# Seasonal mobility of boron and salt in relation to rainfall across the growing season

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## Abstract
Boron and salinity are serious constraints to cropping around the world and commonly occur together. Cropping on boron and saline toxic land is restricted by the low tolerance of crops to these abiotic factors, especially as stresses are highest at the start and end of the growing season.
The aim of this study was to determine the seasonal mobility of boron and salt in the soil in relation to rainfall during the 2010 growing season. Measurements were taken at ten sites, across five farms between Ballidu and Cadoux, Western Australia. Movement of salt and boron was recorded, at three soil depths to 50 cm, across the growing season at monthly intervals (2-weekly during the break of season).
Salinity, on average, decreased from the first sample date in March to the final reading in September; although there were large fluctuations at 0-2 cm. Salinity levels were highest in the top 0-2 cm soil samples. Boron concentrations were on average highest at soil depths of 25-50 cm and were also found to fluctuate more at higher concentrations than at lower concentrations. Boron showed less variation than salinity across the season with no significant decrease in concentration over the growing season.
The dry 2010 growing season resulted in less leaching of minerals through the soil profile than previously reported. Some leaching of salt was observed, but was mainly restricted to the top 0-25 cm. The rainfall received across the season was not sufficient to cause the leaching of boron.

## Key Words
Boron, salinity, wheat, barley, rainfall, wheatbelt

## Introduction
Sodic soils (those with a disproportionately high concentration of sodium in their cation exchange complex) cover approximately 30% of Australia's agricultural areas, with approximately 87% having a soil pH of 8-9.5 (Rengasamy and Olsson 1991). The major chemical constraint for agricultural production in these alkaline/sodic soils under dryland conditions is the toxicity of minerals such as boron and the toxicity of salts such as sodium chloride (Rengasamy 2002; Adcock, McNeil et al. 2007). Adcock et al. (2007) noted the difficulty of identifying the impact of any single subsoil constraint under these conditions where multiple constraints may be present, due to the spatial and temporal variability of the constraints. Understanding subsoil constraints and their interactions is, however, crucial for the development of cultivars adapted to them. Current research has mainly focussed on single subsoil constraints, yet plant tolerance to these soil constraints needs to exist in combination (Nuttall, Armstrong et al. 2006). Where salinity is the dominant toxicity, production and yield improvements are likely to be small unless cultivars are tolerant to both salinity and boron (Reid 2010).
Monitoring the mobility of available and limited nutrients and salts through the soil profile by monitoring the process of leaching and evaporation over the growing season is essential in increasing our understanding of subsoil constraints. The majority of studies to date have focussed on the topsoil. However, subsoil constraints such as boron and salt may accumulate with time and depth (Adcock, McNeil et al. 2007) and this needs to be assessed.
The aim of this study was to determine the concentration levels and seasonal mobility of boron and salt through the soil profile, in relation to rainfall during the 2010 growing season. It is hypothesised that salt and boron minerals will be leached through the soil profile during the growing season.

## Methods
*Site details*
Five farms were selected from members of the Duli Improvement Group in the Balidu and Cadoux shires in the northern Wheatbelt of Western Australia. Soils across the farms ranged from loams to a heavy clay at site 1, and from pH 4.7 to 9.3. At all sites pH increased with depth. At each farm two sites were selected; one

 
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with suspected salinity and boron and one without. These were based on farmer's identification, foliar symptoms and EM38 readings over summer. Total distance between the farms was approximately 40km.

*Soil collection and laboratory analysis*

Movement of salt and boron over the 2010 growing season was investigated from March to September using soil cores taken monthly, and over the break of the season, fortnightly. At each site, soil was sampled at depths of 0-2 cm, 0-25 cm and 25-40 cm using a hand auger. Two cores were taken at each sampling date for the 0-25 cm and 25-50 cm soil samples and five small samples were taken for the 0-2 cm sample. The soil samples were taken from a 1 m² area over the sampling period. The core samples were weighed, oven-dried at a constant temperature of 50°C for 7 days and then crushed. Samples were sent to CSBP soil laboratories and were analysed for standard soil properties including colour, % gravel, texture, nitrogen, phosphorus, potassium, sulphur, organic carbon and pH, plus conductivity, sodium, chloride and boron levels. Soil moisture was recorded throughout the experiment at each date and depth. All data analysis was conducted using Genstat v.14.1 (VSN International).

## Results

*Rainfall*

Below average rainfall was recorded over the growing season in 2010. Rainfall did not follow the usual average pattern with no rainfall in January and February and below average rainfall in all other months except March, which recorded double the average rainfall as a result of one large rainfall event at the end of the month.

*Soil analysis*

A summary of the soil collected from the ten sites is shown in Table 1. All five variables were found to be greater at the saline sites, and in most instances the saline sites were more variable. The data, other than pH were not normally distributed; therefore logarithmically transformed data is used for all further analysis. Boron was found to increase with depth, whereas ECe, chloride and sodium decreased with depth at the saline sites. Following analysis of variance boron showed a significant difference between soil sampling depths ($P<0.001$), saline/non-saline sites ($P<0.001$) and there was a significant interaction between depth and site salinity ($P<0.01$). Both ECe and chloride showed a significant difference between depth ($P<0.001$) and saline/non-saline sites ($P<0.001$), but there was no interaction and sodium was only significantly different between saline/non-saline sites ($P<0.001$).

**Table 1. Summary of soil samples taken from 5 farms in the Ballidu and Cadoux shires of Western Australia. Letter suffixes after values show significant differences between depths and saline/non-saline sites at each variable, following analysis of variance (P<0.01) on transformed data.**

| Soil depth (cm) | Boron (Mg/kg) | | ECe (dS/m) | | Chloride (mg/kg) | | Sodium (meq/100g) | | pH ($CaCO_3$) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | s.e. | Mean | s.e. | Mean | s.e. | Mean | s.e. | Mean | s.e. |
| *Non-saline sites* | | | | | | | | | | |
| 0-2 | 1.48*a* | 0.407 | 1.07*c* | 0.214 | 1245*b* | 295.7 | 3.99*a* | 0.684 | 5.15 | 0.098 |
| 0-25 | 1.15*a* | 0.104 | 0.37*b* | 0.066 | 513*a* | 98.5 | 1.61*a* | 0.246 | 4.92 | 0.065 |
| 25-50 | 1.90*b* | 0.282 | 0.25*a* | 0.038 | 349*a* | 59.9 | 1.76*a* | 0.232 | 5.75 | 0.104 |
| *Saline sites* | | | | | | | | | | |
| 0-2 | 5.57*c* | 0.731 | 3.20*f* | 0.314 | 3786*d* | 526.9 | 15.68*b* | 1.803 | 6.55 | 0.111 |
| 0-25 | 8.64*d* | 1.069 | 2.25*e* | 0.204 | 2283*d* | 273.2 | 11.39*b* | 1.092 | 6.53 | 0.175 |
| 25-50 | 13.17*e* | 1.147 | 1.57*d* | 0.131 | 1514*c* | 147.2 | 11.10*b* | 0.826 | 7.49 | 0.151 |

ECe was the only variable to show any reduction in intensity (leaching of salinity into the soil profile) across the growing season, and this was only observed at the 0-25 cm soil sampling depth (Figure 1a), and was greater at the saline sites compared to the non-saline sites. ECe values at the 0-2 cm soil sampling depth were highly variable and at the 25-50 cm depth showed little variation. Boron did not show the same degree of leaching at any of the soil sampling depth, nor at the saline versus the non-saline sites. Figure 1b shows the variation in boron levels across the growing season at the 0-25 cm depth.

Repeated measures analysis of variance conducted to determine significant differences in boron and salinity levels over time found that boron showed no significant difference over time (highlighted in Figure 1b), but that ECe, sodium and chloride levels showed a significant difference over time ($P<0.001$) and that there was an interaction between time and salt in chloride and sodium levels ($P<0.05$) with chlorine and sodium levels at the saline sites increasing at the beginning of the growing season and then decreasing, whereas chlorine and sodium levels at the non-saline sites were stable and then decreased marginally in the latter half of the growing season. Ece also showed a significant interaction between time and depth (P<0.001) with the 0-2 cm soil sample being highly variable across the season, the 0-25 cm sample decreasing over the growing season and the 25-50 cm sample remaining relatively stable (Figure 2).

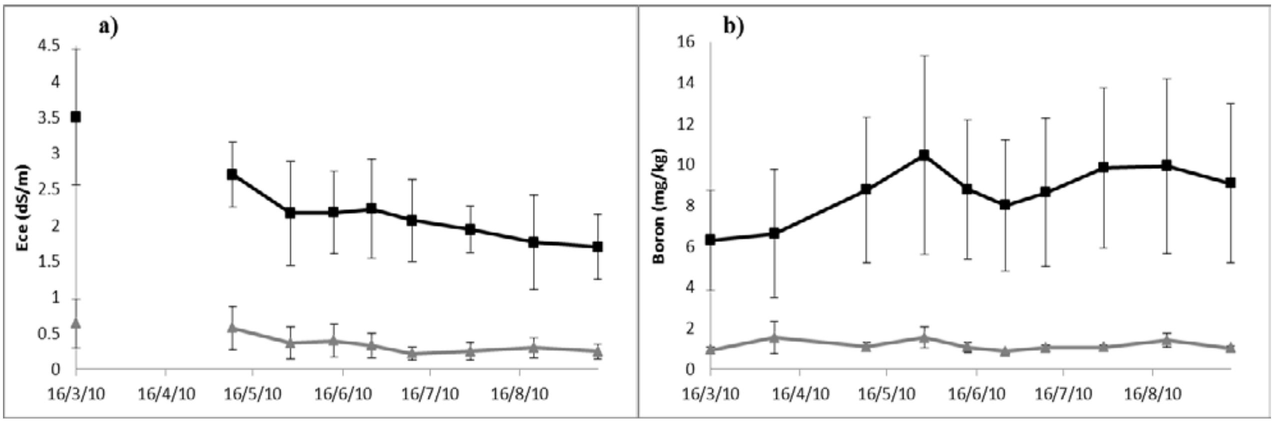


**Figure 1. Variation in a) ECe and b) boron across the 2010 growing season at soil sampling depths of 0-25 cm across the ten sampling sites at five farms in the Ballidu and Cadoux shires. Values are shown are means with standard error bars of the five saline (—■—) and five non-saline (—▲—) sites.**

Generalised linear regression models were used to determine the relationships between boron, salinity and soil pH. Data were analysed with saline/ non-saline sites as a factor to identify the variation attributed to this variation and in all analyses saline/ non-saline sites were a significant parameter (P<0.001). Data were also separated into the different soil sampling depths and data collected at 0-2 cm depth was not included due to the high variation across the sampling dates at this depth. At the 0-25 cm soil sampling depth boron showed a significant relationship with soil pH (P<0.001), and at the 25-50 cm soil sampling depth boron showed a significant relationship with both pH (P<0.001) and ECe (P<0.001). ECe was not found to be related to soil pH.

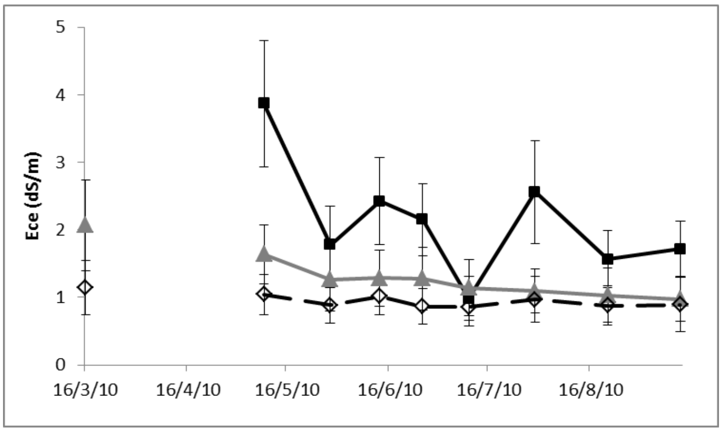


**Figure 2. Variation in ECe averaged over all sites across the 2010 growing season at soil sampling depths of 0-2 cm (—■—), 0-25 cm (—▲—) and 25-50 cm (—◇—) across the ten sampling sites at five farms in the Ballidu and Cadoux shires. Values shown are means with standard error bars.**

## Discussion

The concentration levels of both boron and salt were determined at sites on five farms in the Ballidu and Cadoux shires of WA. However, the hypothesis that salinity and boron would leach through the soil profile due to rainfall during the growing season was not supported. Salinity showed some leaching at 0-25cm soil depth, but was stable at 25-50cm depth. Measurements from the 0-2 cm soil sample were highly variable. Levels of boron were relatively stable at all depths with little leaching recorded. The amount of leaching is thought to be less than expected due to the extremely low rainfall falling during the 2010 growing season. McDonald (2006) has previously suggested that low rainfall reduces the leaching of subsoil constraints, including boron and salt. As some leaching occurred in salinity concentrations, but not in boron levels, it is suggested that boron requires greater amounts of water to be added to the profile to initiate leaching. Moore (2004) has suggested that boron requires three times more rainfall that salt to leach through the soil, although the exact amounts are unknown.

Sites with the highest levels of salinity were also found to have the highest levels of boron and those sites with the highest concentrations of boron had a soil pH of >8. This is consistent with reports by Brennan and Adcock (2004) and suggests that where soils are alkaline landholders should be conscious of the potential of toxic levels of boron being present in soil. In other areas of south and eastern Australia, boron is known to occur at toxic levels and breeding for crops tolerant to boron has occurred (Reid 2010). Boron toxicity occurs where boron in the soil is >12 mg/kg, so in this study saline sites at a depth of 25-50 cm on average contained toxic concentrations of boron. Those sites that were deficient in boron (<0.5 mg/kg) (Hall 2010) were found to have acid soils (pH 5.2 to 6.6), but not all acid soils were deficient in boron. Factors other than soil pH must therefore be impacting on boron accumulation, such as organic matter, moisture content and soil texture.

Both boron and salinity levels tend to be patchy with an irregular distribution. Spatial and temporal variation may help to explain this variability, and in particular the high variability recorded at 0-2 cm soil sampling depth. The non-uniform distribution of salinity in relation to time and space has previously been reported by Bennett et al. (2009), who suggest that measures of salinity should be taken at 25-50 cm as the salinity level is relatively stable across the year at this depth.

## Conclusion

It is recognised that the results presented here may have been very different under conditions with average growing season rainfall and that greater levels of leaching may have occurred in both boron and salt. However, as there have been few studies on the mobility of these two salts over the growing season the results presented are an important addition to our current knowledge. Further work is required to determine the amounts of rainfall required to initiate leaching in both of these salts.

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