Available online at www.sciencedirect.com
ScienceDirect
Soil & Tillage Research 97 (2007) 249–255
Soil & Tillage Research
www.elsevier.com/locate/still

Amelioration of soil compaction can take 5 years on a Vertisol under no till in the semi-arid subtropics

B.J. Radford [a,*], D.F. Yule [b], D. McGarry [c], C. Playford [d]

[a] Queensland Department of Natural Resources and Mines, Locked Mail Bag No. 1, Biloela, Qld 4715, Australia
[b] CTF Solutions, 56 Iona Terrace, Taringa, Qld 4068, Australia
[c] Queensland Department of Natural Resources and Mines, Meiers Road, Indooroopilly, Qld 4068, Australia
[d] Queensland Department of Primary Industries and Fisheries, P.O. Box 6014, Rockhampton, Qld 4702, Australia

Received 18 August 2005; received in revised form 6 January 2006; accepted 28 January 2006

Abstract

Heavy wheel traffic causes soil compaction, which adversely affects crop production and may persist for several years. We applied known compaction forces to entire plots annually for 5 years, and then determined the duration of the adverse effects on the properties of a Vertisol and the performance of crops under no-till dryland cropping with residue retention. For up to 5 years after a final treatment with a 10 Mg axle load on wet soil, soil shear strength at 70–100 mm and cone index at 180–360 mm were significantly ($P < 0.05$) higher than in a control treatment, and soil water storage and grain yield were lower. We conclude that compaction effects persisted because (1) there were insufficient wet–dry cycles to swell and shrink the entire compacted layer, (2) soil loosening by tillage was absent and (3) there were fewer earthworms in the compacted soil. Compaction of dry soil with 6 Mg had little effect at any time, indicating that by using wheel traffic only when the soil is dry, problems can be avoided. Unfortunately such a restriction is not always possible because sowing, tillage and harvest operations often need to be done when the soil is wet. A more generally applicable solution, which also ensures timely operations, is the permanent separation of wheel zones and crop zones in the field—the practice known as controlled traffic farming. Where a compacted layer already exists, even on a clay soil, management options to hasten repair should be considered, e.g. tillage, deep ripping, sowing a ley pasture or sowing crop species more effective at repairing compacted soil.

Keywords: Amelioration; Compaction; Cone index; Soil shear strength; Soil water storage; Grain yield

1. Introduction

Compaction-induced soil degradation affects about 68 million hectares of land globally, principally as a result of vehicular traffic (Flowers and Lal, 1998). Research on compaction has revealed a number of facts. During a single cropping cycle, more than 100% of ground area is trafficked by the tyres of heavy machinery under conventional tillage, 60% under minimum tillage and 30% under no tillage (Tullberg, 1990). The first pass of a wheel causes most compaction (Alakukku, 1996). Damage from wheels under high axle loads increases on wet soil because its strength is reduced (Kirby and Kirchhoff, 1990). This is unfortunate because tillage and harvest operations commonly need to be done on wet soil. Compaction is often associated with a decrease in crop yield because it results in restricted movement of water, air and roots (Voorhees et al., 1985).

* Corresponding author. Tel.: +61 7 49929106; fax: +61 7 49923468.
E-mail address: bruce.radford@nrm.qld.gov.au (B.J. Radford).

0167-1987/$ – see front matter
doi:10.1016/j.still.2006.01.005

Various processes help alleviate compaction. In the surface soil, both tillage and natural processes may be brought to bear. Below tillage depth, natural processes such as freezing/thawing, drying/wetting and biological activity are the usual means of alleviating compaction (Håkansson et al., 1987). Deep loosening is another option but it is expensive, seldom ameliorates the compacted structure completely, and the loosened soil is often recompacted within a few years (Kooistra and Boersma, 1994). It is also possible to use management practices to enhance the natural processes of compaction amelioration at depth. For example, planting a ley pasture or cropping more frequently on a clay soil with swell–shrink potential can increase the number of wet–dry cycles (Pillai and McGarry, 1999). Also conservation tillage can increase earthworm numbers (McGarry et al., 2000), which hastens amelioration because it increases burrowing activity in the soil (Zund et al., 1997). Conservation tillage also increases rainfall infiltration (Radford et al., 1995), thus resulting in greater potential for soil wetting at depth.

Subsoil compaction has been long-lived in countries outside Australia and has persisted on a broad range of soils for 3–11 years after the application of high axle loads (Blake et al., 1976; Gaultney et al., 1982; Voorhees et al., 1986; Gameda et al., 1987; Lowery and Schuler, 1991; Logsdon et al., 1992; Etana and Håkansson, 1994). Vertisols, with their combination of high clay content and a large proportion of swelling clays, have inherent properties to facilitate repair (Pillai and McGarry, 1999) and would be expected to undergo rapid amelioration.

Penetrometers provide the best estimates of resistance to root growth in soil, short of direct measurement of root force (Bengough and Mullins, 1990). Kirkegaard (1990) reviewed the effect of soil strength on root growth for a range of species and concluded that in general, root elongation in most species is reduced by 50% at penetrometer resistances of 0.7–1.5 MPa and is restricted completely at resistances greater than 4 MPa.

This paper describes the adverse effects of a series of applied compaction treatments on the physical properties of a Vertisol and on crop performance in central Qld, Australia. Effects were measured firstly during a 5-year phase when compaction and repair treatments were being applied, and secondly during a regeneration phase when no further compaction or tillage treatments were carried out. During the regeneration phase, all measurements were taken in unwheeled areas between sets of permanent wheeltracks.

2. Materials and methods

The study was conducted for 10 years in a semi-arid environment at Biloela, Qld, Australia (24°22′S, 150°31′E) on a Vertisol (50% clay, 28% silt and 20% sand at 0–1.2 m), FAO UNESCO unit: Chromic Vertisol. The clay fraction was dominated by smectites. The mean annual rainfall is 680 mm and mean annual evaporation (from a class "A" pan) is 1870 mm.

The design was a split-plot with two replications of two irrigation treatments (raingrown, supplementary irrigation at crop anthesis) with each main plot split into 8 subplots: 4 compaction treatments × 2 fertiliser treatments (control, N-fertilised). Each plot was 30 m × 9 m. (The design also included three amelioration treatments but these are not reported here.) There was an initial 5-year phase (with compaction/repair treatments) followed by a regeneration phase (with no further applied compaction between the permanent wheel tracks and no tillage).

Cultural operations were done with wheels spaced 3 m apart on permanent wheel tracks. In recognition of the fact that the first wheel pass causes most compaction (Alakukku, 1996) and more than 100% of ground area is trafficked during one cropping cycle under conventional tillage (Tullberg, 1990), a single pass of each compaction treatment was applied to the entire areas between the permanent wheel tracks.

The four treatments during the initial compaction application phase were:

- control: no applied compaction, reduced tillage;
- 10 Mg wet: compaction with a 10 Mg axle load on wet soil (25–32% soil water at 0–100 mm) on six occasions (at 0, 0.7, 1.6, 2.7, 3.7 and 4.7 years), no tillage;
- 6 Mg wet: compaction on wet soil with 10 Mg initially and 6 Mg on the other five occasions, tillage for all weed control with a chisel plough or scarifier;
- 6 Mg dry: compaction on wet soil with 10 Mg initially and on dry soil (<22% soil water at 0–80 mm) with 6 Mg on the other five occasions, reduced tillage (only when the soil was dry).

An initial compaction treatment (10 Mg on wet soil) was applied to all but the control (C0) plots on "Day 1" of the experiment (to measure the repair of this single compaction application in all seven treatments.) Final compaction treatments were applied 4.7 years after Day 1, after which all treatments were managed with no tillage (herbicides were used for all weed control). Compaction repair was measured in the untrafficked areas between sets of permanent wheel tracks.