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Strategic tillage on a Grey Vertosol after fifteen years of no-till management had no short-term impact on soil properties and agronomic productivity

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ABSTRACT

Over half of the arable land in the northern grains region of Australia is managed using no-till (NT), a farming method which has improved crop yields and soil quality while reducing the input and labour costs. However, concerns have arisen among farmers over the control of weeds in continuous NT systems. An occasional targeted tillage operation (termed strategic tillage — ST) has been proposed as a management tool to reduce problem weed populations but may adversely influence soil properties and those of associated microbial communities. To assess the potential impacts of a ST operation on soil properties, a Grey Vertosol with fifteen years of NT in Northern New South Wales, Australia was tilled using either a chisel cultivator or disc chain on March 15th 2013 or on April 5th 2013. We hypothesised that ST using these minimal or low soil inversion implements at either timing would not adversely influence soil properties in the short-term (4–7 weeks). The measured soil properties were soil volumetric moisture content (VMC), pH, bulk density (BD), electrical conductivity (EC), available phosphorus (P), soil organic carbon (SOC), microbial biomass carbon (MBC), metabolic activity (MA), genetic structures of bacterial communities and wheat yield (t ha^{-1}). We found that ST with either a chisel cultivator or a disc chain has great potential to assist in weed management as it did not statistically influence crop productivity or the physical, chemical and biological properties of the soil, regardless of the tillage timing.

1. Introduction

No-till (NT), as a sustainable agricultural practise, has experienced an increasing rate of adoption during the last decade, and is currently being practised on over 125 million hectares of arable land worldwide (Friedrich et al., 2012). Within Australia in 2014, NT farm management was employed on 17 million hectares, accounting for 13.6% of the world's NT cropping lands (FAO, 2014). NT has led to many benefits in cost-effectiveness (less fuel and labour), crop productivity (increase in crop yield) and environmental improvements, such as increased organic carbon, reduction in soil erosion and increases in soil biological biodiversity (Bayer et al., 2006; Dang et al., 2015b; Triplett and Dick, 2008).

However, long-term NT soils are prone to problems such as soil compaction, nutrient stratification in surface layers of the soil profile, stubble- or soil-borne diseases and prevalence of herbicide-resistant weeds (Dang et al., 2015b). In Australia, herbicide-resistant weeds have become a major threat to agricultural productivity. A survey carried out in 2008 by the Australian Grains Research and Development Corporation indicated that widespread herbicide-resistant weeds along with the increased price of herbicides has led many farmers to apply occasional tillage operations to combat weeds in their NT farms (Llewellyn and D'Emden, 2010). Strategic tillage (ST), which refers to the practise of occasional tillage utilising a variety of implements and timings, may address these problems without compromising the benefits of NT. Yet, tillage in any form will inevitably change the soil physical, chemical properties and the habitats of soil biota. It is this change and the impact on productivity that needs to be assessed to fully understand the risks associated with ST.

The impact of ST largely depends on the tillage implement used. For instance, tillage with a mouldboard plough (MP) is reported to cause greater impacts on soil properties as compared with chisel or disc (Dang et al., 2015b). However, even destructive ST operations with a MP have produced variable results. Either negative and positive impacts (Grandy and Robertson, 2006; López-Garrido et al., 2011; Melero et al., 2011; Pierce et al., 1994) or no changes (Kettler et al., 2000; Wortmann et al., 2010) have been reported from the imposition of ST on soil quality

Abbreviations: CCM, chisel cultivator on March 15th, 2013; DCM, disc chain on March 15th, 2013; CCA, chisel cultivator on April 5th, 2013; DCA, disc chain on April 5th, 2013.
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and productivity. A common theme of the aforementioned studies was the use of a MP, which is representative of industry standards for the trial locations within America and Europe. Implements which cause less/minimal soil inversion such as disc, tine and chisel tillage are commonly used in the northern grain-growing regions (NGR) of Australia (Dang et al., 2015b). The impacts on the physical and chemical soil properties and especially the change in habitats of soil biota regarding the use of these implements for ST are largely unknown.

To address this, a base level of information is required on soil microbial biomass carbon (MBC), microbial activity and genetic structure of the microbial communities in different soil types and climatic conditions. Recent reviews by Dang et al. (2015a, 2015b) and research by Crawford et al. (2015) and Liu et al. (2016) have begun to explore the possible impacts of ST in NT systems in different soil types and climatic regions. Crawford et al. (2015) stated that soil total microbial activity (TMA) was not affected by ST when utilising less/minimal soil inversion implements. This study however, did not explore the tillage effects on soil MBC and the composition of bacterial communities, and therefore knowledge gaps need to be explored to better understand the impacts on different soil types.

The primary aim of this study was to identify possible impacts of timing and the type of tillage implement used in a ST on a long-term NT farm with regards to soil productivity, physical, chemical and biological properties. Based on the fact that disc chain and chisel cultivator are tillage implements that produce minimal soil inversion compared to a MP, our hypothesis is that ST using these two implements would not change soil properties and agronomic productivity even in the short-term. In conjunction with the widely used soil parameters of volumetric moisture (VCM), pH, bulk density (BD), electrical conductivity (EC), available P, and total soil organic carbon (SOC), a suite of biological indicators including MBC, metabolic activity (MA), total microbial activity (TMA) and soil bacterial genetic fingerprinting were used to test this hypothesis. The method used for measuring soil MA in this study was MicroResp™ analysis which is a cheap but quick and effective method through assessing soil carbon substrate utilisation ability (Campbell et al., 2003). Quantitative real-time PCR and terminal restriction fragment length polymorphism (T-RFLP) were used for determining the structure of soil bacterial communities, and the latter method was demonstrated to be as a robust and reproducible method as pyrotag sequencing in covering integrate bacterial communities in soils (Bacchetti De Gregoris et al., 2011; Pilloni et al., 2012). Altogether, our approach of using the selected soil indicators and methods is predicted to be powerful for discriminating between soil properties from different ST treatments.

2. Materials and methods

2.1. Site description

The experimental field selected for this study was located approximately 65 km North East of Moree, New South Wales, Australia (29°08'S, 150°07'E). The soil was an Endocalcareous Epipedal Grey Vertosol (Australian Soil Classification (ASC), Isbell, 2002) or Vertisol (World Reference Base (WRB), IUSS, 2006) developed on Croppa Creek Plains: extensive alluvial fans and rolling downs on Quaternary sediments and planar surfaces of Cretaceous calcareous silty sandstones and shales (Isbell, 2002; Németh et al., 2002). The mean annual precipitation is 610 mm, and the mean annual maximum and minimum temperature ranged between 12.2 °C and 26.5 °C. The rainfall history is shown in Fig. 1. A summary of chemical and physical properties of Moree soils is described in Table 1. The experimental site has been under NT management for fifteen years, with the most recent crop grown immediately before collection of soil samples being chickpea (*Cicer arietinum* L.). Common weed species at the experimental site were African Turnip (*Sisymbrium thellungii*), Milk Thistle (*Sonchus oleraceus*), Scotch Thistle (*Cirsium vulgare*) and Wild Oats (*Avena fatua*).

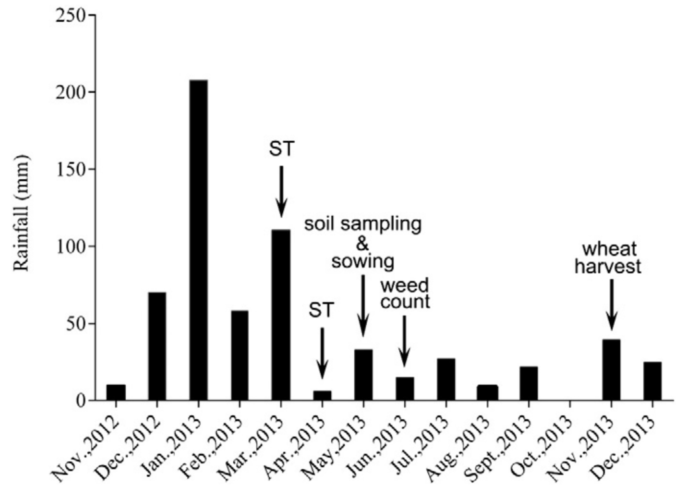

Fig. 1. Rainfall conditions recorded from November, 2012 to December, 2013 at the experimental site (obtained at http://www.bom.gov.au/).

2.2. Experimental design and sampling protocol

The experimental design was a randomised complete block (12 m × 100 m) with four replications per treatment. A single ST with either a chisel cultivator or a disc chain was applied within the farm management spray regime on March 15th, 2013 and April 5th, 2013 instead of herbicide treatment to a depth of 0–10 cm (disc chain) or 0–15 cm (chisel cultivator). The effect of two factors was examined in this study: I) chisel cultivator or disc chain as tillage implements; II) March 15th or April 5th for application timing. Soil chemical and physical properties were analysed at depths of 0–5 cm, 5–10 cm, 10–20 cm and 20–30 cm; and soil microbial properties were analysed at depths of 0–10 cm and 10–20 cm. The soil health indicators investigated in this study were soil volumetric moisture content (VMC), pH, bulk density (BD), electrical conductivity (EC), available phosphorus (P), soil organic carbon (SOC), microbial biomass carbon (MBC), metabolic activity (MA), compositions of bacterial communities and soil agronomic productivity. Soil agronomic productivity was assessed by wheat (*Triticum aestivum* L.) grain yield (t ha^{-1}) for the 2013 winter cropping season.

Soil samples for physical and chemical analysis were collected on the 3rd of May 2013 to depths of 0–30 cm using a tube sampler (43 mm in diameter) attached to a hydraulic soil sampling rig. Two soil samples were taken in each plot and were sectioned into depths of 0–5 cm, 5–10 cm, 10–20 cm and 20–30 cm. Seven sub-soil samples were taken from both 0–10 cm and 10–20 cm depths using a hand shovel at each plot to be used for soil microbial analysis. All samples collected from the same depth of the same plot were mixed thoroughly after sampling on site. Soils were then transported to the laboratory where they were sieved (porosity <4 mm) and tested for gravimetric water content immediately, before they were stored at 4 °C until used for further tests.

2.3. Physical and chemical analysis

Bulk density was calculated from the first sample by taking the mass of oven-dried soil (105 °C) per unit volume of the soil sample. The calculation of VMC involved multiplying the gravimetric moisture content with the BD value. To determine soil EC and pH, the second sample was used. The process involved 20 g oven-dry (48 h at 40 °C) soil and pH/EC aqueous (1:5) electrode (Method 3A1 & 4A1, Rayment and Lyons, 2011). The Colwell procedure was used to determine available P, and SOC was determined using the method previously developed by Rayment and Lyons (2011).