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Short communication

Soil mixing and redistribution by strategic deep tillage in a sandy soil

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ABSTRACT

Strategic deep tillage (SDT) is proposed as a single or occasional practice to help sustain the long-term productivity of the no-till system. Soil water repellence, herbicide resistant weeds, subsoil acidity and compaction are constraints that can evolve in long-term no-till systems and SDT may provide an effective solution for these. While the effect of SDT on the lateral and vertical movement of soil is understood, soil heterogeneity and mixing caused by SDT is not. Soil mixing may be an important factor for the availability of soil nutrients after SDT or for the effectiveness of soil amendments. Soil mixing and redistribution were quantified using coloured soil tracers and digital image analysis. Trenches of synthetic coloured soil were installed at four depths at a field site and four tillage treatments were applied; offset disc harrow and deep ripping (DHDR), disc plough (DP), mouldboard plough (MP) and rotary spader (RS). Digital images were acquired for soil pit faces at 5 cm intervals to capture the location of the coloured soil after SDT, these images were segmented and the 3-dimensional distribution of the coloured soil tracers was reconstructed. The mixing indices for the tillage treatments were low level (0.04–0.12). The vertical movement of soil differed between treatments; approximately 80, 60, 60 and 10% of soil from 0 to 10 cm was redistributed to deeper soil layers by MP, DP, RS and DHDR respectively. The soil profiles after the SDT treatments were composed of layered, or rotated soil that had been translocated within the working depth of the implement; however, there was some mixing at the interface between layers, or seams of soil that originated from different depths. The impact of a change in the spatial distribution of soil nutrients created by SDT on crop growth is an important knowledge gap.

1. Introduction

Strategic deep tillage (SDT) may provide an effective solution to soil constraints that evolve in long term no-till crop production systems. The lack of soil disturbance in no-till systems can contribute to: an accumulation of hydrophobic organic compounds on the soil surface leading to soil water repellence (Roper et al., 2015), subsoil acidity due to the slow rate of movement of surface-applied lime to the subsoil (Ebelhar et al., 2011), development of herbicide resistance in weeds due to a greater reliance on herbicides for weed control (Llewellyn and Powles, 2001; Owen et al., 2007; Powles, 2008) and a build-up of soil and stubble-borne diseases (Dang et al., 2015). Soil compaction by machinery is also likely in long-term crop production systems (Hamza and Anderson, 2005). SDT is proposed as a single, or occasional practice (> 4 year intervals) with a mouldboard plough, rotary spader, deep ripper or disc plough to ameliorate one or more soil constraints in one operation, to sustain the long-term productivity of the no-till system (Kuhwald et al., 2017; Renton and Flower, 2015; Rincon-Florez et al., 2016).

The yield benefit of SDT has been demonstrated but little is known about whether changes to the distribution of soil nutrients, organic matter and texture within the root zone require a change in agronomic management in the long term (Roper et al., 2015). For example, the average wheat yield benefit from SDT on water repellents soils in Western Australia was 0.6 t ha^{-1} at 12 sites for rotary spading and was 0.5 t ha^{-1} at 16 sites for mouldboard ploughing where SDT had been implemented less than three years previously (Davies et al., 2012; Roper et al., 2015); however, the impact on SDT on soil nutrient supply, and whether additional yield gains could be achieved by a change in nutrient management is unknown. The redistribution of top- and subsoil within the root zone may affect the agronomic management that is required to maximise productivity; the level of heterogeneity of soil nutrients influences their availability to crop plants (Ma et al., 2007, 2011) and root growth (Hodge, 2004; Robinson, 1994), and the heterogeneity of soil physical properties influences soil water flow (Coquet et al., 2005).

Knowledge on soil heterogeneity caused by SDT, and its implications for agronomic management, is being constrained by methods used

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to measure it. Bead tracers have been used to quantify the vertical (Mohler et al., 2006) or lateral movement and dispersion of soil by tillage (Van Oost et al., 2000) by measuring their position post tillage in relation to their position pre-tillage. Similarly, coloured limestone was used as a tracer to measure the vertical and upslope / downslope redistribution of soil by tillage (Logsdon, 2013). While these methods provide valuable information on the vertical or horizontal movement of soil by tillage, it is difficult to assess soil heterogeneity, mixing of soil originating from different depths and to visualise the post-tillage soil profile because these point-based measurements provide limited data on the movement of the whole soil profile within the working depth of the tillage implement.

To gain a better understanding of soil heterogeneity caused by SDT, a new method was developed based on digital image analysis and coloured soil tracers. Here, we report the method and its implementation at a field site. This method enabled a 3-dimensional (3D) analysis of soil redistribution to be done and the use of a soil mixing index to quantify the mixing of soil originating from different depths by SDT.

2. Methods

2.1. Site description

The experiment was located near Moora, Western Australia (30°41′17.03″S, 115°48′4.50″E). The soil at this site (near Site MRA 9, McArthur, 2004) is classified as a Red-Orthic Tenosol in the Australian Soil Classification (Isbell, 2002) or a Cambic Arenosol in the World Reference Base for Soil Resources (IUSS Working Group WRB, 2015). The soil texture was sand from 0 to 40 cm depth. The site had been used for canola production in the year preceding the experiment.

2.2. Experimental design

The design included four tillage treatments: disc harrow followed by deep ripping (DHDR), disc plough (DP), mouldboard plough (MP) and rotary spader (RS). DHDR was applied in two operations; first, an International 3-3 disc harrow fitted with 55 cm discs with a working depth of approximately 10 cm was used and second, an Agrowplow deep ripper with a working depth of approximately 30 cm was used. The disc harrow and deep ripping operations were conducted in the same direction. DP was a McCormick International A1-41 4-disc plough fitted with 65 cm discs with a working depth of approximately 30 cm. MP was a three-furrow Kvernerland mouldboard plough fitted with skimmers and had a working depth of approximately 30 cm. RS was a Farmax 4.5 m trailed rotary spader with a working depth of approximately 25 cm. This treatment was ripped to 35 cm with the Agrowplow deep ripper before the trenches of coloured soil were installed (see below). The tillage treatments were arranged as parallel strips. After the tillage treatments were completed, all treatments were levelled with a rubber-tyred roller to prepare the surface for sowing a wheat cover-crop with a 1.8 m wide plot seeder fitted with no-till seeding points.

A synthetic coloured soil was installed at the field site in May, prior to the cultivation treatments. The synthetic soil was created by mixing a colour-coated sand with kaolinitic-clay at a ratio of 10:1 by weight to produce a soil that had similar physical properties the field soil (Table 1). The synthetic and field soil were structureless with predominately single grain arrangement of soil particles. The coloured sand had a particle density of 2.6 g cm^{-3} and was obtained from a commercial supplier (http://www.rainbowquartz.com.au/) in green and blue to create a synthetic green-coloured (green soil) and blue-coloured (blue soil) soil.

The coloured soil was installed at two sites (Sites A and B) in each of the cultivation treatments (Fig. 1). It was installed in narrow trenches where the long edge was positioned perpendicular to the direction of ploughing and sowing. At site A, a trench 100 cm wide, 10 cm long and 30 cm deep was excavated using a narrow trenching shovel. A 10 cm layer of green soil was installed at 20 to 30 cm, followed by a layer of field soil (soil excavated from the trench) at 10 to 20 cm and a layer of blue soil at 0–10 cm. At site B, a trench 100 cm wide, 10 cm long and 40 cm was excavated. A 10 cm layer of green soil was installed at 30 to 40 cm, followed by a layer of field soil at 20 to 30 cm, a layer of blue soil at 10 to 20 cm and finally a layer of field soil at 0–10 cm. The use of two sites within each tillage treatment, and two tracer colours, allowed the movement of soil from three depths (0–10, 10–20, and 20–30 cm) to be quantified. For each tillage treatment, sites A and B were spaced 10 m apart to avoid coloured soil tracer from Site A being carried forward to Site B by the tillage operation (Fig. 1). The coloured and field soil was weighed and packed to achieve a bulk density of 1.5 cm^{3} to match the bulk density measured at 0 to 10 cm at this site.

Table 1
Physical properties of the soil the experiment site and the synthetic coloured soil. Texture of soil from the experiment site was determined from particle size analysis and the Australian texture classes (Minasny and McBratney, 2001). Texture of the blue and green soil was determined using the method by McDonald et al. (1998).

	% sand (2000 to 50 μm)	% silt (50 to 2 μm)	% clay (< 2 μm)	Soil bulk density (g cm^{-3})	Texture	Angle of repose (%)
Site 0 to 10 cm	93	0	7	1.5	Sand	32
Site 10 to 20 cm	93	1	6	1.6	Sand	33
Site 20 to 30 cm	93	0	7	1.6	Sand	33
Site 30 to 40 cm	91	2	7	1.6	Sand	33
Blue soil	–	–	–	1.5	Sand	32
Green soil	–	–	–	1.5	Sand	32

2.3. Agronomic management

All treatments received the same agronomic management. Wheat (*Triticum aestivum* cv. Carnamah) was sown on 4th June 2014 at 80 kg seed ha^{-1}, with 14 and 16 kg ha^{-1} of N and P respectively drilled 3 cm below the seed as diammonium phosphate. A further 17 kg N ha^{-1} was applied to the soil surface as urea (46% N) at sowing. No crop measurements were made. The treatments were sown with wheat one week after the tillage treatments were applied to prevent wind erosion and help stabilise the soil for excavation and preparation of the pit face for photography; root systems improve the mechanical stability of soil (Preti and Giadrossich, 2009). The soil pits were excavated and the image capturing was done when the wheat crop was mid-flowering.

2.4. Soil measurements

Standard methods were used for soil physical and mechanical analysis. Soil bulk density using the core method (Grossman and Reinsch, 2002), particle size distribution (Indorante et al., 1990) and angle of repose (Ucgul et al., 2014) were measured.

2.5. Image capture and processing

A series of digital images were acquired for all tillage treatments and sites to capture the 3D distribution of the coloured soil tracer. At each site, a pit approximately 100 cm deep, 200 cm wide and 200 cm long was excavated in September with a mini-excavator and the pit face was prepared for photography manually. The location of the pits in relation to the placement of the coloured soil and the direction of tillage is shown in Fig. 1. The large pit size allowed the photographer to position the camera at about 30 cm below ground level and to have an unobstructed view of soil in the working depth of the implements. The