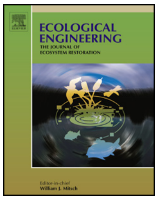
Ecological Engineering 106 (2017) 471–481

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng



Compaction conditions greatly affect growth during early plant establishment

C.T.S. Beckett[a,*], D. Glenn[a], K. Bradley[a], A.L. Guzzomi[c], D. Merritt[b], A.B. Fourie[a]

[a] School of Civil, Environmental and Mining Engineering, University of Western Australia, Perth, WA, Australia
[b] Botanic Gardens and Parks Authority, Kings Park and Botanic Garden, Perth, WA, Australia
[c] School of Mechanical and Chemical Engineering, University of Western Australia, Perth, WA, Australia

ARTICLE INFO

Article history:
Received 17 September 2015
Received in revised form 13 April 2017
Accepted 27 April 2017
Available online 15 June 2017

Keywords:
Soil compaction
Soil microstructure
root growth
cover design

ABSTRACT

Successful plant establishment is critical for the success of store/release cover systems. Such cover systems comprise several soil layers: highly compacted lower layers to isolate the waste; and nominally-loose upper layers to support vegetation. However, compaction of the upper layers under heavy machinery is often unavoidable, retarding plant growth and compromising the system's ability to capture infiltration.

It is well known that compaction at different water contents imparts differing soil microstructures as well as densities. However, how to take advantage of those microstructures to mitigate compaction's effect on plant growth has yet to be investigated. This paper presents results for the growth of *Avena sativa* (oats) under different compaction conditions. Seeds were planted in soil columns comprising a sandy or clayey soil or layers thereof and allowed to grow under controlled climatic conditions for seven weeks. Plants were then extracted to examine the effects of compaction on plant features (root length and mass and shoot mass). Soil apparent hydraulic conductivity (unvegetated) was also measured. Results showed that compaction at the optimum water content, typical of geotechnical practice, was the most detrimental for plant growth. Rather, plant growth was greatest for compaction conditions which imparted both a lower dry density and hydraulic conductivity, for example typical of compaction at water contents above optimum. Results therefore highlighted the need to consider all facets of compacted soil texture when estimating the likely success of plant establishment.

1. Introduction

Soil compaction is an important issue for modern store/release covers. Their primary function is to restrict net infiltration to reduce long-term seepage, acidification and oxidation of underlying waste (Rajesh et al., 2014). To achieve this, multiple soil layers are deposited and compacted to reduce their hydraulic conductivity. However, the store/release system relies upon an upper layer of vegetation to intercept infiltration, store it in the upper soil layers and release it via evapotranspiration (Campbell, 2004). Topsoil is placed in a nominally *uncompacted* state to maximise water storage capacity and evaporative loss during dry periods. However, in many cases, compaction is difficult to avoid due to the use of heavy plant, which can severely impact plant survivability (Unger and Kaspar, 1994; Cui et al., 2010; Lamandé and Schjønning, 2011a,b,c).

The effects of compaction on soil properties can be physical, chemical or biological. The most obvious physical effect is an increase in soil strength and a consequent reduction in the amount of friable substrate available to plant roots. Increased penetration resistance limits root exploration and can significantly alter root architecture as well as plant growth rates and seedling establishment (Henderson, 1989; Harrison et al., 1994; Rokich et al., 2001; Siegel-Issam et al., 2005; Benigno et al., 2012). Although some beneficial effects of compaction have been reported (e.g. increased nutrient transfer due to increased soil-root contact area, Carter (1990)), such effects are for levels of compaction below those commonly encountered in trafficked areas (Hamza and Anderson, 2005). Rather, compaction generally decreases soil fertility by reducing the store and supply of nutrients and water while reduced oxygen diffusion through the soil profile can result in denitrification and decreased micro-organism activity (Renault and Stengel, 1994).

For a given compactive effort (that is, the compacting energy delivered to the soil), a maximum soil dry density exists at a corresponding Optimum Water Content (OWC). Compaction water

---

[*] Corresponding author.
E-mail address: christopher.beckett@uwa.edu.au (C.T.S. Beckett).

http://dx.doi.org/10.1016/j.ecoleng.2017.04.053
0925-8574/

contents above or below this value produce lower dry densities for the same compactive effort. Reduced dry density either side of the OWC is due to changes in aggregate strength and soil suction. Dry of optimum, soils generally comprise small, strong aggregates of reduced deformability, preventing compaction. Wet of optimum (near and above field capacity), aggregates are large, highly saturated and deformable. Compaction under these conditions is restricted by high volumes of incompressible water (Cetin et al., 2007; Tarantino and De Col, 2008). Changes in aggregate strength with water contents above or below the optimum value result in different characteristic compacted microstructures (i.e. aggregate arrangement); generally, soils compaction dry of optimum comprise significant inter and intra-aggregate pore volumes whilst those compacted wet of optimum nominally comprise intra-aggregate pores only (Delage, 2010; Alaoui et al., 2011). A single dry density can therefore characterise multiple soil microstructures. Although limiting subsoil densities for root growth impedance have been suggested by several authors (Daddow and Warrington, 1983; Jones, 1983; Siegel-Issam et al., 2005; Dal Ferro et al., 2014), what effect changes in microstructure may have on root growth has not yet been considered.

This paper investigates the effect of changes in compaction water content and density on early root growth of *Avena sativa* (oats) in a sandy and a clayey Western Australian agricultural subsoil. Seeds were planted in growth columns comprising either a single soil or layers of both soils, compacted to different conditions on the Standard Proctor curve. Results demonstrated a significant effect of compaction condition on plant performance, doubling root and shoot mass between the most and least beneficial cases. The experimental programme used in this investigation is described in the following section, after which results are presented and discussed.

2. Experimental programme

2.1. Material selection and compaction conditions

Two soils were obtained from the Northam region of WA. Northam is classed as category Csa under the Köppen-Geiger Climate Classification and has a mean annual rainfall of 427 mm, predominantly falling in the winter months (June to August) (Australian Government Bureau of Meteorology, 2015). “Soil A” is a sand, obtained from an elevated site. “Soil B” is a clayey loam, obtained from a nearby valley (United States Department of Agriculture classifications). Both soils were overlain by a 100 mm layer of topsoil, which was removed prior to collection as per common geotechnical practice. Particle grading curves for Soils A and B are shown in Fig. 1.

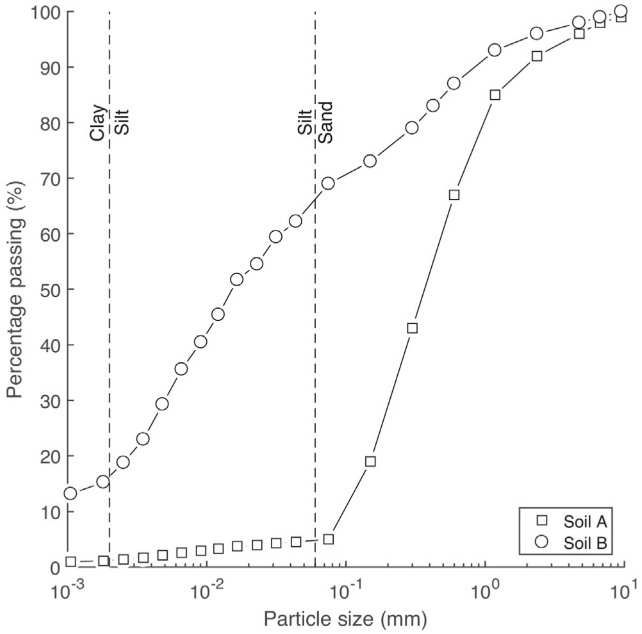


Fig. 1. Particle size distributions: Soil A (sand) and Soil B (clayey loam).

Compaction curves for both soils are shown in Fig. 2, determined using the Standard Proctor Test (SPT, AS1289.5.1.1, Standards Australia, 2003). Håkansson et al. (1988), Håkansson (1990) argued that the SPT overestimated compaction under 20th century agricultural vehicles. However, Suzuki and Reinert (2013) demonstrated that the SPT accurately captures compaction at a depth of roughly 100 mm beneath heavier 21st century vehicles, as might be used on remediation sites. The SPT is also familiar to geotechnical engineers, expediting comparison to existing engineering literature and practice. Hence, the SPT was selected to examine effects of compaction conditions on root growth. Compaction curves for Soils A and B are shown in Fig. 2. Four compaction conditions were tested per soil:

(1) $\rho_d = \rho_{d_{\max}}, w < \text{OWC}$

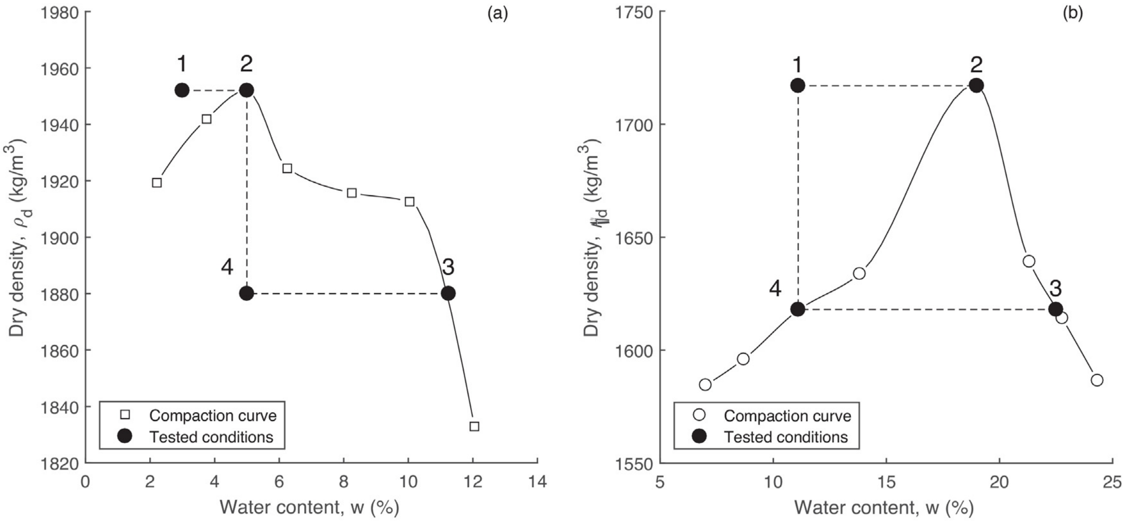


Fig. 2. Compaction curves: (a) Soil A; (b) Soil B. Testing compaction conditions 1, 2, 3 and 4 are also shown.