Simulating seasonal response of wheat yield to subsoil amelioration in the Victorian Mallee and Wimmera

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Abstract

Subsoil constraints in alkaline soils of south-eastern Australia commonly restrict root growth, water extraction and yield of rain-fed crops. Agronomic management can ameliorate potential constraints including compaction and waterlogging and improve soil water dynamics and crop yield. A simulation study of the effect of subsoil amelioration on the grain yield of wheat on two soil types representative of the Victorian Mallee and Wimmera regions was undertaken. The purpose of this simulation was to test the interaction between various seasonal rainfall conditions and the effectiveness of different amelioration treatments. The treatments included application of composted organic matter (16 t/ha), deep ripping to 45 cm and deep placement of fertiliser to 20 cm compared to a district practise control treatment. The model accurately simulated grain yields over a three year validation period (RMSE=314 kg/ha) that was characterised by below average rainfall, but there were no observed treatment responses over this period. The model was then run over 119 years of historical weather data measuring the impact of subsoil treatment on yield with respect to season. The simulation found that the organic matter treatment produced small but consistent increases in yield (Birchip 508 kg/ha median response and Lubeck 736 kg/ha median response). At the extremes (dry and wet seasons) no yield benefits from organic matter amelioration were detected. Likewise no yield response to deep ripping and deep placement of nutrients occurred.

Key Words

Crop lower limit, Modelling, Organic matter, Root hospitality, Subsoil constraints

Introduction

Field experiments have shown large but variable responses to the physical/chemical (deep ripping and deep ripping and fertiliser placement, respectively) amelioration of subsoil where known subsoil constraints exist (Armstrong et al. 2001; Nuttall et al. 2003; Sadras et al. 2005). The responses, however, are not consistent from farm to farm (soil type) or across seasons and significant interactions are believed to exist between rainfall distribution and crop response to subsoil treatment.

Because of the expense of running long-term field experiments, it is often difficult to assess particular treatments over a large range of seasonal conditions and soil types. Two large replicated field experiments were established in 2004 to examine the interactions between a range of amelioration treatments designed to improve the chemical/physical environment for root growth in the subsoil and seasonal conditions on the growth, grain yield and water use of a range of crops. However during the experiment only a limited range of seasonal conditions (ranging from Decile 1 to 4) were experienced. This study applies a simulation model that has sufficient explanatory variables that should help evaluate the likely extent of the seasonal interaction with a number of subsoil treatments.

Methods

The APSIM-Wheat model (McCown et al. 1996) was validated using data from field experiments across two sites over three years (2004, 2005 and 2006). These were located on a Calcarosol at Birchip in the southern Mallee region and on a Sodosol soil at Lubeck in the southern Wimmera region of Victoria. Three experimental treatments, all initiated immediately prior to sowing in the first year of the experiment, (1) comprised of 16 t/ha (dry weight) topdressed composted organic matter, (2) deep ripping to 45 cm with approx. 7.5 t slotted gypsum per ha and (3) deep placement (15-20 cm) of nutrients (granular 25kg/ha N and 50kg/ha P). These were all compared to an untreated control (4) with no organic matter or gypsum added no deep ripping and no deep fertiliser placement. All four treatments received the same basal supply of granular 25kg/ha N and 15kg/ha P at sowing and weed management.

Daily weather data from the Australian Bureau of Meteorology sites at Birchip (35.98?S, 142.92?E) and Longerenong (36.67?S, 142.30?E) (used for the Lubeck site) were obtained for the experimental period (2004-2006) and from 1889 as Patch Point Data for 119 years of simulation analyses. Measured soil water, bulk density, organic carbon and pH at each site were used to initialise the model.

Subsoil treatments

We assumed that the water-extraction coefficient (kl) was 39% greater in the top 60 cm of the profile under the Organic Matter and Deep Ripping treatments and 48% for Deep Nutrients to 20 cm (Table 1). These values were selected to provide increased water extraction to 60 cm for both the Organic Matter and Deep Ripping treatments and to 20 cm for the Deep Nutrient placement treatment. These kl values are based on our experience in modelling water extraction and not directly measured (see Results and Discussion below). We used the same root exploration factors (xf) for each treatment to 60 cm at each site, but different values below 60 cm reflected different subsoil conditions at Birchip and Lubeck.

Table 1. The water extraction coefficient (kl) defined for each treatment for wheat (cv. Yitpi).

	Control	**Organic Matter[1]**	**Deep Ripping[2]**	**Deep Nutrient[3]**
Depth (cm)		kl factor		
0-10	0.06	0.1	0.1	0.1
10-20	0.06	0.08	0.08	0.08
20-40	0.06	0.08	0.08	0.06
40-60	0.06	0.08	0.08	0.06
60-80	0.06	0.06	0.06	0.06
80-100	0.06	0.06	0.06	0.06
100-120	0.06	0.06	0.06	0.06
120-140	0.06	0.06	0.06	0.06

[1] 16 t/ha (dry weight) of composted wheat straw/pig manure applied one week prior to sowing each year

[2] One deep tillage operation to 45 cm depth one week prior to sowing each year

[3] 25 kg/ha N + 50 kg P/ha banded P placed at 20 cm depth one week prior to sowing each year.

After successful validation the model was run using the 119 years of historical weather data. The model was reset each year on the 1st of January, to 10% initial plant available water, that is 24 mm at Birchip and 21 mm at Lubeck. Initial nitrate values on 1 January were 41 kg N/ha at Birchip and 100 kg N/ha at Lubeck. The model was reset each year to reflect typical January soil water and nitrogen conditions. The time of sowing was set to the 1 June each year with the water extraction coefficients listed in Table 1.

Results and Discussion

Validation

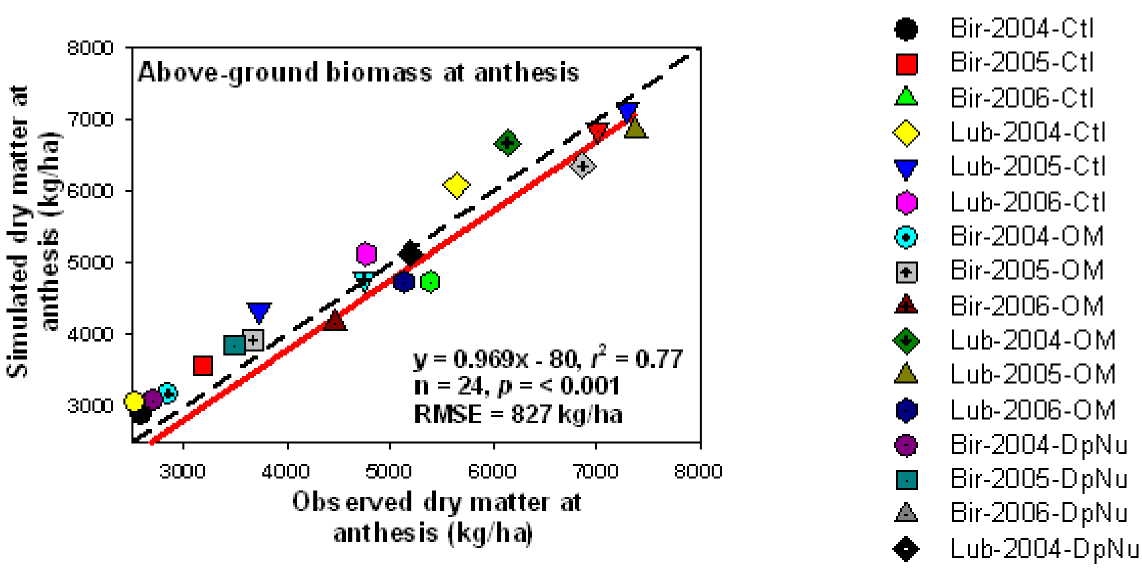
The wheat model performed well against the measured biomass at anthesis (Root Mean Squared Error (RMSE) = 827 kg/ha; Figure 1) and final grain yield (RMSE = 314 kg/ha; Figure 1). The model also performed well in predicting soil water content during the season (RMSE = 0.010-0.019 g/cm^3; data not shown).

Seasonal response

At both experimental sites, the growing season rainfall (GSR) was Decile 2 in 2004 and 2006 (ca. 145 mm) and was about 225 mm in 2005. The low GSR affected early growth vigour and the final yield. The long term simulation also showed lower yield response in years with low GSR.

The 119 years of simulation are presented as probability of exceedence curves for the crop yield response (Figure 2). Only the composted organic matter treatment had any impact on yield with respect to season producing small, but consistent increases in grain yield between the 20th and 60th percentiles (Birchip 508 kg/ha median response and Lubeck 736 kg/ha median response). At the extremes (dry and wet seasons) no yield benefits from organic matter (OM) amelioration were obtained. A yield response to deep ripping and deep placement of nutrients did not occur.

This simulated response would be the maximum expected because the amelioration treatments were applied each year. Normal practice would be to apply these treatments every few years with an expected decrease in residual effectiveness over time.



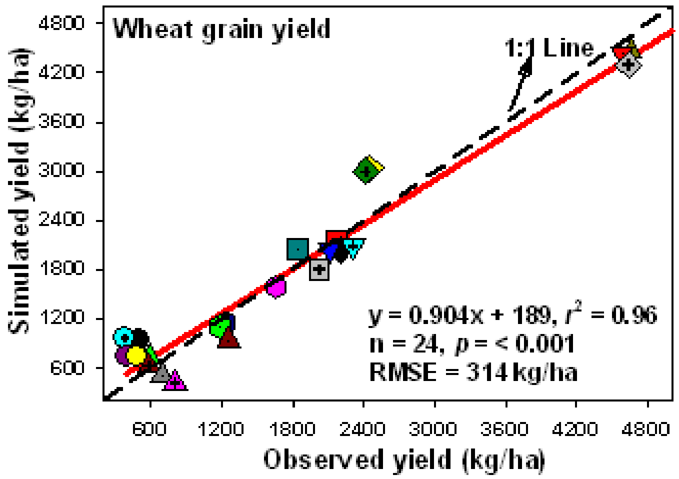


Figure 1. Comparison of simulated and observed above-ground biomass at anthesis grain yield (kg/ha) for wheat from various subsoil treatments over three years at Birchip and Lubeck.

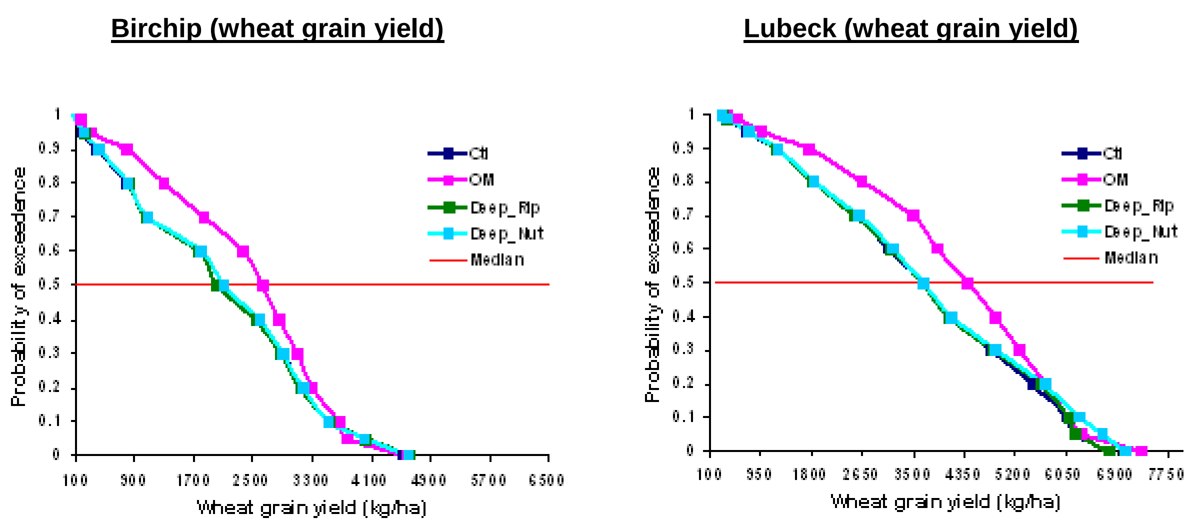


Figure 2. Probability of exceedence of wheat grain yield (kg/ha) as affected by subsoil amelioration at Birchip and Lubeck.

Whilst a satisfactory validation of the model against three years of data was achieved, we have not validated it against data where significant treatment responses were observed due to the limited range of seasonal conditions experienced during field experimentation. The key model parameters, kl and xf, were altered on the basis of presumed effect of amelioration treatment rather than actual measured values. However these changes appeared justified when actual model outputs e.g. crop water use and depth of rooting (assessed at anthesis using the core break method) were compared (data not presented). The model may have incorrect parameters for some of these processes. For future studies in modelling subsoil constraints attention should be given to the organic component of the nitrogen submodel. It may be necessary to check that when large additions of organic matter are added to the soil surface a comprehensive account of the various carbon and nitrogen pools are made to be sure that the appropriate mineralisation/immobilisation response is achieved. It is also likely that whilst the model appears to be sufficiently valid it may not be explaining the true response because of its limited explanatory variables.

Whilst our conclusions are conservative in that we have examined the maximal response, there are potential greater benefits from subsoil amelioration not demonstrated by the model. It is interesting to note that improved growth was observed in the field early in the season in the organic matter and deep nutrient treatments but this positive response did not translate into final yield. An observation supported by the model over a much wider range of seasonal conditions. A major limitation of APSIM at present is the limited scope for accounting for the effect of subsoil constraints (xf and kl variables), although this is being addressed (Hochman et al. 2007).

Conclusion

From our simulation analyses only the composted organic matter treatment had any impact on yield with respect to season producing small, but consistent increases in grain yield between the 20th and 60th percentiles (Birchip 508 kg/ha median response and Lubeck 736 kg/ha median response). At the extremes (dry and wet seasons) no yield benefits from organic matter amelioration were indicated. Likewise no yield response to deep ripping and deep placement of nutrients occurred. Whilst our conclusions are conservative in that we have examined the maximal response, there are potential greater benefits from subsoil amelioration not demonstrated by the model.

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