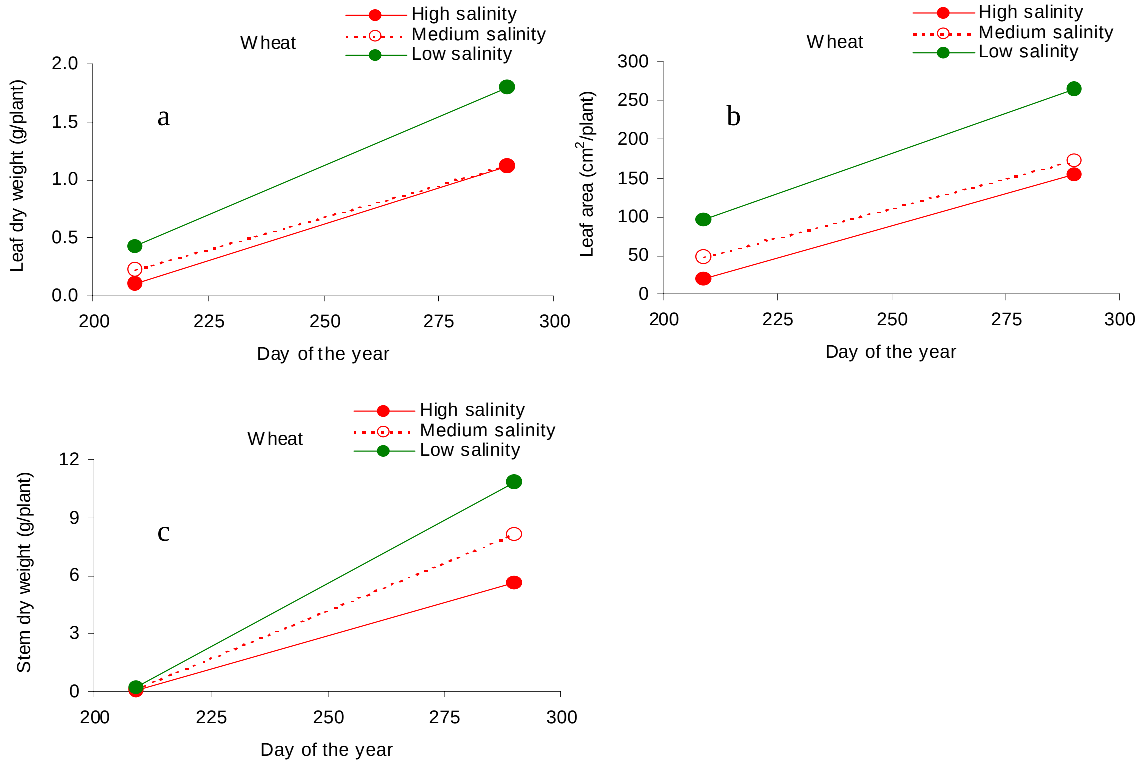


Figure 1a, b& c. Leaf dry weight (g/plant), leaf area (cm^2/plant) and stem dry weight (g/plant) of wheat at low, medium and high salinity levels.

There was about 50% and 77% decrease in leaf area for medium and high salinity in compare to low salinity at tillering and 35% and 42% at around anthesis. This shows that leaf growth was more affected by salinity at early stages.

The growth rate of leaf area from tillering to anthesis is respectively 2.08, 1.55, 1.67 cm^2/day at low, medium and high salinity levels. This shows that the rate of growth of leaf area is about 25% lower for medium and 20% lower for high salinity level in compare to low salinity level indicating decline in leaf area growth with increase in salinity from 0.25 to 1.14 dS/m but slight decrease in leaf area when salinity increased from 1.14 to 1.63 dS/m. The adverse effect of salinity on leaf growth was clearly observed and it was observed to be even higher at early crop growth of the crop.
Different levels of salinity also affected stem growth and it is about 44% and 74% less for medium and high salinity in compare to low salinity at tillering and 25% and 47% less at around anthesis. This shows that stem growth was more affected by salinity at early stages of crop growth in the same manner as leaf growth.

The growth rate of stem from tillering to anthesis was observed to be 0.13, 0.1 and 0.07 g/day at low, medium and high salinity levels showing the salinity levels negatively affected stem growth.

Accumulated intercepted radiation and radiation use efficiency
Radiation use efficiency (RUE) is the biomass production per unit of photosynthetically active radiation intercepted by the plants. Effect of different salinity levels on accumulated intercepted radiation and radiation use efficiency of wheat was observed and the results show that both parameters were significantly reduced by higher level of salinity. The RUE was found to be 2.06, 1.54 and 0.99 g/MJ at low, medium and high salinity points respectively.

The accumulated intercepted radiation was reduced by 23% and 37% and RUE was reduced by 25% and 52% at medium and high salinity levels respectively, in comparison with low salinity level. The reduction in accumulated intercepted radiation and radiation use efficiency further contributed to the reduction in biomass production.

Water use
Neutron probes (NP) were installed at each point to measure soil water content during the crop growth period. NP readings were translated into volumetric soil water content and finally into the available water at each soil layer.
The effect of water uptake by wheat at different salinity level was observed.

Figure 3a,b&c show the water use by wheat at different depths during different stages of crop growth at high, medium and low salinity level. From these results it can be concluded that the top 50cm layer contributed most to the water used by plant at all salinity levels and sharp depletion rate was observed at 50 cm depth at different stages of crop growth from sowing to harvest.

Intitial water content was higher at low salinity point than medium and high salinity levels and around anthesis, the soil water was very low at low salinity level. This indicates that low level of salinity provided conducive environment for plant to use water. Higher salinity increases osmotic potential of water and hence reduces ability of plants to absorb that water and plants need to exert more pressure in order to absorb that water. Reduction in soil water use induced by high salinity levels results in inhibited crop growth and production of lower biomass and yield.

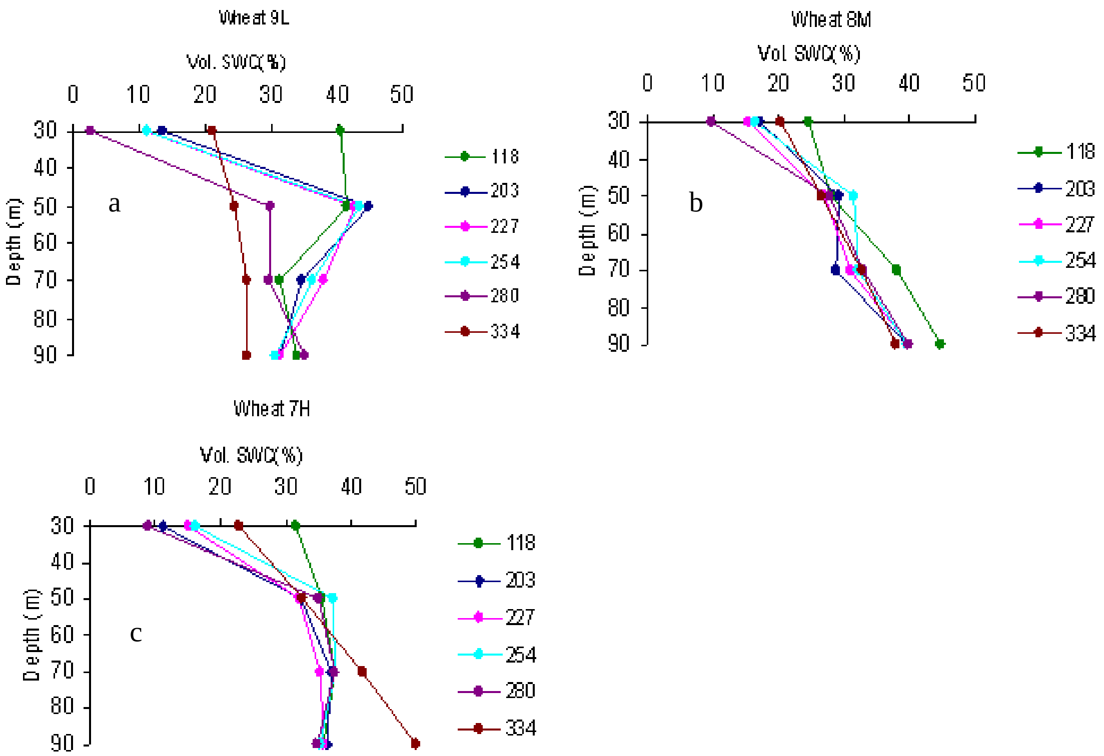


Figure 3a,b&c. Water use at different depth at different stages of crop growth in wheat.

Figure 4 a,b,c&d show the soil water content (SWC) at four different soil layers i.e., 15-30 , 30-50 , 50-70 and 70-90 cm.. Crop was sown on 133 Julian day. At 15-30 cm layer the SWC was higher at low salinity level before crop sowing which could be probably because low salinity level provided higher infiltration rate and better movement of water within soil profile. Which can also be seen at 30-50 cm layer as higher SWC was observed during first two points even though sharp water depletion was seen at 15-30 cm layer. Also at this stage not many roots were present below 30 cm.

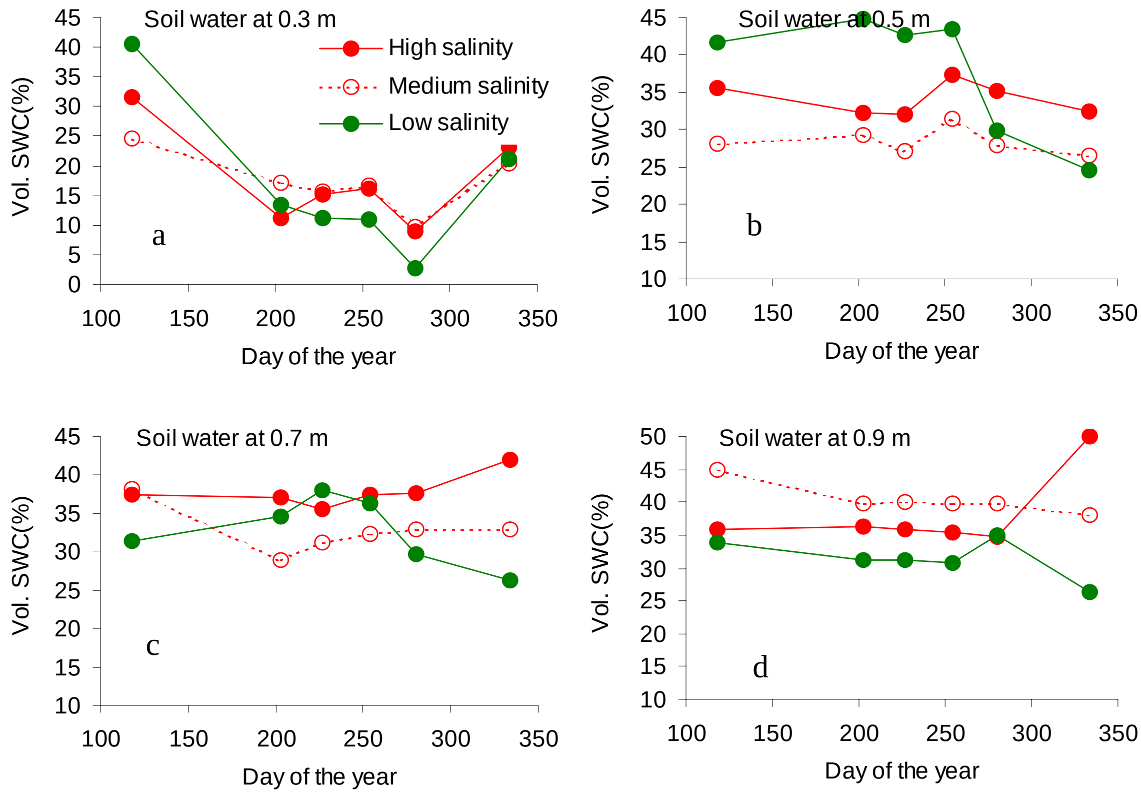


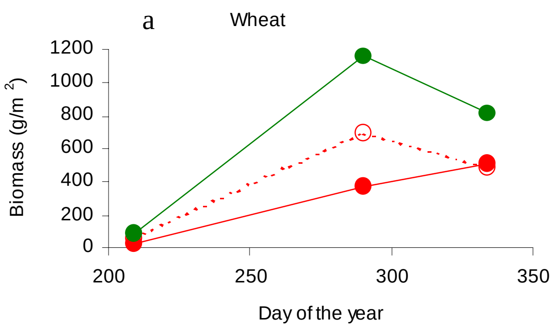
Figure 4a,b,c&d. Soil water content at different soil layers at low, medium and high salinity levels in wheat.

At early stage of crop growth, water was mainly depleted from topsoil layer at all salinity levels because of the shallow roots. At low salinity level decline in soil moisture content was more rapid indicating low salinity provided good environment for plant water uptake and more water was absorbed by the plant. However, not much difference was seen in case of medium and high salinity levels. After about 200 Julian days there was increase in soil moisture at medium and high levels of salinity which indicates occurrence of rain, but water kept depleting in low salinity level because of more water uptake by plants. During later phase of crop growth around 250 to 280 Julian day there was sharp decline in water content in all the cases in top layer indicating good plant growth and need of water to the plants. However, during this time period, a high decline is observed in 30-50 and 50-70cm layer at low salinity level. This shows that low salinity also facilitated root penetration in lower layers and good root growth as well. In case of medium and high salinity levels there were not much noticeable differences. Only at low salinity level, moisture was depleted below 70 cm soil depth and it was almost same at medium and higher at high salinity level indicating that high salinity inhibited proper root growth and penetration. Overall, low salinity level provided conducive environment for plants to absorb more water and good root growth penetration, which resulted in higher leaf area, biomass and yield.

Biomass and yield

As shown in Figure 5a it is evident that the above ground biomass production was adversely affected by level of salinity. A 35% and 70% decrease in biomass at tillering and 40% and 68% at anthesis was observed at medium and high salinity respectively in comparison with low salinity indicating huge impact of salinity in biomass production. Figure shows that at high salinity, the anthesis was delayed as biomass kept increasing. At harvest, higher biomass was achieved at low salinity. However, it was found to be almost same at medium and high salinity levels.

The harvest index is 0.56, 0.54 and 0.46 at low, medium and high salinity respectively and the final yield is 4.53, 2.69 and 2.36 t/ha at harvest at low, medium and high salinity levels respectively. The effect of salinity on harvest index grain yield is obvious and about 3.6% and 18% decrease in harvest index and 41% and 48% reduction in grain yield was observed at medium and high salinity levels in comparison with low salinity.



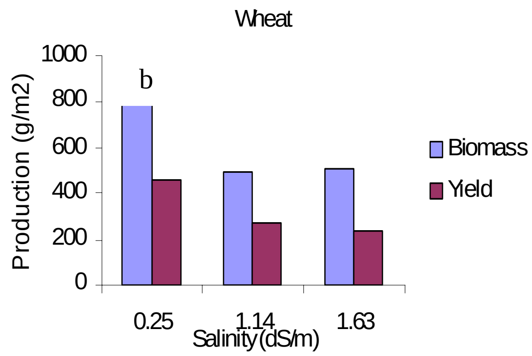


Figure 5a& b. Biomass production and yield of wheat at different growth stages and salinity levels

Conclusions

These results indicate that subsoil salinity adversely affected crop physiological parameters, water use, yield and overall plant growth of wheat. The adverse effect was more prominent during early stage of crop growth. This exercise was done mainly, to observe the effect of salinity on crop growth and yield so that to include these effects in a crop simulation model which presently perform poorly because of subsoil constraints in the region. We conclude that to account for the impact of salinity on crop yield in crop simulation models, the impacts of salinity on the amount of intercepted radiation, the conversion efficiency of intercepted radiation into biomass, and harvest index need to be taken into account.

References

ABARE (2004) Australian crop report No.129, Australian Bureau of Agricultural and Resource Economics (ABARE). Australia.

Beecher G (2002) Electromagnetic soil surveys - EM surveys. Research Update - Southern Region - Spring 2002, NSW Agriculture, Yanco Agricultural Institute, Yanco NSW, Australia.

Cahn MD, Hummel JW, Brouer BH (1994) Spatial analysis of soil fertility for site-specific crop management. *Soil Science Society of America Journal* **58**, 1240-1248.

Nuttall JG, Armstrong RD, Connor DJ (2001a) Understanding subsoil water-use by cereals on Southern Mallee soils I Spatial characteristics of subsoil constraints. In *Proceedings of the 10th Australian Agronomy Conference*, 2001. Hobart. Australia

Nuttall JG, Armstrong RD, Connor DJ (2001b) Understanding Subsoil Water-Use by Cereals on Southern Mallee Soils: II. Crop Response. In *Proceedings of the 10th Australian Agronomy Conference*, 2001. Hobart. Australia.

Nuttall JG, Armstrong RD, Connor DJ (2003a). Evaluating physiochemical constraints of Calcarosols on wheat yield in the Victorian southern Mallee. *Australian Journal of Agricultural Research* **54**, 487-497.

Nuttall JG, Armstrong RD, Connor DJ, Matassa VJ (2003b) Interrelationships between edaphic factors potentially limiting cereal growth on alkaline soils in north-western Victoria. *Australian Journal of Soil Research* **41**, 277-292.

Pedler J, Kentish M, Walker C, Norton R, Ferrier J, Angus J (2003) Determining zones for yield response to N fertiliser in a paddock with subsoil limitations, using electromagnetic induction techniques. In *Proceedings of the 11th Australian Agronomy Conference*, Geelong. Australia.

Potgieter AB, Hammer GL, Butler D (2002) Spatial and temporal patterns in Australian wheat yield and their relationship with ENSO. *Australian Journal of Agricultural Research* **53**, 77-89.

Rodriguez D, Nuttall J (2003) Adaptation of the APSIM-Wheat module to simulate the growth and production of wheat on hostile soils. In *Proceedings of the 11th Australian Agronomy Conference*, Geelong. Australia.

Sadras V, Roget D, O'Leary G (2000) On-farm assessment of environmental and management constraints to wheat yield and efficiency in the use of rainfall in the Mallee. *Australian Journal of Agricultural Research* **53**, 587-598.

Volkenburgh EV, Stahlburgh R, Bultynck L (1998) Physiological mechanism controlling the rate of leaf growth. *In* H. Lambers, H. Poorter and Van Vuuren, M.M.I. eds. *Inherent variation in plant growth. Physiological mechanisms and ecological consequences*. Backhuys Publishers, Leiden, The Netherlands, p. 41-56.

Whelan BM, McBratney A (2003) Definition and interpretation of potential management zones in Australia. In *Proceedings of the 11th Australian Agronomy Conference*, Geelong. Australia.

