Simulating the impacts subsoil constraints on wheat yields in the Northern Grain Zone

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Abstract

This paper sets out to test a previously proposed hypothesis that the impacts of subsoil constraints (SSCs) on wheat yield in Australia's northern grain zone can be accounted for by the associated increase in lower limit of a crop's available soil water (CLL). The hypothesis was tested through simulation of 26 farmers' paddocks selected to represent a wide range of values of the common indices of SSCs: electrical conductivity (EC), chloride concentration (Cl^-), and exchangeable sodium percentage (ESP). The paddocks were in South West Queensland and North West NSW and were monitored in 2003 and 2004. All paddocks had measured CLL, Drained Upper Limit (DUL), pre-season soil moisture and nitrate data to beyond the depth of maximum root penetration, as well as on-farm rainfall and grain yield data (0.97 - 5.7 t/ha). The APSIM model was set up using a standard configuration of the ASPIM-Wheat module for all sites, with the measured soil data, weather data from the nearest Bureau of Meteorology weather station, the farmer's measured rainfall and recorded agronomic practices. The simulated results accounted for 83% of observed variation in grain yield (RMSD = 0.57 t/ha) and matched observed results as well as might be expected from sites without SSCs. All attempts to introduce to the model further constraints based on EC, Cl or ESP failed to improve the fit of simulated and observed results. These results provide strong support for the proposed hypothesis.

Key Words

Subsoil constraints, wheat, simulation, crop lower limit, salinity, sodicity

Introduction

Many subsoil factors constrain root growth and function, and plant growth including high salt concentrations in the soil solution; increased osmotic potential of the soil water; toxic concentrations of Cl^-; high sodicity and an associated deterioration of soil physical properties; and acidic subsoils containing toxic levels of aluminium (Dang *et al.* 2006). Hochman *et al.* (2004) proposed that the net impact of SSCs on wheat crops can be accounted for by consideration of their effect on CLL and thus the PAWC of a soil. This proposition enabled them to use the Agricultural Production Systems Simulator (APSIM, Keating *et al.* 2003) to predict both crop production and NRM impacts of various levels of SSCs over a range of locations.

Evidence from soils in southern Australia suggests that the effect of the variable combinations of subsoil constraints in these soils is to reduce plant available water by increasing the lower limit of cereal crops' available soil water (Sadras *et al.* 2003, Nuttall *et al*. 2005, and Rodriguez *et al.* 2006). However, the chemical constraints that characterise northern soils (Dang *et al.* 2006) were found to have significantly different levels and combinations of subsoil constraints when compared to those described in the southern studies. For example, in the current study, the mean value of EC at 70-90cm depth was 1.6 which exceeds the maximum value of 1.31 in Sadras *et al.* (2003). By contrast, the highest boron concentration in our data set was only 6 mg kg^{-1} compared to 29 mg kg^{-1} in Sadras *et al.* (2003). These differences suggest the need for the hypothesis to be tested on soils in the northern grain zone.

In this paper we set out to test, for soils in the northern grain zone, the strength of the hypothesis that the net impact of SSCs on wheat crops can be accounted for by consideration of their effect on CLL and thus the PAWC of a soil. We tested the hypothesis by measuring and simulating wheat grain yields at 26 sites with measured CLL values. The test of the null hypothesis was a comparison of the correlation of simulated and observed yields at these sites against the correlation that was obtained for the standard data set from Queensland that was used to develop the APSIM wheat crop module, *i.e.* RMSD = 0.74 t/ha with R^2 = 0.8 (Wang *et al.* 2003).

Methods

Twenty six paddocks were selected for this study. They included 6 sites in southern Queensland in 2003, plus 6 sites in northern NSW and 14 sites in southern Queensland in 2004, on grey, brown and red cracking clays (Vertosols; Isbell 1996). Sites were sampled to determine their PAWC characteristics using the methods of Dalgliesh and Foale (1998). In April-May soil samples were taken using a 50-mm diameter tube and a hydraulic sampling rig. Seven depths were examined in the segments: 0-10, 10-30, 30-50, 50-70, 70-90, 90-110 and 110-130 cm. Each soil segment was separately dried at 40?C in a forced draught oven and ground to <2 mm. Soil pH, EC, Cl and NO_3-N were determined in a 1:5 soil:water suspension (Rayment and Higginson 1992). Exchangeable cations (K^+, Na^+, Mg^{2+} and Ca^{2+}) were determined using a 1 M NH_4Cl (pH 8.4) extracting solution for 60 min (Rayment and Higginson 1992) after washing with 60% aqueous alcohol to remove soluble salts (Tucker 1985). The extracts were analysed for exchangeable cations on an inductively coupled plasma-optical emission spectrometer. Exchangeable sodium percentage (ESP) was calculated as the ratio of exchangeable Na^+ to the cation exchange capacity.

All sowing, harvesting and crop management operations were carried out using the co-operating farmers' equipment, and planting rates and other management practices followed the accepted district practice. All crops were well managed with no significant weeds, pests, diseases or nutrient deficiencies experienced. Meteorological data was collected from the nearest met station using the Silo Patch Point Data set (http://192.168.0.60/silo/ppd/PPD_frameset.html) to obtain daily records of maximum and minimum temperatures, solar radiation and vapour pressure, while rainfall data was obtained from on-farm records.

The APSIM model (Version 4.1) configured with the modules Wheat, SOILN2, SOILWAT2, and RESIDUE2 was used to simulate wheat yield in response to the environmental and management factors at the 26 sites. A standard parameterisation of the model was applied to all unmeasured parameters at all sites and the yield results of the APSIM simulations were tested against observed paddock yields.

Results

Soil Analysis

The selected sites varied in the extent and type of SSCs present. This is illustrated by the means, standard deviations and ranges of values measured for pH, EC, Cl^- and ESP at 70-90cm depth (Table 1). Of the 26 soils, 21 soils had ESP values >15%; 11 soils had Cl^->600 mg/kg; 11 soils had EC > 0.9 dS/m; 5 soils had all 3 parameters over these threshold values and only 4 soils were below all these threshold values. The 1 soil with pH < 5.5 was above all the other threshold values.

Table 1. Mean, Standard Deviation and range of subsoil constraint indicators measured at the 70-90cm depth layer of 26 soils.

Chemical Analysis	Mean	Standard Deviation	Minimum	Maximum
pH	7.6	1.17	4.8	9.5
EC (dS/m)	1.6	1.7	0.2	5.8

Cl^- (mg/kg)	598	480	1	1985
ESP (%)	21.2	8.7	0.4	35.5

Observed and predicted Grain Yields

The range of observed grain yields harvested at these sites was 0.97 to 5.70 t/ha. Figure 1 shows the performance of the APSIM model when measured PAWC data is used and no specific parameter is employed to account for SSCs. The model accounted for 83% of the observed variability in grain yield with a root mean squared deviation (RMSD) of 0.57 t/ha. All attempts to improve the models performance by using functions based on Cl^-, EC, or ESP to restrict root development (via the root expansion factor) did not improve on these simulation results.

Given that the performance of APSIM for the 26 subsoil constrained sites in this study was at least as good as that reported by Wang *et al.* (2003) for Queensland soils without SSCs, we continue to hold the view that SSCs impact on wheat crops primarily by increasing their CLL and thus reducing the PAWC. Confirmation of this hypothesis allows the approach to be used in exploration of the implications of SSC on production and NRM issues such as those explored by Hochman *et al.* (2004) and Farquharson *et al.* (2006). Because the determination of CLL in the field is a laborious and slow process, it remains a challenge to determine a SSC proxy for this measurement to allow for local extrapolation from characterised soils of the same soil type with different levels of SSCs.

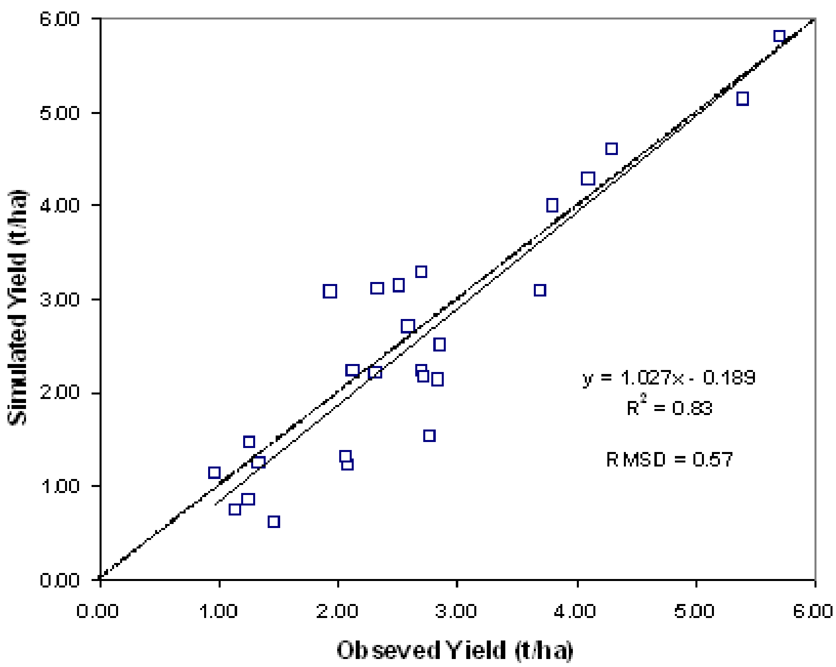

Figure 1: Simulated and observed wheat yields at 26 sites with various levels of EC, Cl^- and/or ESP in Australia's north eastern cropping zone using CLL to account for the impact of the SSC.

Conclusion

The results support the view that SSCs impact on wheat crops primarily by increasing the CLL and thus reducing the PAWC. This result provides a solid basis for use of simulation in exploration of the implications of SSC on production and NRM issues.

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