EFFECTS OF COMPACTION ON CROP PERFORMANCE

B.J. Radford[1] and D.F. Yule[2]
[1]Qld Department of Natural Resources, LMB 1, Biloela Qld 4715
[2]Qld Department of Natural Resources, PO Box 736, Rockhampton Qld 4700

Abstract

An alluvial soil at Biloela (24° 22'S, 150° 31'E) was compacted in various ways to determine the effects on soil water storage, crop establishment, growth, yield and water use efficiency. Annual compaction with header tyres on wet soil reduced grain yield by reducing soil water storage at sowing. When compaction had no effect on soil water storage, it did not reduce wheat or sorghum yields, provided satisfactory crop establishment was obtained. Biological repair of compacted soil by crop or pasture roots is recommended in preference to deep ripping. This requires suitable machinery for sowing into compacted soil.

Introduction

Wheel traffic in fields has been recognised as a major source of forces causing undesired soil compaction (Schafer et al., 1992). The first pass of a wheel causes most of the total soil compaction (Burger et al., 1983). Wheel damage increases on wet soil, which has reduced strength (Kirby and Kirchoff, 1990). A large proportion of the area of a field is covered by wheel tracks during a cropping cycle. The ground area trafficked by heavy tyres is estimated at 30% under zero tillage, 60% under minimum tillage and 100% under conventional tillage (Tullberg, 1990; Soane et al., 1982; Erbach, 1986).

The aim of this work was to measure the effect of applied soil compaction on crop performance and to determine ways to repair compaction damage. Such data show the value of controlled traffic systems, which avoid the problem of soil compaction.

Materials and Methods

Site

The site is located on the Queensland Dept of Primary Industries Research Station, Biloela, Queensland, Australia (latitude 24° 22'S, longitude 150° 31'E, altitude 173 m). It was cleared in the 1930s. The ground surface is relatively level (slope = 0.2%).

The soil is a black cracking clay developed on an alluvium, locally termed Tognolini series (Shields, 1989) or Vertisol (Soil Survey Staff, 1975). The soil had minimal, visible structure degradation before the experiment (P.G. Muller pers. comm.). However, a former owner reported a history of subsoil "hardpan" formation and deep ripped in 1977 to a depth of 0.45 m. The clay content in the 0-0.1m layer is 47%.

The long-term mean annual rainfall is 685 mm with 73% failing in the summer months (October-March). The long-term mean annual evaporation is 1868 mm.

Treatments

The experiment commenced in April 1993 when all but a control treatment were initially compacted with the lugged rubber tyres of a commercial header on wet soil. This is a short-term economic necessity when grain is ready for harvest and summer storms threaten heavy yield losses. The entire area of each compacted plot received a single pass of a front header wheel. This experimental treatment is not unrealistic because random wheel traffic during a fallow typically covers most of the ground area. Average mass on each front wheel of the header was 5 t. Inflation pressures were deliberately kept high to maximise compaction: 235 kPa (front) and 205 kPa (rear).

Subsequently there were 6 compaction repair treatments and the uncompacted control:

C_0: Control - nil compaction, reduced (dry) tillage (only on soil drier than the plastic limit);

C_1: Extreme compaction - annual compaction with a header on wet soil, minimal tillage;

C_2: Traditional practice - annual compaction with a tractor on wet soil, frequent tillage;

C_3: Reduced tillage - annual compaction with a tractor on dry soil, reduced (dry) tillage;

C_4: Zero tillage - initial compaction with a header on wet soil, no tillage;

C_5: Current best advice - initial compaction with a header on wet soil, deep ripping (dry) after first crop, no tillage thereafter; and

C_6: Pasture - initial compaction with a header on wet soil, pasture ley (lucerne + Gatton panic) for 3 years, reduced (dry) tillage thereafter.

When tillage was avoided, weeds were controlled with herbicides.

Design

The experimental design was a randomised block of 2 main treatments (raingrown, supplementary irrigation) and 2 replications. The main plots were split into 14 subplots: the 7 compaction/repair treatments x 2 fertiliser treatments (control, fertilised with N and Zn). Each plot measured 30 x 9 m (3 passes of a tractor with wheels spaced 3 m apart).

Crop sequence

Crops grown were wheat (Hartog) in 1993, wheat (Hartog) in 1994, sorghum (MR31) in 1995 (double crop), wheat (Hartog) in 1996, wheat (Sunstate) in 1997 and maize (DK689) in 1998 (double crop).

Measurements

The following measurements were taken:
Soil water storage: 0-1.5 m in 0.1 m increments, by neutron moisture meter;
Crop establishment: percentage of seeds sown (from 5-15 m of row for wheat and 50 m for sorghum and maize);
Aboveground dry matter at anthesis: from 1 m^2 quadrats in each plot;
Grain yield at 12% moisture content: by small plot header and grain moisture meter;

Water use efficiency: grain yield/(soil water use + incrop rainfall).

Results

Soil water storage

In all years, particularly 1993, some rainfall was already stored in the soil prior to the application of the annual compaction treatments. Nevertheless annual compaction with the header significantly reduced total soil water at sowing in all years except 1993 and 1995. Mean soil water content was reduced from 543 (control) to 489 mm (Table 1). Annual compaction with tractor tyres on wet soil significantly reduced soil water content at sowing from 1995 to 1998. Reduced tillage, zero tillage, current best advice and the pasture treatment attained the level of soil water at sowing in the control in all years.

Table 1. Effect of compaction/repair treatments on total stored soil water (0-1.5 m) at sowing (mm)

Treatment	Wheat 1993	Wheat 1994	Sorghum 1995	Wheat 1996	Wheat 1997	Maize 1998
C_0	556	561	472	549	571	547
C_1	537	528	448	474	501	448
C_2	-	546	416	484	536	499
C_3	-	567	472	551	556	526
C_4	-	583	542	559	571	554
C_5	-	538	470	536	540	533
C_6	-	-	-	-	562	559
lsd, P=0.05	ns	27	37	58	32	46

Crop establishment

Compaction with the header significantly reduced crop establishment in 1993, 1994 and 1995 (in comparison with the uncompacted control treatment) (Table 2). In 1996, however, the rate of seed metering was found to have varied during planting, and in 1997 seed was sown at a shallow depth and the soil was wet up with spray irrigation. Reductions in establishment occurred only in the extreme compaction treatment, and even these reductions were only small. This result is attributed to the use of "state of the art" zero tillage planting machinery (smooth coulters, spearpoint soil openers, rigid tines and press wheels).

The small reductions in establishment percentage (and hence plant populations) are unlikely to have caused significant variation in crop dry matter production or grain yield.

Table 2. Effect of compaction/repair treatments on crop establishment (% of seed sown)

Treatment	Wheat	Wheat	Sorghum	Wheat	Wheat	Maize

	1993	1994	1995	1996	1997	1998
C_0	93	76	35	55	53	87
C_1	71	59	22	56	56	79
C_2	-	73	39	51	55	85
C_3	-	82	39	53	60	78
C_4	-	67	41	38	56	80
C_5	-	76	46	50	65	86
C_6	-	-	-	-	57	84
lsd, P=0.05	8	15	11	ns	ns	9

Aboveground dry matter at anthesis

Compaction with the header did not reduce anthesis dry matter for wheat in any year (compared with control) but reduced it for sorghum (1995) and maize (1998) (Table 3). Zero tillage and current best advice significantly exceeded control in 1995.

Table 3. Effect of compaction/repair treatments on weight of aboveground plant dry matter at anthesis (t/ha)

Treatment	Wheat 1993	Wheat 1994	Sorghum 1995	Wheat 1996	Wheat 1997	Maize 1998
C_0	5.77	5.21	3.54	5.71	4.35	7.00
C_1	5.49	4.67	2.49	5.12	3.64	4.01
C_2	-	4.77	2.88	6.09	4.00	5.22
C_3	-	5.48	4.10	6.45	4.52	6.27
C_4	-	4.60	4.33	5.76	4.15	6.58
C_5	-	5.49	4.52	5.30	4.47	6.78
C_6	-	-	-	-	4.59	7.76
lsd, P=0.05	ns	0.66	0.65	0.77	ns	1.38

Grain yield

Compaction with the header significantly reduced the grain yield of wheat in 1996 and 1997, and of maize in 1998 (by 2.43 t/ha or 43%) (Table 4). In 1997 and 1998 the former pasture treatment outyielded all other treatments.

Table 4. Effect of compaction/repair treatments on grain yield at 12% moisture content (t/ha)

Treatment	Wheat 1993	Wheat 1994	Sorghum 1995		Wheat 1996	Wheat 1997	Maize 1998
			Dryland	Irrigated			
C_0	5.32	2.55	1.61	3.52	3.51	3.25	5.63

C_1	5.18	2.40	2.36	2.70	3.04	2.33	3.20
C_2	-	2.41	2.08	1.90	3.32	3.10	4.45
C_3	-	2.61	1.92	4.02	3.45	3.31	5.02
C_4	-	2.35	3.17	3.68	3.30	3.01	5.92
C_5	-	2.52	2.77	3.40	3.25	3.21	5.96
C_6	-	-	-	-	-	3.58	6.54
lsd, P=0.05	ns	ns	0.95	0.95	0.26	0.12	0.58

Water use efficiency

Compaction with the header significantly reduced water use efficiency in 1996 and 1998 (compared with control) (Table 5). In 1998, the former pasture treatment had significantly higher water use efficiency than control, current best advice and the three annually compacted treatments.

Table 5. Effect of compaction/repair treatments on water use efficiency (kg/ha/mm)

Treatment	Wheat 1993	Wheat 1994	Sorghum 1995		Wheat 1996	Wheat 1997	Maize 1998
			Dryland	Irrigated			
C_0	10.2	6.6	5.4	9.6	10.5	9.9	13.2
C_1	10.2	7.0	9.0	9.2	8.5	9.6	9.2
C_2	-	7.7	9.9	6.3	9.8	10.0	11.3
C_3	-	7.7	6.7	11.7	10.9	10.8	12.8
C_4	-	6.9	9.7	9.4	9.8	9.8	14.0
C_5	-	7.0	9.2	9.8	10.3	9.6	13.1
C_6	-	-	-	-	-	10.1	14.9
lsd, P=0.05	ns	ns	3.8	3.8	0.9	0.8	1.7

Discussion

Annual compaction with header tyres on wet soil generally reduced the amount of water stored in the soil at sowing compared with control (Table 1), which resulted in reduced grain yields (Table 4). When compaction with the header was not associated with reduced soil water content at sowing (in 1993 and 1995), compaction did not reduce yield. This result is attributed to repair of the compaction damage by the fibrous root systems of the crop species tested (wheat in 1993 and sorghum in 1995). Any effects on crop establishment were small and unlikely to affect yield (Table 2). Compaction by the header reduced water use efficiency in 1996 (wheat) and 1998 (maize) (Table 5).

Annual compaction with tractor tyres on wet soil generally reduced soil water content at sowing and grain yield, despite subsequent tillage operations to repair the compaction damage (Tables 1 and 2). Annual compaction with tractor tyres on dry soil combined with subsequent tillage of dry soil (reduced tillage) generally did not reduce soil water at sowing or yield.

The pasture treatment not only repaired the compacted soil but resulted in a better soil condition for grain yield than the control in both 1997 and 1998 (Table 4).

Compaction repair by crop or pasture roots can only be effected with suitable planting machinery to establish plants in the compacted soil. Although costly, this option is recommended in preference to deep ripping, which is costly and delays cropping.

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