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Evaluation of the dynamic cone penetrometer to detect compaction in ripped soils

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ABSTRACT

Land degradation due to compaction is a critical issue facing 21st century agriculture. Deep ripping is a popular solution to remediate compacted Western Australian soils. However, these soils are particularly susceptible to recompaction under vehicle traffic: reliable methods to detect and monitor compaction are therefore needed to inform remediation strategies.

Cone penetrometer testing (CPT) is a popular method to detect compaction under vehicle traffic in a range of soil conditions. However, traditional CPT equipment is unsuitable for large-scale use due to its expense and bulk. Dynamic penetrometers circumvent this issue by being inexpensive and man-portable. Such devices have seen recent success in determining properties of soft geotechnical materials but little is known of their performance in ripped soils. This study evaluated the ability of the "PANDA 2" dynamic penetrometer to detect compaction in ripped soils after the passage of aMassey Ferguson four-tonne tractor, which was typical of vehicles used at the test site. Two test sites of contrasting soil types were identified which had previously been ripped and left fallow and untrafficked for several years. Penetration resistance was measured along a high-resolution grid prior to trafficking and after one and five vehicle passes and compared to results from trial pits. Laboratory testing also examined the device's accuracy at shallow depths under controlled conditions. Results showed that the PANDA 2 was able to detect significant changes in penetration resistance after trafficking. However, several limitations on the device's use when interpreting field data were identified. Based on the findings of this study, dynamic penetrometers are not recommended to monitor compaction in ripped soilsfor the weight of vehicle used here. However, the devices may be of use when examining the passage of heavier vehicles.

1. Introduction

Land degradation is an issue that is gaining recognition globally as a threat to food security. Causes of degradation are numerous: chemical factors, such as changing soil mineralisation and non-wetting behaviour; biological changes, such as variation in the soil organic content; and physical changes, such as soil erosion and compaction (Håkansson et al., 1988; Gretton and Salma, 1996; Hamza and Anderson, 2005). Degradation due to soil compaction, brought about through intensive cropping, short cropping cycles and increased vehicle and herd sizes, is of particular concern for Western Australia (WA), threatening over three quarters (roughly *eight million* hectares) of WA's agricultural land (Hall et al., 2010; Davies and Lacey, 2011).

"Deep ripping" is a popular technique to remediate soil compaction by shattering dense subsoil horizons and hardpans. Unlike ploughing, it does not invert the soil profile, but loosens it to reduce density (increase void space) and permit free movement of air (Ellington, 1987). Ripping is well suited for duplex soils (that is, soils whose lower horizons show an abrupt increase in clay content) as it elevates underlying clayey soil and buries water-repellent topsoil layers (Ellington, 1986). Although an expensive procedure, ripping has been shown to result in increased crop yields for Australian soils on a number of occasions (Davies et al., 2010; Hall et al., 2010). A disadvantage is that ripped soils are particularly susceptible to recompaction, particularly if controlled traffic practices cannot be employed due to practical or economic restrictions (Blackwell et al., 2013). Soil compaction states should therefore be monitored to employ ripping most effectively.

Cone penetrometer testing (CPT) is a popular method to assess the

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severity of soil compaction under traffic in virgin (Grunwald et al., 2001; Raper, 2005; Patel and Mani, 2011), tilled (Ehlers et al., 1983; Aase et al., 2001) and ripped soils (Ellington, 1986; Lardner and Tibbett, 2013). Several designs of penetrometer exist, however all fundamentally measure the force required to drive the device vertically down through the soil profile. Traditional CPT requires the use of a heavy vehicle from which the cone is driven into the ground at a constant velocity ("static" CPT). Such devices are not readily usable for agricultural land, in part due to their weight and effect on compaction but also their cost (Herrick and Jones, 2002). Manual static penetrometers exist but skill is needed in their operation to control penetration speed. The "dynamic" penetrometer was developed to circumvent these issues. In dynamic cone penetrometer testing (DCPT), the device is driven into the ground by repeated hammering; the kinetic energy delivered to the device is used to determine soil resistance when combined with device parameters (e.g. cone diameter and angle, etc.). The first dynamic penetrometers were designed to operate with an automated hammer, delivering constant kinetic energy per blow: the large accompanying rigs were unsuitable for agricultural work. Modern designs, however, are hand-held and can be used by a single operator manually delivering hammer blows. As such, they are suitably mobile (and inexpensive) to be deployed for use in soft soils, for example mine tailings (Villavicencio and Lemus, 2013), railway ballast (Cui, 2016) and temporary working platforms (Kazmee et al., 2016).

Penetrometer resistance, q_c (or q_d for DCPT), is affected by soil density and so can give a measure of soil compaction when compared to historic data; it cannot be converted to density directly as resistance is also strongly affected by soil composition and water content (Yu and Mitchell, 1998; Pournaghiazar et al., 2013; Robertson and Cabal, 2015). Although some precautions are taken to ensure similar water contents with depth (e.g. Henderson et al., 1988), penetrometer results are likely to remain highly variable in tilled or ripped soil where fractured elements of differing density and water retention might persist (Dexter, 1997).

This paper examines the ability of a hand-held, single-operator "PANDA 2" dynamic penetrometer (Sol Solution, 2012) to detect compaction in ripped agricultural soils. Two sites of differing soil types were identified which had previously been ripped and left fallow for two years. DCPT results were obtained prior to traffic and following one and five passes of an agricultural vehicle and compared to density and water content measurements from trial pits. DCPT repeatability was also assessed via laboratory testing under controlled conditions. The experimental programme is described in the following section, after which results from the study's laboratory and field components are presented and implications for compaction detection using DCPT discussed.

2. Experimental procedure

2.1. Site selection

The "Eco Restoration" zone (ER) at The University of Western Australia (UWA) Farm Ridgefield was used for testing. The region has a Köppen-Geiger climate classification of Csa (temperate with distinctly dry and hot summers), which is typical of the Western Australian wheat belt (Peel et al., 2007), and experiences a mean annual average rainfall of 426 mm, predominantly in the winter months (Australian Government Bureau of Meteorology, 2015). The predominant soil types are loamy sands with sandy clays (United States Department of Agriculture classifications) present in a strip through the centre of the site. Two test areas, A and B, of contrasting soil types were identified: both were deep ripped to a depth of approximately 300 mm in 2010 and then left fallow and untrafficked. Rip lines were spaced at approximate 2 m intervals (Perring et al., 2012). Soil cores at Sites A and B, obtained during the ER project, indicated a soil depth in excess of 1.9 m with similar soil textures throughout. Sites were orientated to allow traffic to follow a constant contour. The ER zone and the locations and orientations of Sites A and B are shown in Fig. 1.

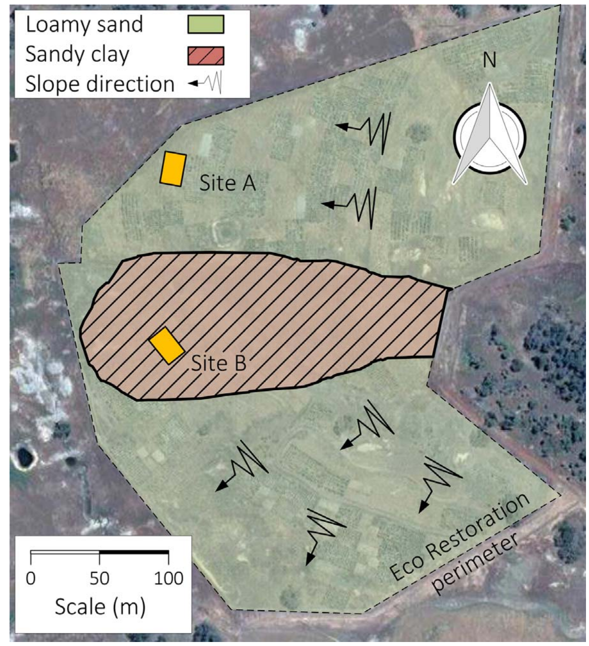

Fig. 1. Aerial view of the UWA Farm Ridgefield Eco Restoration zone, showing soil types and test sites A and B.

Fig. 2. PANDA 2 operation on soft soil. The operator (left) has the mallet in his hand. The logger (bottom right) displays calculated resistance in real time. All equipment fits into the carrying case for transport.

2.2. Field testing

A hand-held "PANDA 2" DCPT device (90° cone angle, projected cone area 200 mm^2, ∅16 mm head, ∅14 mm shaft), capable of measuring cone resistances $q_d \leq 30$ MPa, was used to measure dynamic penetration resistance before and after the passage of an agricultural

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