COMPACTION EFFECTS ON CROP GROWTH, RUNOFF AND SOIL LOSS

K.W. Rohde[1] and D.F. Yule[2]
[1]Dept. of Natural Resources, P.O. Box 19, Emerald, Qld., 4720
[2]Dept. of Natural Resources, P.O. Box 736, Rockhampton, Qld., 4700

Abstract

Applied compaction, at varying frequencies and weight, was used to determine the effects on establishment, growth and yield of sorghum, and on runoff and soil loss. This compaction reduced establishment where no rainfall fell immediately after planting, reduced early growth, and significantly reduced grain yield in one of three seasons. Compaction on 15/12/96 doubled runoff and soil loss on 3/1/96. These effects are much more severe than any cropping effects measured. Applied compaction decreased ground cover by more than 50%, with cultivation decreasing it by a further 58%. Farming systems which minimise compaction and maintain high cover levels provide a sustainable future for the dryland grain industry by improving the on-farm and off-farm natural resources while maximising potential grain production.

Introduction

Soil compaction has been estimated to reduce Australia's annual productivity from field crops by $300-850 million (So, 1990), and has been recognised as the most costly form of land degradation in Australia (McGarry, 1993).

Between 1982 and 1986, the area of grain production on the Central Highlands of central Queensland expanded from 250 000 to 512 000 ha, with the area of crop grown since 1986 varying from 222 000 to 518 000 ha, depending on seasonal rainfall (Carroll *et al.*, 1997). McGarry (1990) found compaction in various forms and extents across all soils and cropping systems in this region, with the principle causes being load bearing wheels, tillage tools and animal hooves.

Under conventional farming techniques, field traffic is uncontrolled and often carried out when the soil moisture content is optimum for soil compaction. During one cropping cycle, it has been estimated that over 30% of the field area is trafficked in a zero tillage system, over 60% in a minimum tillage system, and over 100% using conventional tillage practices (Soane *et al.*, 1982; Tullberg, 1990).

Compaction problems and the possible reduction in crop growth and yield are caused by soil water status, intensity and timing of machinery operations, and size and weight of the machinery used. Chamen *et al.*, 1992 and Rusanov, 1991 reported yield responses are variable, and both positive and negative. The interacting effects of climatic conditions (mainly in crop rainfall) and pre-planting wheel traffic on crop yield are discussed by Hakansson *et al.* (1988). Increased yields were obtained in dry conditions, and depressed yields when rainfall was high, on a clay loam soil in Minnesota.

Poor seed germination is often attributed to poor seed-soil contact. This contact may vary with soil water availability and soil hydraulic conductivity (Brown *et al.*, 1996). Tillage operations undertaken to increase the degree of contact may have other adverse effects - aggregate size reduction may increase the vulnerability to soil erosion, while compaction can cause impedance of seedling roots and shoots.

The high variability of rainfall in central Queensland produces insufficient rainfall to plant a crop, or times of very high rainfall causing severe soil erosion (5% of rainfall >100 mm/day) (Carroll *et al.*, 1997). A major concern is that many management practices have an adverse effect on the infiltration of rainfall, and subsequent runoff and soil erosion. For example, significant reductions in macropore volume and continuity can affect soil aeration, infiltration, drainage, water holding capacity, mechanical impedance etc., all of which are known to reduce crop growth (Murray, 1994).

Parker *et al.* (1995) showed that the velocity of runoff water near the soil bed and erosion rates increased as bulk density increased. Soil compaction can decrease or increase erosion by water (Voorhees, 1977), and can produce erosion control benefits and hazards (Voorhees *et al.*, 1979).

In 1994, a study commenced to study the effect of soil compaction on crop growth and yield, and the rate of repair of soil structural degradation using various management options. This paper presents results from the study in terms of the effect of compaction on crop growth, yield, runoff and soil loss.

Materials and Methods

Location and Climate

The experimental site was located on the Queensland Department of Primary Industries Emerald Research Station (latitude 23°29' S., longitude 148°09' E., 190 m a.s.l.), central Queensland. The average ground surface slope was 1.0%. Long term mean annual rainfall is 639 mm with 75% falling in the summer months, and mean annual pan evaporation is 2265 mm.

The soil type was a black cracking clay (Vertosol). The Australian soil classification (Northcote, 1977) is Ug5.12. Particle size distribution in the 0-10 cm depth was 28% sand, 10% silt, and 61% clay.

Treatments and Design

Treatments were first imposed during September, 1994, with the initial compaction treatment applied. Treatment application is described in Rohde and Yule (1995).

T_1: *Control* - nil compaction, chemical weed control
T_2: *Extreme compaction* - heavy compaction each year when wet, mechanical and chemical weed control
T_3: *Current best advice* - initial compaction, chemical weed control
T_4: *Zero tillage* - initial compaction, chemical weed control, double cropped
T_5: *Traditional practice* - light compaction each year when wet, mechanical and chemical weed control.

Soil management practices and planting dates for each sorghum crop are shown in Table 1. Main compaction treatments were 120 x 5.4 m.

Measurements

Crop Establishment - determined in each crop as a percentage of seed sown, by calibrating the planter for seed output and counting the established seedlings. Counts were taken 15-25 days after sowing from a total row length of 6.0 m in every main treatment.

Above ground drymatter production - plant tops at anthesis and harvest were cut at ground level from an area of 1.0 x 1.8 m in each fertiliser sub-plot and dried to constant weight at 80°C in a fan-forced dehydrator. All above ground drymatter is expressed on an oven dry basis.

Grain yield - grain was thrashed from drymatter samples taken at harvest and dried at 80°C to constant weight. Grain yields were standardised to 12% moisture content.

Runoff and Soil Loss - automated measuring instrumentation was located at the bottom end of each main compaction treatment. Runoff was collected from one permanent bed and wheel track (contributing area 237.6 m^2), and measured by a tipping bucket, with the data recorded at one minute intervals by a data logger. Each bucket was calibrated. Soil loss was measured in two components: the finer suspended material was sampled using a splitter sampler, and the coarser bedload material was collected in a trough. Rainfall intensity was measured by a pluviometer, and rainfall volume by a raingauge. Soil surface cover was measured after each runoff event in two locations per treatment.

Table 1 Soil management activities undertaken in the five treatments

Activity	Date	Treatment				
		Control	Extreme compaction	Current best advice	Zero tillage	Traditional practice
Compacted	12/9/94		▨	▨	▨	▨
Cultivated	23/9/94		▨			▨
Planted crop 1	3/10/94	▨	▨	▨	▨	▨
Cultivated	20/4/95		▨			▨
Planted wheat					▨	
Compacted	15/12/95		▨			▨
Planted crop 2	17/1/96	▨	▨	▨	▨	▨
Planted wheat	21/5/96				▨	
Cultivated	27/6/96		▨			▨
Compacted	16/10/96		▨			▨
Planted crop 3	13/12/96	▨	▨	▨	▨	▨

Results and Discussion

Crop growth

Table 2 summarises the effect of each compaction treatment on the dryland growth and yield of three sorghum crops.

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

	Crop 1				Crop 2			
Treatment	Establish. (%)	DM at anthesis (kg/ha)	DM at harvest (kg/ha)	Grain Yield (kg/ha)	Establish. (%)	DM at anthesis (kg/ha)	DM at harvest (kg/ha)	Grain Yield (kg/ha)
T_1	81	5754	7220	1879	83	4597	6200	2861
T_2	58	3515	4728	997	50	1823	2107	806
T_3	70	4612	6523	1913	72	4394	4967	2095
T_4	64	4760	6238	1702	67	4241	4956	1905
T_5	77	4616	6427	2020	56	2946	3731	1583
	n.s.	*	n.s.	n.s.	P=0.064	*	**	***

	Crop 3			
Treatment	Establish. (%)	DM at anthesis (kg/ha)	DM at harvest (kg/ha)	Grain Yield (kg/ha)
T_1	83	4429	5625	1968
T_2	63	1423	3183	1251
T_3	76	4457	5244	1936
T_4	80	5426	5823	2055
T_5	68	2354	4532	1932
	n.s.	***	**	n.s.

DM - drymatter; n.s. - $P>0.10$; * - $P<0.05$; ** - $P<0.01$; *** - $P<0.001$

Sorghum establishment was only significantly reduced by compaction (T_2 and T_5, 50 and 56%, respectively) compared to the control (T_1 83%) in crop 2. After planting crop 1, the trial area was spray irrigated. No rain fell immediately after planting crop 2, but 27 mm of rain fell within three days of planting crop 3. We conclude that rainfall or irrigation soon after planting can overcome the establishment reduction caused by compaction. The relatively good establishment in the compacted treatments may be due to the zero tillage planter used. We expect traditional planting equipment to result in greater reductions in establishment.

Compaction significantly reduced drymatter at anthesis and the effects of annual compaction were cumulative. The initial compaction of T_3 and T_4 prior to crop 1 showed no effects by crop 2.

In crop 1, there was no difference between treatments in drymatter production at harvest (6227 kg/ha). Crop 2 showed reductions in T_2 (2107 kg/ha) and T_5 (3731 kg/ha), compared to T_1 (6200 kg/ha). T_4 (5823 kg/ha) produced higher drymatter at harvest of crop 3 than T_2 and T_5 (3183 and 4532 kg/ha, respectively).

Sorghum was generally able to compensate for lower establishment on reduced early growth to produce similar grain yields except for crop 2. Slower root development in the compacted treatments (calculated from weekly neutron moisture meter measurements) delayed peak water use, allowing for more stored soil water at the critical time of grain filling.

Runoff and soil loss

Nine runoff events were measured between December 1995 and May 1998. Six of these events are summarised in Table 3.

Table 3 Treatment effects on ground cover, runoff and soil loss

	11/12/95 (Rain=10mm) (I_{15}=66mm/hr) (pre-comp.)	3/1/96 (Rain=59mm) (I_{15}=43mm/hr) (post-comp.)	1/5/96 (Rain=110mm) (I_{15}=30mm/hr) (harvest)	9/10/96 (Rain=69mm) (I_{15}=30mm/hr) (pre-comp.)	21/11/96 (Rain=26mm) (I_{15}=50mm/hr) (post-comp.)	5/5/98 (Rain=43mm) (I_{15}=24mm/hr) (fallow)
Ground cover (%)						
T_1	44.8	42.3	52.3	52.1	25.2	37.1
T_2	33.9	14.2	34.0	13.9	6.4	16.2
T_3	39.1	44.7	52.0	48.9	29.6	35.9
T_4	34.5	35.9	48.4	58.5	29.9	37.2
T_5	31.2	17.1	41.9	18.3	7.9	21.2
	**	***	**	***	***	***
Runoff (mm)						
T_1	8.3	21.9	3.1	62.0	3.0	2.9
T_2	11.5	44.7	12.0	52.0	4.7	8.7
T_3	13.1	24.7	1.9	51.7	1.3	3.3
T_4	1.8	21.2	3.3	49.7	3.4	3.4
T_5	12.9	40.1	12.0	65.0	5.5	10.0
	$P=0.094$	***	*	n.s.	**	***
Total soil loss (t/ha)						
T_1	1.07	2.28	0.04	0.81	0.31	0.18
T_2	1.63	4.73	0.21	2.12	0.63	0.80
T_3	1.57	2.44	0.00	0.63	0.12	0.20
T_4	0.24	1.43	0.01	0.64	0.33	0.20
T_5	1.56	5.28	0.14	1.97	0.45	0.72
	*	***	***	***	*	***

n.s. - $P>0.10$; * - $P<0.05$; ** - $P<0.01$; *** - $P<0.001$

On 11/12/95, T_4 produced least runoff and soil loss. This was due to a drier profile from double cropping. Treatments T_2 and T_5, compacted on 15/12/95, produced double the runoff and soil loss on 3/1/96. Compaction reduced ground cover in these treatments by 45-58%. Even though runoff from T_4 was similar to T_1 and T_3, soil loss was significantly reduced, presumably due to the double cropped wheat.

Runoff and soil loss at harvest of crop 2 (1/5/96) was significantly higher in T_2 and T_5 than all other treatments. This may be attributed to the lower ground cover levels in these treatments.

On 9/10/96, runoff was similar across all treatments, but soil loss in T_2 and T_5 was more than double that of other treatments. T_2 and T_5 had been cultivated during the fallow, repairing any compaction that may have been present at the previous event. This cultivation removed any treatment effect on runoff, but soil loss increased dramatically associated with 56-59% reduction in ground cover (Table 3).

Following a twelve month fallow after crop 3 when all treatments had been zero tilled, runoff and soil loss on 5/5/98 were significantly greater in T_2 and T_5. Even though there was no difference in grain yield in crop 3 (Table 2), lower ground cover levels were measured in these two treatments.

Conclusions

These results show that applied compaction reduces establishment when dry periods are experienced after planting (crop 2). Early crop growth was reduced, but the crop was generally able to compensate and produce similar grain yields. The performance of T_4 (zero tilled following initial compaction) shows that natural amelioration due to cracking and self-mulching properties of this soil are an important phenomenon in the compaction/repair process.

Compaction dramatically increased both runoff and soil loss. The cumulative total runoff and soil loss for T_5 was 175 mm and 12.12 t/ha, respectively, where T_4 produced 89 mm runoff and only 3.54 t/ha soil loss. Cultivation is known to quickly repair compaction, but the resulting decrease in ground cover increases soil loss dramatically.

A combination of reduced compaction (controlled traffic) and maintaining high ground cover (growing good crops and zero tillage) will minimise runoff and soil loss. These farming systems provide a sustainable future for the dryland grain industry by improving the on-farm and off-farm natural resources while maximising grain production.

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