Impacts of soil compaction by livestock on crop productivity– a modelling analysis

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Abstract
A major constraint to adoption of integrated crop-livestock farming systems in Australia's Northern Grain Zone is the perceived adverse impacts of soil compaction caused by grazing livestock on crop production. Treading by livestock can reduce soil porosity and infiltration rate, and increase soil bulk density and soil strength, although these effects are mainly in the soil surface (top 5-10 cm). Despite these effects, rarely have reductions in crop performance been measured. This simulation analysis used APSIM (Agricultural Production Systems Simulator) to investigate the sensitivity of wheat crop growth and yield to reductions in root growth and water conductivity in the surface soil (0-10cm). Mild surface soil compaction was found to reduce grain yield by less than 10%. In more severe cases, crop losses could be up to 30%, especially if surface conductivity was greatly reduced and ground cover levels were low. Crop growth and yield were more sensitive to reduced surface conductivity and rainfall infiltration than to reduced root growth in surface layers.

Key Words
APSIM, simulation, grain yield, infiltration, wheat, root growth.

Introduction
One of the major concerns and constraints for increased integration of crop and livestock enterprises is the potential for livestock to cause compaction of cropping soils. Much work has shown that vehicle traffic can have significant and long-lasting effects on crop productivity, but the impacts of grazing livestock on soil properties in cropping systems is not as widely understood. Livestock have a similar static pressure to nominal tyre (74-81 kPa) and track (58 kPa) contact pressures of unloaded tractors & vehicles (Greenwood & McKenzie 2001). Pressures exerted by animals when moving can be greater because of the transfer of kinetic energy as their weight is distributed on only 2-3 hooves. For example, the pressure measured under hooves of a 530 kg walking cow was 300 kPa, greater than twice its static pressure (Scholefield *et al.* 1985). However, the wider the applied stress, the greater the depth of influence for a given contact pressure (Soehne 1958). Hence, the compaction effect of livestock is shallower than for vehicles, with livestock rarely causing soil compaction below 10 cm depth.

Many scientific studies have examined the impacts of livestock treading on soil physical conditions, but most have been concerned with grazing pastoral systems (Drewry *et al.* 2008; Greenwood & McKenzie 2001). It has been found that treading by livestock can affect three important aspects of soil physical properties – 1. increased soil strength and bulk density; 2. reduced soil porosity; and 3. reduced soil hydraulic conductivity and infiltration rate. Despite these effects, few studies have shown a significant reduction in subsequent crop growth and production after treading by livestock, possibly because effects are too small in magnitude or depth to influence plant growth greatly (Proffitt *et al.* 1995; Clarke *et al.* 2004; Radford *et al.* 2008). It may be that the harmful effects of livestock on crop or plant growth may only occur in particular years or under certain conditions which have not occurred in the few experiments conducted. Furthermore, most of the experiments have been conducted in areas with quite different climatic conditions to Australia's northern cropping zone. For these reasons the sensitivity of wheat crop growth and grain yield to different severities of surface compaction by livestock was simulated at 5 locations in Australia's subtropics using APSIM (Agricultural Production Systems Simulator), a farming system model (Keating *et al.* 2003).

Methods
Livestock treading effects on soil physical conditions were simulated by changing APSIM soil parameters to investigate how sensitive crop growth and yield are to these changes across a range of climatic conditions. Two main effects, reduced surface root growth and reduced surface water conductivity, were first explored independently and then combined. These effects were set at three severities to represent, mild, medium and severe compaction effects (Table 1). Plant root growth in the surface layer (0-10cm) was reduced by

lowering XF (root exploration factor), which regulates the potential rate that roots extend into deeper soil layers, and by lowering KL (i.e. the proportion of available soil water that can be extracted each day), which is related to the root density in a particular soil layer. Surface conductivity was reduced by increasing the Curve Number, and infiltration rate was reduced by lowering SWCon in the surface layer (0-10 cm). SWCon regulates the rate of water movement between soil layers, and soil curve number, influences the relationship between daily rainfall and surface runoff (Table 1). The effect of soil cover (another factor influencing runoff) was also explored by simulating the when crop stubble was set to 3.5 t/ha (high cover – 80%) and 1.5 t/ha (low cover – 20%) on 1 Jan each year. The model does not account for the possible impacts of waterlogging or increased disease incidence which may occur due to degraded surface soil structure.

Table 1. **Adjustments to APSIM soil parameters made in the top soil layer (0-10 cm) to simulate response of crops to surface soil compaction effects of reduced root growth and reduced surface conductivity of increasing severity.**

Severity of effect	Reduced root growth		Reduced surface conductivity	
	KL	XF	SWCon	Curve No.
Standard	0.06	1.0	0.30	73
Mild	0.04	0.4	0.20	78
Medium	0.03	0.2	0.15	83
Severe	0.02	0.1	0.10	88

Simulations used 50 years of historical meteorological data (1956-2006) at 5 locations from central Queensland to northern NSW, chosen to represent the range of mean annual rainfall (MAR) and summer-winter rainfall distribution (Emerald, 546 mm MAR; St George, 524 mm MAR; Clifton, 719 mm MAR; Goondiwindi, 616 mm MAR; Narrabri, 686 mm MAR). All simulations used common crop management rules and the same soil type, a grey Vertosol with a plant-available water-holding capacity (PAWC) of 218 mm. Wheat cv. Baxter was sown between the 10 May and 10 Jul after 20 mm of rain had fallen over the past 4 days and 100 kg of urea fertiliser was applied at sowing. Established plant density was 150 plants/m^2 with a row spacing of 250 mm. The standard Wheat parameter set (APSIM vers. 7.0) was adjusted so that initial root depth of wheat at germination was 40 mm (the depth of sowing) instead of 100 mm. In all simulations soil water (to 44 mm plant-available water), nitrogen (40 kg mineral-N/ha) and surface organic matter were reset on the 1 Jan each year to avoid differences between scenarios being carried forward into subsequent years and to enable crop growth each year to be compared directly between simulated scenarios.

Results

Simulated effects on root growth and rainfall infiltration

Rainfall infiltration was increasingly affected by reductions in soil surface conductivity, so that with increasing severity the average percentage of rainfall that infiltrated was reduced by 1-2%, 4-6% and 7-10%, respectively (Table 2). Under higher ground cover conditions the reductions in rainfall infiltration were smaller; on average about 75-80% of those under lower ground cover conditions. Adjustments made to soil parameters influencing crop root growth were found to slow the rate that roots explored deeper, imitating the likely impact of increasing soil strength in the soil surface layers (Table 3); but, between scenarios there was no difference in the crops final rooting depth.

Table 2. Change in average annual rainfall infiltration (mm) as a result of simulating different severities of reduced root growth in surface layers, reduced surface conductivity and when both effects are combined. Low ground cover scenarios are presented.

Location	Reduced root growth			Reduced surface conductivity			Combination of both		
	Mild	Moderate	Severe	Mild	Moderate	Severe	Mild	Moderate	Severe
Emerald	0	0	- 1	- 26	- 64	- 112	- 16	- 65	- 119
St George	0	0	0	- 11	- 29	- 51	- 7	- 30	- 55
Clifton	0	0	0	- 24	- 57	- 100	- 14	- 59	- 105
Goondiwindi	0	0	- 1	- 14	- 34	- 60	- 9	- 35	- 64
Narrabri	0	0	- 1	- 18	- 44	- 77	- 12	- 47	- 83

Effects on crop growth and grain yield

Reducing root growth was found to reduce crop biomass growth more than it reduced grain yield (Fig. 1a and 1d). In fact when root growth was severely reduced, grain yield was often found to increase, despite lower crop biomass (Table 4). This occurred because early stress reduced growth of these crops allowing more water to be available during grain filling. Grain yield was more sensitive to reductions in surface

Table 3. Reduction in average crop rooting depth (mm) at floral initiation (i.e. Zadok growth stage 30) under different severities of reduced root growth in surface layers, reduced surface conductivity and when both effects are combined. Data are averaged for all locations.

	Severity of reduced root growth		
Compaction effect	Mild	Moderate	Severe
Reduced root growth	- 66	- 184	- 458
Reduced surface conductivity	- 16	- 29	-53
Combination of both	- 74	- 192	- 460

conductivity (Fig. 1b). The largest effects were at Emerald and St George with the least at Narrabri, apparently driven by the amount of in-crop rainfall (Table 4). When both soil compaction effects were applied grain yield was reduced by up to 10% in mild scenarios, by up to 20% in moderate scenarios and by up to 30% in severe scenarios (Fig. 1). Although, the average reductions in grain yield were typically less than 10% across all locations, except in the most severe scenarios (Table 4). Crop biomass was reduced by similar amounts to grain yield, except in the when root growth was severely reduced when benefits during grain filling were found (discussed previously).

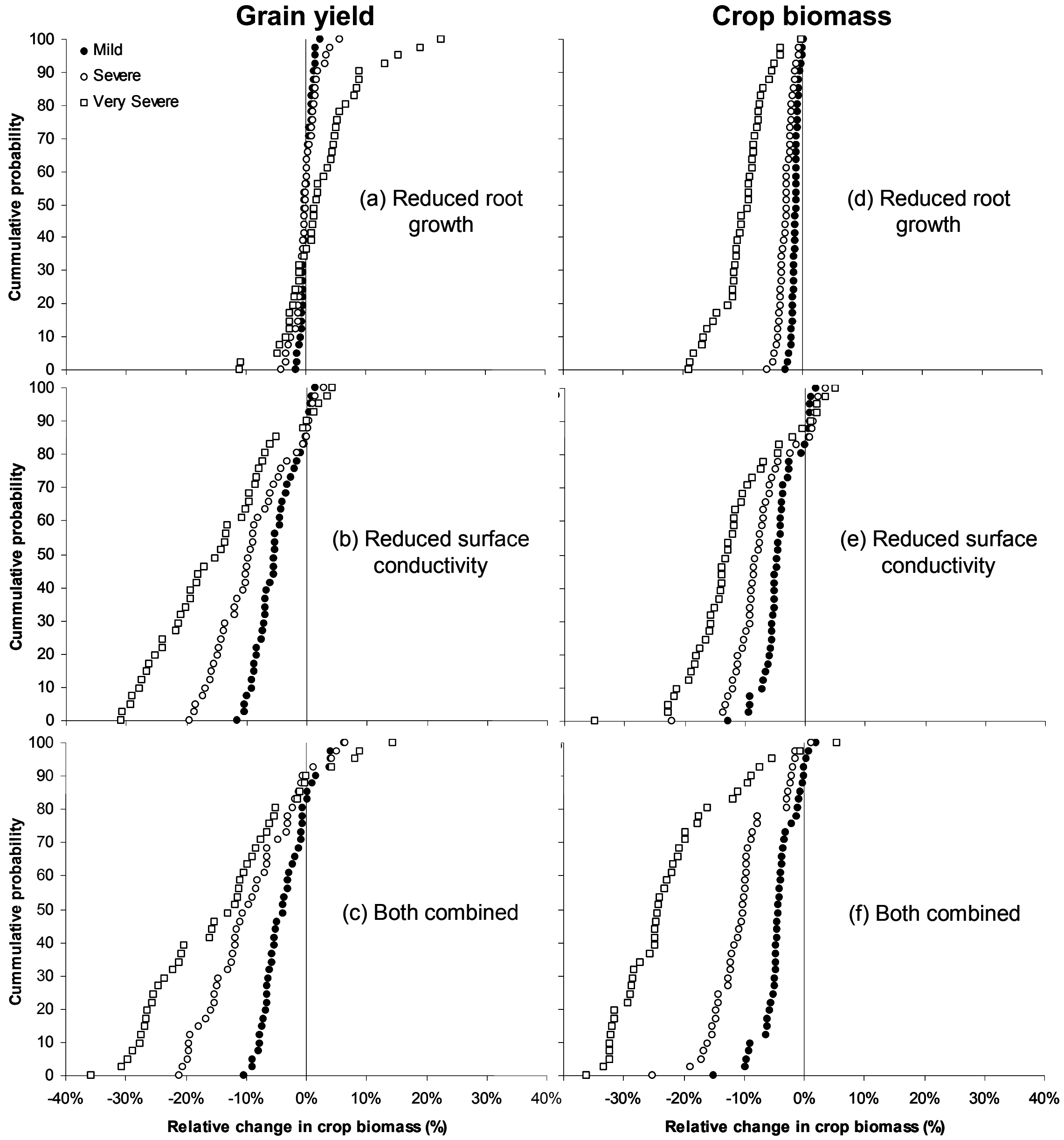

Figure 1. Cummulative probability of changes in grain yield (a-c) and crop biomass growth (d-f) as a result of simulating different severities (●- mild, ○- moderate, □- severe) of reduced root growth in surface layers, reduced surface conductivity and when both effects are combined at Goondiwindi, Queensland.

Table 4. Changes in average crop grain yield (% change from control) at five locations in sub-tropical Australia due to different severities (●- mild, ○- severe, □- very severe) of reduced root growth in surface layers, reduced surface conductivity and when both effects are combined. Low ground cover scenarios are presented.

Location	Reduced root growth			Reduced surface conductivity			Combination of both		
	Mild	Moderate	Severe	Mild	Moderate	Severe	Mild	Moderate	Severe
Emerald	0	1	8	-5	-10	-18	-4	-10	-10
St George	0	0	4	-5	-9	-16	-4	-10	-12
Clifton	1	1	5	-3	-6	-12	0	-6	-8
Goondiwindi	0	0	2	-4	-8	-14	-3	-9	-14
Narrabri	1	1	3	-3	-5	-8	1	-4	-6

In scenarios where more stubble cover was maintained the effects of soil compaction on crop growth and yield were lessened (Table 5). This was mainly due to the stubble facilitating rainfall infiltration when surface conductivity was reduced.

Table 5. High stubble cover lessens reductions in average crop yield (% change from control) due to combined effects of reduced root growth and reduced surface conductivity.

Location	Mild		Moderate		Severe	
	Low	High	Low	High	Low	High
Emerald	-4	-2	-10	-6	-10	-3
St George	-4	-2	-10	-5	-12	-4
Clifton	0	2	-6	0	-8	2
Goondiwindi	-3	0	-9	-2	-14	-3
Narrabri	1	2	-4	0	-6	-1

Conclusion

This simulation study suggest that mild surface soil compaction from livestock, would result in reductions in grain yield of less than 10%. These mild compaction effects are similar to most documented changes in soil conditions after treading by livestock. This implies that in most cases the impacts of compaction by livestock on crop performance are small, which is supported by the few studies that have investigated this experimentally. Crop losses could be larger if more severe soil compaction occurred, especially if surface conductivity is greatly reduced and ground cover levels are low. Crop growth and yield were more sensitive to reduced surface conductivity and rainfall infiltration than to reduced root growth in surface layers. Better information on how crops respond to changes in soil surface condition from to livestock grazing would help to improve our confidence in modelling the impacts on crop performance over the long-term.

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