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Soil structure in permanent beds under irrigated cotton-based cropping systems in a Vertisol

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ABSTRACT

Much of the research pertaining to soil structure in Australian cotton (*Gossypium hirsutum* L.) farming systems has been conducted using cropping systems where cotton was followed by a single rotation crop such as wheat (*Triticum aestivum* L.) and a lengthy fallow. Research on systems where the fallow was very short or absent is sparse. The objective of this study was to quantify soil structure within beds in an irrigated Vertisol by assessing the changes in shrinkage curve indices caused by (a) imposing permanent bed systems in a site that had been under intensive tillage, and (b) eliminating or shortening fallow periods in cotton-based crop rotations by sowing vetch (*Vicia* spp.). Shrinkage curve indices in Vertisols are indicators of soil structure degradation such as compaction. The experimental treatments sown on permanent beds were: cotton monoculture, CC; cotton-vetch (*Vicia* spp.), CV; cotton-wheat, CW where wheat stubble was incorporated into the beds after harvest with a disc-hiller; and cotton-wheat-vetch, CWV where wheat stubble was retained as an *in-situ* mulch into which the following vetch crop was sown. Soil clods were extracted during September 2002 from soil pits. Clods were also sampled with a spade during September 2009 and 2010 from the beds in every plot. The field-moist clods were coated with saran resin dissolved in ethyl-methyl ketone (2002) or paraffin wax (2009, 2010). As the clods dried, soil specific volume was determined at various soil water contents. Soil specific volume was plotted against soil water content, and linear functions fitted to the zones of structural, normal and residual shrinkage, and several shrinkage indices determined. Average soil specific volume of oven-dried soil was 0.58 $m^3 Mg^{-1}$ with CV, 0.65 $m^3 Mg^{-1}$ with CC, 0.62 $m^3 Mg^{-1}$ with CW and 0.58 $m^3 Mg^{-1}$ with CWV (SEM = 0.005, $P < 0.001$). Soil compaction in beds was less in cropping systems that had a lengthy fallow (CC, CW) than in those that had no or a very short fallow (CV, CWV). Higher compaction in the latter systems may be due to management practices associated with the vetch component. The virtual elimination of the fallow was, however, beneficial in wet years as it reduced potential soil structural degradation under wet conditions, presumably due to the drier conditions under a growing crop.

1. Introduction

Sowing winter cereal or leguminous crops in rotation with cotton (*Gossypium hirsutum* L.) (cotton-winter rotation crop-summer and winter fallow-cotton) to improve soil physical quality of Vertisols is a common practice in irrigated Australian cotton farming systems (Hulugalle and Scott, 2008). The objective of sowing rotation crops is to enhance the frequency and intensity of wet/dry cycles in these soils, and thus, improve soil structural attributes (Sarmah et al., 1996; Pillai and McGarry, 1999; McHugh et al., 2009). Wheat (*Triticum aestivum* L.) is reported to be more effective than legumes in ameliorating soil compaction under field conditions whereas the latter may improve aggregate stability (Hulugalle and Scott, 2008). Pillai and McGarry (1999), however, in a greenhouse study, suggested the opposite. Much of the research pertaining to soil structure in Australian cotton farming systems has been conducted using cropping systems where cotton was followed by a single rotation crop and a lengthy (≥6 months) fallow (McGarry and Daniells, 1987; Daniells, 1989; McKenzie et al., 1990; Constable et al., 1992; Hulugalle and Scott, 2008). Research on systems where the fallow was very short or absent (*i.e.* cotton-winter rotation crop-summer rotation crop-short fallow or winter rotation crop-cotton or cotton-winter rotation crop-cotton) is sparse. Under irrigated conditions, elimination of the fallow by

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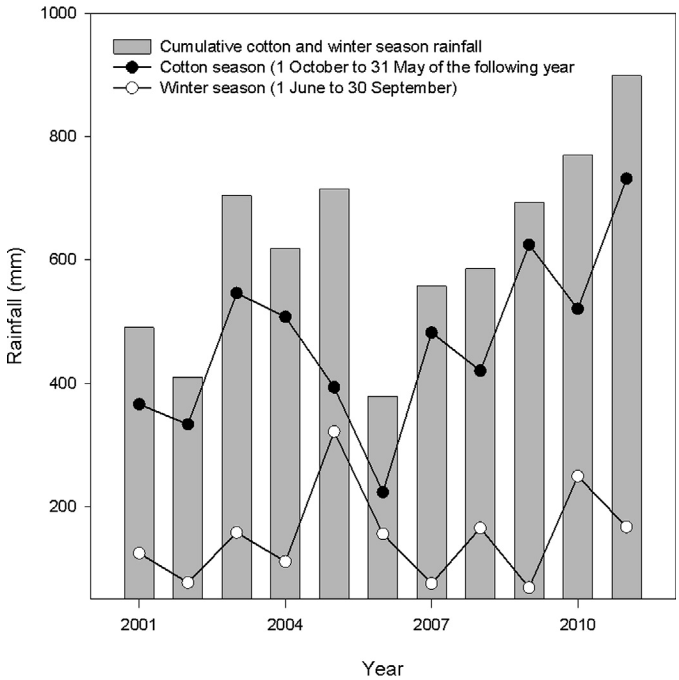

Fig. 1. Variations in seasonal rainfall, 2001–2011.

sowing vetch (*Vicia villosa* Roth., *Vicia benghalensis* L.) in cotton-based farming systems had either a very small or negligible impact on subsequent cotton yields and greenhouse gas emissions per unit of lint produced, reduced N fertiliser requirements and excessive drainage and no effect on seedling diseases of cotton (Rochester and Peoples, 2005; Hulugalle et al., 2012b). However, where the fallow was replaced by maize (*Zea mays* L.) cotton yield was increased and CO_2-e emissions per unit of lint produced and cotton seedling disease incidence were reduced (Hulugalle et al., 2014). Hence, there appears to be a potential to increase productivity of irrigated Vertisols by eliminating or reducing the traditional fallow. The effect of eliminating fallow on soil structure has not, however, been previously reported. This report is the first one that describes soil structural changes associated with fallow elimination in cotton farming systems.

Appropriate crop rotations when combined with minimum tillage practices such as "permanent beds" are known to further improve soil physical quality in a range of farming systems and soil types (McGarry and Daniells, 1987; Daniells, 1989; McKenzie et al., 1990; McHugh et al., 2009; Boulal et al., 2011; Li et al., 2014; Antille et al., 2016). "Permanent beds" are raised beds that preserve the same wheel tracks and remain in place for several seasons before renovation or realignment requires them to be ploughed down and reconstructed), although some pre-sowing light cultivation may be necessary to renovate or reshape beds (McKenzie et al., 1990). Bed disturbance is also necessary to destroy heliothis (*Helicoverpa* spp.) pupae, a major insect pest of cotton (Hulugalle et al., 2011). Research over the past four decades has indicated that permanent beds can result in significant improvements to both surface and subsoil structure in Vertisols (McKenzie et al., 1990; Constable et al., 1992; McHugh et al., 2009; Antille et al., 2016).

The objective of this study, therefore, was to quantify soil structure within beds in an irrigated Vertisol with a dispersive and sodic sub-soil by assessing the changes in shrinkage curve indices caused by (a) imposing permanent bed systems in a site that had been under intensive tillage, and (b) eliminating or shortening fallow periods in cotton-based crop rotations by sowing vetch. Observations were made in a long-term experiment on cotton cropping systems located at the Australian Cotton Research Institute, near Narrabri, NSW, Australia.

2. Materials and methods

2.1. Site

The experiment was located at the Australian Cotton Research Institute (ACRI), near Narrabri (149°47′E, 30°13′S) in New South Wales (NSW), Australia. Narrabri has a sub-tropical semi-arid climate, BSh (Kottek et al., 2006) and experiences four distinct seasons with a mild winter and a hot summer. The hottest month is January (mean daily maximum of 35 °C and minimum of 19 °C) and July the coldest (mean daily maximum of 18 °C and minimum of 3 °C). Mean annual rainfall is 593 mm. Cotton and winter season rainfall during the experiment are summarised in Fig. 1. The soil at the experimental site was a fine, thermic, smectitic, Typic Haplustert (Soil Survey Staff, 2010). Soil properties in the 0–0.1 m, 0.1–0.3 m, 0.3–0.6 m and 0.6–1.2 m depths at the commencement of this study during September 2002 are summarised in Table 1.

2.2. Site history

Prior to the commencement of this experiment in October 2002, the site had been conventionally-tilled and sown with a cotton-wheat rotation (summer cotton-winter wheat-summer and winter fallow-summer cotton). This involved incorporating cotton stubble after picking with two passes of a disc-plough at (or to) a depth of ~0.2 m, followed by two passes to depth of ~0.3 m with a chisel plough. Wheat was usually sown on the flat, but in some years when irrigation was necessary it was sown with an air-seeder on 1-m beds were constructed with a listering rig (bed-furrow maker or ridger). Seedbed preparation involved 1–2 passes with a cultipacker. After wheat harvest, the stubble was incorporated with two passes of a disc-plough a depth of ~0.2 m and 1-m beds constructed with a listering rig. Before sowing cotton, the bed surfaces were smoothed by cultivating with a Lilliston cultivator (http://www.excelagr.com.au/excel-agri-rc-rolling-cultivator.php). A Kinze planter (http://www.kinze.com/planters.aspx) was used to sow cotton. All machinery was adjusted to a width of 4-rows.

Table 1
Soil properties in the 0–0.1 m 0.1–0.3 m, 0.3–0.6 m and 0.6–1.2 m depths during September 2002. pH was measured in 0.01 M $CaCl_2$. $EC_{1:5}$, electrical conductivity of a 1:5 soil: water suspension; ESP, exchangeable sodium percentage; ESI, electrochemical stability index ($EC_{1:5}$/ESP).

Depth	Clay	Silt	Sand	Plastic limit (g 100 g^{-1})	Soil organic carbon	pH	$EC_{1:5}$ (dS m^{-1})	Exch. Ca (cmol kg^{-1})	Exch. Mg	Exch. Na	Exch. K	CEC	ESP	ESI
0–0.1	62	13	25	27	0.83	6.8	0.36	24	13	0.9	1.6	39	2	0.16
0.1–0.3	64	9	27	27	0.64	7.0	0.25	22	13	1.1	1.2	37	3	0.08
0.3–0.6	65	10	25	26	0.51	6.9	0.24	20	15	2.2	0.8	37	6	0.04
0.6–1.2	65	12	23	26	0.47	7.3	0.26	16	15	4.1	0.8	36	12	0.02