Combined effect of soil moisture and external loads on soil compaction

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Abstract

This experiment was designed to study the influence of combinations of external load (tractor weight) and soil water on soil compaction. Four soil water levels: air dry, 50% FC, FC and saturation were combined with four external loads: no load (0 kg), small tractor (2638 kg), medium tractor (3912 kg) and large tractor (6964 kg). Soil bulk density, soil strength and soil water infiltration rate were measured at 0-100, 100-200 and 200-300 mm soil depths. Combined increases in soil water and external load together increased soil compaction, as indicated by increasing soil bulk density and soil strength and decreasing soil water infiltration rate. However, at soil water below field capacity, the soil compaction increases were not significant for any external load. The interaction between soil water and external load was not significant for bulk density for all soil depths but was significant for soil strength and soil water infiltration rate for all soil depths.

Introduction

Soil compaction is an important component of the land degradation syndrome, which is an issue for soil management throughout the world (Batey 2009). Soil water content is the most important factor influencing soil compaction processes (Soane and Van Ouwerkerk 1994; Hamza and Anderson 2003, 2005). However, uncertainty still exists regarding the effect of soil water on the susceptibility to compaction. Contradictory results have been reported in the literature. This paper is designed to study such an effect.

Materials and methods

Site description

The experiment was located at the Agricultural Experiment Station at Sultan Qaboos University, Oman (23^o 35' N; 580^o 09' E). The soil has a loamy texture down to 300 mm depth, with clay content of about 21%, increasing with depth. The average maximum temperature is 45? C in summer and 28? C in winter. The average annual rainfall is 67 mm and soil organic matter in the experimental site was 1.34 %.

Treatments

Four soil water contents and four external loads were used in a complete factorial experiment as follows: soil water - air dry (AD), 50% field capacity (50% FC), field capacity (FC) and saturated (Sat). External loads - no load (L0), small tractor (L1), medium tractor (L2) and large tractor (L3). The small tractor was a Massey Ferguson 240 (2638 kg weight), the medium tractor was a Massey Ferguson 5340 (3912 kg) and the large tractor was a Ford Backhoe 655D (6964 kg). The tyres used in this experiment were diagonal ply, except for the large tractor rear tyres, which were radial.

Results and discussion

Soil bulk density

The original air-dry soil bulk density increased with soil depth: 1.34, 1.42 and 1.49 Mg/m^3 for the soil depths 0-100, 100-200 and 200-300 mm (Table 1). The bulk density stayed almost constant, regardless of the soil water unless external loads were applied, and likewise was almost constant for all AD treatments regardless of the applied external loads. However, when load was applied together with water, there was a significant increase in bulk density for all soil water levels above AD treatments.

External load and soil water interaction

The interaction between soil water and external load was insignificant for all soil depths. However, it showed a similar pattern as for soil strength and water infiltration rate where bulk density at a given load increased as water levels increased and likewise bulk density increased at a given soil water as external loads increased. Figure 1 shows the interaction for the 0-100 mm soil depth only as similar interactions occurred for the 100-200 and 200-300 mm soil depths.

Table 1. Soil bulk density for the 0-100, 100-200 and 200-300 mm depths at four water contents and four external loads.

	Bulk density (Mg/m^3)			
Depth (mm)	ADL0	ADL1	ADL2	ADL3
100	1.34	1.35	1.37	1.36
200	1.42	1.44	1.43	1.44
300	1.49	1.48	1.48	1.49
?	50%FC L0	50%FCL1	50%FCL2	50%FCL3
100	1.34	1.43	1.45	1.49
200	1.42	1.46	1.50	1.53
300	1.48	1.47	1.48	1.51
?	FCL0	FCL1	FCL2	FCL3
100	1.33	1.48	1.53	1.55
200	1.43	1.56	1.58	1.59
300	1.49	1.57	1.59	1.60

?	SatL0	SatL1	SatL2	SatL3
100	1.34	1.53	1.56	1.64
200	1.43	1.57	1.58	1.63
300	1.49	1.56	1.58	1.64

F values for the 0-100 and 100-200 mm were highly significant (<0.001) while that of 200-300 mm were highly significant (<0.001) for soil water and significant (0.019) for the external load. L.S.D. for 0-100 mm was 0.057, for100-200 mm was 0.053, and for 200-300 mm was 0.043.

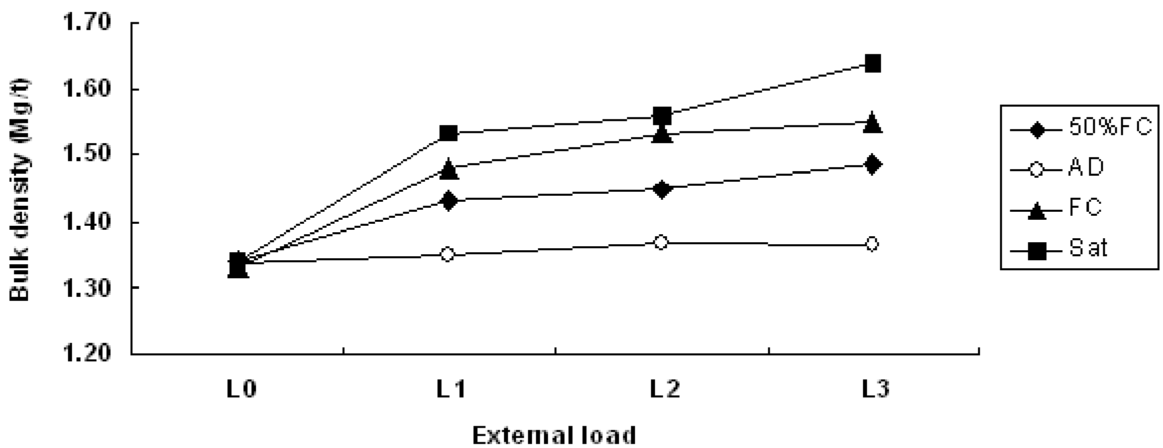

Figure 1. Soil bulk density for the 0-100 mm soil layer as affected by the interaction between external loads and soil moisture treatments.

Soil strength

The original averages of the soil strength were 1.14, 1.70 and 2.38 MPa for the 0-100, 100-200 and 200-300 mm soil depths (Figure 2). Thus, soil strength in the field increased with increasing soil depth similar to the pattern of increasing soil bulk density. The differences between treatments were highly significant for all depths and for both the soil water and external load treatments (P<0.001, see Figure 2). For the AD treatments, the increases in soil strength ranged from 3 to 25% and the effect of external load decreased with increasing soil depth. For soil water treatments above AD, that is 50% FC, FC and Sat. treatments, the increases in soil strength ranged from 2 to 44% for the 50% FC, 2 to 99% for the FC and 3 to 169 % for Sat. treatments.

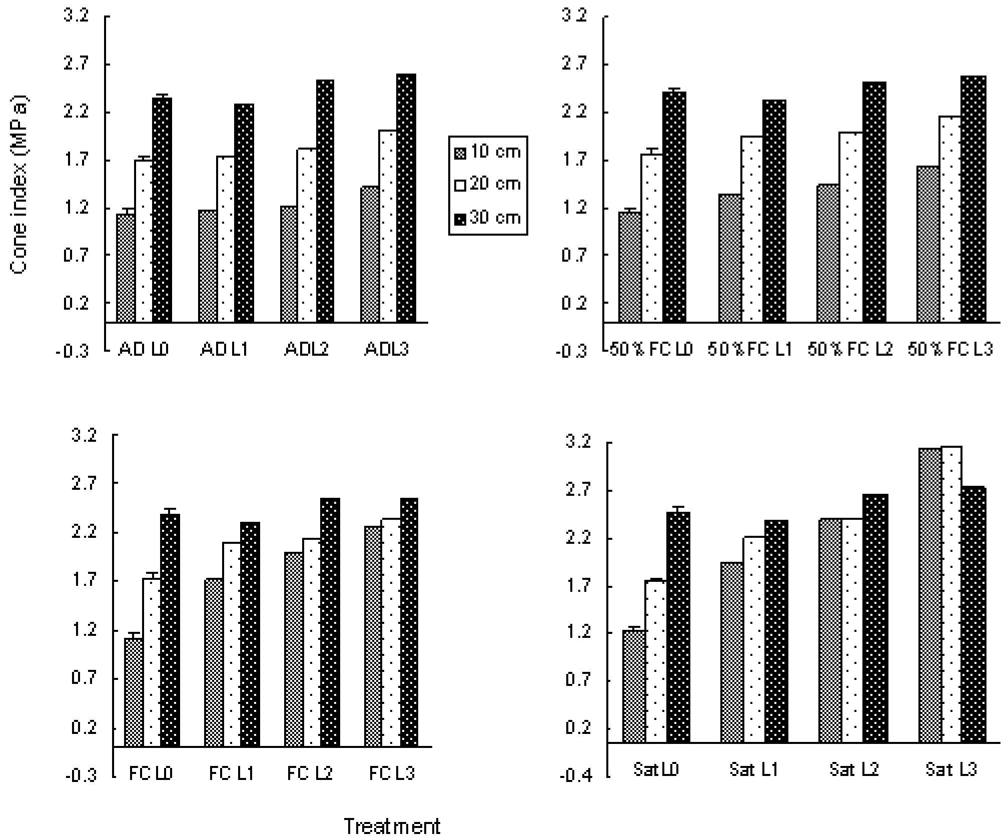

Fig. 2. Soil cone index (MPa) for all treatments and for 0-100, 100-200 and 200-300 mm soil depths. Vertical bars indicate l.s.d. (P = 0.05).

External load and soil water interaction

There was a highly significant interaction ($P<0.001$) for 0-100 and 100-200 mm soil depth and significant interaction ($P = 0.05$) for the 200-300 mm soil depth between soil water and external load as shown in Figure 3. When load was applied together with water, there was an increase in soil strength, which means that the increase in soil strength at a given load treatment was greater at higher water levels and likewise the increase in soil strength at a given soil water treatment was greater at higher external loads.

Soil water infiltration

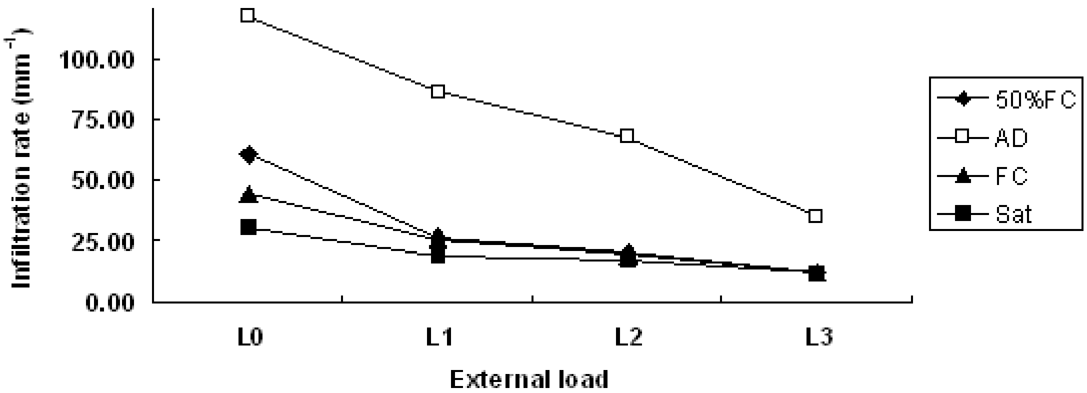

Figure 3. Water infiltration rate for the 0-100 mm soil layer as affected by the interaction between external loads and soil moisture

Also, infiltration rate decreased with increasing external load and soil water. For example, the infiltration rate for the FC treatments decreased by 41, 56 and 72% when soil loads increased from L0 to L1 to L2 then to L3, while infiltration rate for the L2 treatment decreased by 70, 71 and 78 % when soil water increased from AD to 50% FC to FC and then to Sat. The interaction between soil water and load treatments was significant (P = 0.001). Figure 3 shows the effect of the interaction between external load and soil water on soil water infiltration rate. For AD treatments, the infiltration rate was proportional to the soil strength and decreased with increasing soil strength regardless of the external load.

Tyre inflation pressure and surface area contacts

The rear tyre weight of each of the three tractors was higher than that of the front tyre because of the heavy weight of the hydraulic assembly and other attachments. An exception to this was for the small tractor MF 240, which had a heavier front weight than that of the rear because a front-end loader assembly was attached to the front of the tractor. The front tyre compaction of the tractors was 340, 102 and 235 kPa for the Backhoe 655D, MF 5340 and MF 240 tractors respectively, whilst the corresponding rear tyre compactions for the same tractors were 378, 97 and 89 kPa (Table 2)

Table 2. Infilation pressure, tyre and tractor/ground surface area contact, tyre weight, tyre compaction and maximum compaction per tractor (Max compaction) for the large tractor Ford Backhoe 655D, medium tractor MF 5340 and small tractor MF 240.

Tractor	Inflation pressure		Tyre/ground surface area contact	Tyre weight	Tyre compaction		Max compaction
	kPa	kg/cm^2	cm^2	kg	kg/cm^2	kPa	kPa
Backhoe							

655D							
Front tyre	193	2.6	237	822	Front 3.47	Front 340	378
Rear tyre	207	0.7	710	2740	Rear 3.86	Rear 378	
M F 5340							
Front tyre	69	1.0	1023	1064	Front 1.04	Front 102	102
Rear tyre	69	1.2	1173	1162	Rear 0.99	Rear 97	
MF 240							
Front tyre	193	2.2	315	754	Front 2.39	Front 235	235
Rear tyre	69	2.5	639	578	Rear 0.90	Rear 89	

When the maximum surface soil compaction per tractor is calculated, it shows that the large tractor Backhoe 655D has the highest compaction at 378 kPa, the second highest was the small tractor MF 240 at 235 kPa and the third or the lowest tyre compaction belonged to the medium tractor MF 5340 at 102 kPa.

Conclusions

Both soil water and external load significantly affected soil compaction as measured by soil bulk density, soil strength and soil water infiltration rate. There were significant interactions between soil water and external loads in increasing soil strength and soil water infiltration rate but the interaction was not significant for soil bulk density. The combined impact of soil water and external load on soil compaction demonstrates that soil should be worked at the lowest possible soil water contents and exposed to a minimum external load when conducting farm operations. Tyre load and inflation pressure are key factors and should be kept as low as practically possible during farm operation.

Acknowledgement

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