SOIL AND CROP RESPONSES TO COMPACTION BY RUBBER TYRES ON A CRACKING CLAY IN CENTRAL QUEENSLAND

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ABSTRACT

One pass of a bald tractor tyre was used to compact a moist, shallow cracking clay. The effects on soil physical properties and sorghum growth were measured. The average surface depression was 35 mm. Compaction significantly increased bulk density to a depth of 150 mm and penetration resistance to 195 mm, and decreased hydraulic conductivity by 91% at the soil surface and 72% at 100 mm depth. Compaction significantly reduced crop establishment, plant height, water extraction front advance rate from 43 mm day^{-1} to 30 mm day^{-1} and dry matter at anthesis. There was no effect on dry matter at harvest or grain yield (mean 1700 kg ha^{-1}). In this season better early growth in the uncompacted soil was no advantage as water stress at and after anthesis dominated grain yield. Treatments with zero-tillage after compaction performed well indicating the effectiveness of compaction repair by cracking and self-mulching.

INTRODUCTION

Compaction may be broadly defined as the act of moving soil particles closer together by force. Degradation by wheels, tillage implements and animal hooves are the principle causes of compaction. It has been estimated that soil compaction reduces annual productivity of field crops in Australia by $300-850 million (So, 1990).

Traffic-induced compaction directly affects soil physical, chemical and biological properties and processes, and indirectly influences plant root growth. Physical properties affected include bulk density and porosity, pore size and continuity, temperature, aeration, soil-water relationships and permeability, and penetration resistance (Panayiotopoulos *et al.*, 1994). Root elongation is reduced, while root diameter and branching usually increase (Tardieu, 1994). In general, a soil penetrometer resistance of approximately 1100 kPa will reduce root elongation by 40-50% (Bennie, 1991, cited by Volkmar, 1994).

Tullberg and Lahey (1990) showed that tractor wheelings always cover at least 15%, but more commonly 20-25%, of the tillage implement width. The energy requirement of sweeps working in wheel tracks varied from 1.1-2.9 times that of sweeps in unwheeled soil.

One method of limiting soil compaction induced by wheels is a controlled traffic system. Such a system can potentially (Tullberg, 1986) :-

- reduce the energy required for crop establishment by at least 50%;
- reduce the requirement for tractor power by at least 30%;
- maintain yield without the necessity for deep-tillage operations; and
- increase rainfall infiltration, thereby reducing runoff and erosion in some circumstances.

MATERIALS AND METHODS

Site

The experimental plots are located at the Emerald Research Station (23°29`S, 148°09`E, 190m a.s.l.). Slope is 1.0%. The soil is a shallow open downs cracking clay, developed from weathered basalt. The principle profile form (Northcote, 1977) is Ug5.12. Long-term mean annual rainfall and evaporation are 639 mm and 2265 mm, respectively.

Treatments

The experiment commenced on 13 September, 1994, when all compacted treatments received one wheel pass with a John Deere 4430 tractor. The whole plot was compacted in a series of passes, each beside the previous pass. Bald tyres were used to give uniform compaction and thereby simplify sampling. The site had been sprinkler irrigated four days prior to compaction. Average mass on the front axle was 1070 kg (11.00-16 tyres), and the rear axle 7470 kg (18.4-38 tyres).

Four treatments study the "repair" of initial compaction damage:

- T_1: Control - nil compaction, mechanical and chemical weed control
- T_2: Extreme compaction - heavy compaction each year when wet, mechanical weed control
- T_3: Current Best Advice - initial compaction, deep rip when dry
- T_4: Zero-tillage - initial compaction, chemical weed control, optional double cropping
- T_5: Traditional practice - light compaction each year when wet, mechanical weed control

There are three replications and treatments are split for three fertiliser rates (nil, 40 kg ha^{-1} MAP, MAP+additional 50 kg N ha^{-1}) applied at sowing. Sub-plots receive supplementary flood irrigation at anthesis.

Experimental Details

Treatments T_2 and T_5 received a shallow cultivation on 23 September to create a seedbed, the experiment was irrigated (35 mm) on 26 September and sorghum (var. MR31) sown on 3 October at 290000 seeds ha^{-1}. The sorghum was planted in 600 mm rows with a zero-till planter equipped with narrow sowing points, parallelogram tynes and press wheels. A further 20 mm irrigation was applied on 5 October to ensure emergence during hot, dry weather.

Plots measure 12 x 5.4 m, and each plot contains three beds 1.8 m wide. After compaction, all traffic is restricted to permanent wheel tracks.

Measurements

Soil

a) Bulk Density - (i) soil sampling using 100 mm diameter core, with depth increments of 50 mm to 200 mm, and 100 mm to 500 mm.

(ii) twin probe gamma ray density meter (Campbell Pacific Nuclear Model MC-24S Stratigauge) in 50 mm increments to 500 mm.

b) Soil Water Content - gravimetric determination in association with core bulk density. In-crop soil water measurements are taken using a neutron moisture meter (Campbell Pacific Nuclear Model 503).

c) Surface Profiles - a Rimik Profilemeter with 15 mm spaced pins was used to determine heave and surface depression after each wheel pass.

d) Cone Penetrometer Index - a Rimik CP10 Recording Cone Penetrometer was used to measure force per unit base area in increments of 15 mm to 450 mm depth. The penetrometer was fitted with a standard 30° circular stainless steel cone of 12.83 mm diameter with a 9.83 mm shaft (ASAE Standards, 1992).
e) Hydraulic Conductivity - disc permeameters (Perroux and White, 1988) were used at supply tensions of -1, -2, -3 and -4 cm H_2O, and depths of 0 (surface) and 100 mm to calculate hydraulic conductivity and macropore density.

Crop
a) Establishment - percentage of seed sown was determined by calibrating the planter and taking counts of emerged seedlings at 15 days after sowing (DAS).
b) Early crop growth - 20 plants were measured for height (soil surface to extended leaf tip) from the centre row in each fertiliser sub-plot 24 DAS.
c) Aboveground dry matter - plant tops were sampled at anthesis (60 DAS) and harvest (116 DAS) from an area of 1.8 m^2 in each fertiliser sub-plot. All samples were taken from the centre bed. Plant material was dried at 80°C to constant weight.
d) Grain Yield - grain was hand-harvested in conjunction with the harvest dry matter samples, and dried with the plant material. Final yields were standardised to 12.0% moisture content.

RESULTS

Soil Properties

Table 1 summarises the effect of one tractor wheel pass on selected soil properties.

Average gravimetric soil water content at compaction was 0.4 g g^{-1} at 50-100 mm, decreasing to 0.35 g g^{-1} at 300 mm, and remaining uniform at depth.

The compaction caused by the tractor tyres depressed the soil surface by 40-50 mm. Heave outside the wheel was 10-15 mm. Average compaction across the bed was 35 mm. A significant increase in core bulk density was evident to a depth of 150 mm. At 100-150 mm, compaction increased bulk density from 1.15 to 1.30 g cm^{-3}.

Penetration resistance was significantly increased by compaction to a depth of 195 mm. Maximum resistance occurred at a depth of 30 mm below the new soil surface. This depth below the new compacted soil surface (65 mm below original soil surface) is where crop seeds are sown.

Compaction caused a 91% reduction in hydraulic conductivity at the soil surface, and a 72% reduction at 100 mm depth. Similar reductions in macropore density were measured.

Table 1. Effect of applied compaction on selected soil properties.

Soil Property			Pre-Compaction	Post-compaction
Bulk Density (g cm^{-3})	0-100 mm		1.09	1.21
Penetration Resistance (kPa)	30 mm		267	1738
Hydraulic Conductivity (mm hr^{-1})	Surface		803	70
	100 mm		115	32
Macropore Density (no. m^{-2})	Surface	1.0 mm dia.	168.9	15.0
		1.6 mm dia.	30.0	3.6
		3.0 mm dia.	4.2	0.4
	100 mm	1.0 mm dia.	23.4	4.7
		1.6 mm dia.	4.7	1.4
		3.0 mm dia.	0.6	0.2

Crop Growth

Table 2 summarises the effect of one wheel pass on the subsequent growth of a sorghum crop.

Establishment of sorghum was significantly reduced by compaction in T_2 and T_4. There was a non-significant decrease in T_3 and T_5. Cultivation prior to planting (T_2 and T_5) had no effect on establishment compared to other compacted treatments (T_3 and T_4).

By 24 days after sowing, plants in the control plots were significantly taller than those in the compacted plots (520 mm compared to 370 mm). A positive correlation existed between establishment percentage and plant height at 24 days. The reduction in plant height due to compaction could be associated with slower root growth down the profile. The extraction front advance rate was reduced from 43 mm day^{-1} in T_1, to 30 mm day^{-1} in compacted treatments. These rates are comparable with work undertaken by Robertson *et al.* (1993).

Aboveground dry matter at anthesis was significantly reduced by compaction, except in T_5. The observed effect of compaction on sorghum growth was less evident after anthesis. No significant response to compaction was evident in dry matter at harvest, or grain yield (except in T_2).

Table 2. Effect of applied compaction on dryland sorghum establishment, growth and yield

Treatment	Establishment (%)	Plant Height (mm)	Dry Matter at Anthesis (kg ha^{-1})	Dry Matter at Harvest (kg ha^{-1})	Grain Yield (kg ha^{-1})
T_1	73	523	5573	7220	1879
T_2	58	350	3559	4728	997
T_3	68	393	4533	6523	1913
T_4	61	367	4426	6238	1702
T_5	66	374	4586	6427	1984
lsd (P=0.05):	8	22	1039	1286	722

DISCUSSION

All soil physical properties measured showed significant changes to similar depths (150-200 mm). The most dramatic response to compaction was the 91% reduction in surface hydraulic conductivity, and similar reductions in macropore density. Non-significant changes were measured below 200 mm, but a small change does not necessarily imply soil structural degradation to a sufficient extent to inhibit the development of plant roots.

Compaction reduced establishment in most treatments. The reduction in establishment could be attributed to reduced seed-soil contact, and poor seed coverage with soil. The relatively good establishment in compacted treatments may be due to the zero-till planter used. We expect that traditional sowing equipment would result in greater reductions in establishment.

The reduction in aboveground dry matter at anthesis is attributed to reduced root development. The extraction front advance rate was reduced from 43 mm day^{-1} to 30 mm day^{-1} in compacted treatments. Although the advance rate was decreased, an increase in root diameter and branching may result. Tardieu (1994) reported that an increase in diameter could possibly avoid root buckling. This "biological drilling" has the potential to ameliorate subsoil in poor physical condition (Cresswell and Kirkegaard, 1995).

The absence of a reduction in grain yield due to compaction shows that the plants compensated for reduced establishment and reduced early growth. Slow root development delayed peak water use, and left more stored soil water for grain filling. Harvest index was higher in compacted treatments than the control. With more rainfall after sowing, higher dry matter at anthesis should produce higher grain yields. The irrigation treatment was applied late this season due to equipment problems. Mean yield in irrigated plots was 2660 kg ha^{-1} and the treatment responses were similar to dryland results (Table 2). Most of the yield response to irrigation was due to tillering.

The total mass of the tractor used for this experiment was 8540 kg. This would be considered a very small tractor for dryland farming in this region. Work undertaken by Blunden *et al.* (1994) used tractors with a mass in excess of 15000 kg. Had our tractor been of this magnitude, soil and crop responses may have been more dramatic.

The satisfactory performance of the zero tillage treatment shows that natural amelioration due to the cracking and self-mulching properties of this soil may be an important phenomenon in the compaction/repair process.

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