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Consistent plant residue removal causes decrease in minimum soil water content in a Mediterranean environment**

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Abstract: Residue retention and no-till farming have been widely adopted to reduce erosion risk, but residue retention in particular is becoming less common due to issues with weed control, and competing markets for residue such as bioenergy production. For this reason, the impact of residue removal on soil water contents in a sandy soil in a Mediterranean-type environment was evaluated. Crop residues were removed by burning or conventional tillage annually in autumn (April or May) from 2008 until 2011. Surface residue cover and soil water contents were measured in summer (February–March) every year from 2008 until 2012, at the time of minimum soil water content (approaching air-dry). After three years of residue removal, average ground cover in the subsequent summers (2011 and 2012) decreased from 78% to 51%, and surface soil water contents decreased from 5.1% to 3.1%. Tillage also significantly decreased ground cover (from 72% to 58%) and soil water (from 4.2% to 3.9%) during the same time period. Changes in surface cover and soil water content indicate that residue removal will have implications for soil health and sustainable crop production.

Key words: conservation farming; stubble, soil water holding capacity

Introduction

No-till and stubble retention is widely practised in southern Australia and this has been driven largely by the need to control soil erosion (Malinda 1995; Flower et al. 2007). By 2003, more than 86% of growers in the region had adopted no-tillage (D'Emden & Llewellyn 2006). However, this system is coming under pressure from other factors such as weed control (Powles & Yu 2010) and the need for harvesting plant biomass for bio-energy production (Lal 2005).

Past research has shown that reduced tillage coupled with stubble retention can increase soil water contents compared with conventional managements where cultivation and /or stubble removal are practised (Malhi & O'Sullivan 1990; Bescansa et al. 2006; Monzon et al. 2006). This has been attributed to (1) increases in soil organic matter contents that lead to higher soil water holding capacity (Lal & Kimble 1997; Bescansa et al. 2006), and (2) increased residue cover on the soil surface which moderates extremes of soil surface temperature (Malhi & O'Sullivan 1990; Flerchinger et al. 2003), thereby reducing evaporative losses (Ji & Unger 2001; Ward et al. 2012).

Soil disturbance and stubble removal can each result in a loss of soil carbon (Rasmussen & Collins 1991; Dalal & Chan 2001; Chan et al. 2011; Roper et al. 2010, 2013). However, there is little research that quantifies the impacts of a switch away from crop residue retention and no-till on surface residue cover and soil water content. This paper reports on field-based experiments which quantify the impacts of stubble removal on surface ground cover and minimum soil water contents over a five year period in which stubble treatments were imposed annually prior to seeding.

Material and methods

Site details

The experimental site was located at 33°35.212′ S, 120°48.221′ E on a moderately water repellent (MED value 2.5; Roper et al. 2013) sandy soil near Munglinup, in south-western Australia. The annual average rainfall at the nearby (< 5 km) 'Munglinup Melaleuca' Bureau of Meteorology weather station (33°42.6′ S; 120°52.2′ E: http://www.longpaddock.qld.gov.au/silo/index.html, accessed May 2013) is 513 mm with most of this (317 mm) falling in the cooler months from May to October. Frequently, the summer months (December to February) are dry (average 93 mm) and hot (average maximum temperature 27 °C).

Details of experimental design were given in Roper et al. (2013). Briefly, two residue treatments (residue retained

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Table 1. Weekly rainfall totals for three weeks prior to soil water content measurement. Note that average weekly evaporation (ET0) for February is 33.6 mm.

Date of soil water content measurement	Weeks prior to soil water content measurement		
	One	Two	Three
26 March 2008	5.8	0.0	2.0
9 February 2009	0.0	37.4	2.0
17 February 2010	0.0	74.2	0.0
23 February 2011	2.4	3.0	47.2
22 February 2012	0.0	0.0	28.6

versus residue burned) were combined with two tillage treatments (no-till versus conventional tillage) in a split-plot randomised block design with 4 replicates. Residue burning and tillage were applied to plots in April or May of each year. 'Burned' plots had also been burned in December 2004 prior to the experiment being commenced. Crops were wheat in 2007, canola in 2008, barley in 2009, canola in 2010 and wheat in 2011. Statistical analysis was performed with Genstat 13.1 (VSN International Ltd.) by ANOVA, with level of significance set at 0.05.

Ground cover measurement
Digital images, taken vertically downward from a height of approximately 1.5 m, and covering an area of approximately 2 m^2, were collected with a standard digital camera. Two images were taken for each plot on 26 March 2008, 9 February 2009, 17 February 2010, 23 February 2011 and 22 February 2012. Images were analysed for residue cover, bare soil, and living vegetation using ImagePro Plus 7.0 (Media Cybernetics) as described by Ward et al. (2012). Ground cover was calculated as (residue)/(residue plus bare soil) and expressed as a percentage.

Soil water content
On the same days as digital image collection, soil water content was measured with a hand-held Time Domain Reflectometer (TDR) probe (Hydrosense CS620, Campbell Scientific, Logan, Utah), as described by Roper et al. (2013). Pairs of measurements in crop rows and immediately adjacent inter-rows were collected in 20 random locations per plot to a depth of 0.12 m.

Results

Seasonal conditions at time of soil water measurement
In all years, for the three weeks preceding soil water and ground cover measurement, rainfall was much lower than total potential evaporation (Table 1). However, in 2009, 2010, 2011 and 2012, significant rainfall occurred 2–3 weeks prior to measurement, and in 2011, this led to substantial weed growth.

Ground cover
In 2008, prior to application of treatments, differences between burned and retained stubble plots were due to an intense burn in December 2004 caused by a lightning strike. In subsequent years, residue removal by burning 10 months previously caused a significant ($P < 0.001$) decrease in ground cover in each year (Fig. 1a). Mean ground cover percentage over the five years of measurement was 49% where residue was removed and 75% where residue was retained. Tillage treatment also significantly ($P < 0.001$) affected ground cover percentage, with mean percentages of 58% and 66% for conventional tillage and no-till respectively.

Soil water content
Despite variations in preceding rainfall, soil water content in the top 0.12 m was similar in all years (about 5–6% v/v) in the plots where residue was retained, but there was a significant ($P < 0.001$) interaction between date and residue treatment (Fig. 1b). Initially (2008) prior to the imposition of stubble and tillage treatments, soil water content was marginally higher in the plots where residue was to be removed by burning, but there was no difference in 2009, and in 2010, soil water content was significantly lower (5.4% compared with 4.4%) in plots where residue was removed. In the last two years of measurements, February soil water contents diverged even more, with average values of 5.1% under residue retention compared with 3.1% where residue was burned. In addition, there was a significant ($P = 0.005$) effect of tillage treatment on soil water content, with mean soil water content over the five years of measurement slightly higher in the no-till treatments (5.1%) than in the conventionally tilled treatments (4.8%).

Discussion

In Mediterranean-type climates, soil water content close to the soil surface usually reaches a consistent minimum value (approaching air-dry) due to the hot and dry conditions. In the current research, consistent minimum values of 5–6% (v/v) in all five years of measurement were observed where residue retention and no-till was practised, as has been the case at the trial site for many years. Slight (non-significant) variation from year to year was likely the result of seasonal conditions (Table 1), combined with differences in ground cover (Fig. 1). However, when the farming system was perturbed by residue removal, and to a lesser extent, cultivation, the minimum soil water content declined significantly, and after four years, was more than 2% v/v lower than where residue was retained.

Removal of crop residues by burning created significant areas of bare surface soil (Fig. 1) exposing it to extremes of temperature during the hot dry summers typical of a Mediterranean-type climate. Heating soils

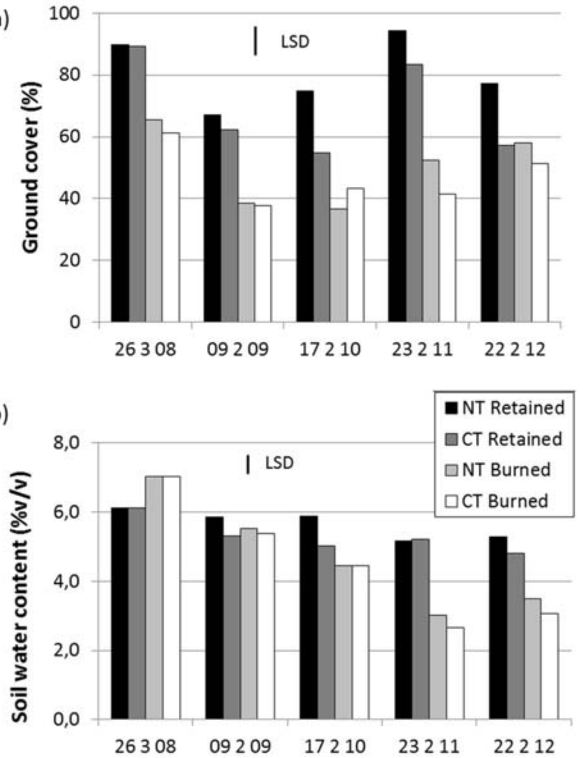

Fig. 1. Percentage of ground cover (a) and soil water content (b) in late summer following residue retention or removal in no-till or conventional-till plots. Vertical lines indicate L.S.D. ($P = 0.05$) values.

can cause a marked drop in water penetration (Novák et al. 2009). In non-wetting soils, the reduction in water infiltration over summer (Roper 2005; Lichner et al. 2012) has been attributed to high temperatures allowing the diffusion of hydrophobic materials onto the surfaces of sand grains (Franco et al. 1995). Apart from moderating soil surface temperatures, surface residue cover can have a direct impact on soil water evaporation reducing evaporative losses (O'Leary & Connor 1997; Ji & Unger 2001), but this is not always the case on sandy soils (Ward et al. 2009). A significant impact of the removal of crop residues was the loss of soil organic carbon in the burned treatments (Roper et al. 2013) and it is possible that this resulted in reduced water holding capacity in these treatments (Lal & Kimble 1997). Measurements of soil water contents during the wet winter growing season support this suggestion, with average soil water contents in stubble retained treatments being more than twice that in the stubble removed treatments at the end of four years (Roper et al. 2013).

In addition to impacts on soil water, maintenance of ground cover over the summer period can have a number of implications for crop production. By protecting soil surfaces from extreme temperatures, soil microbial functions including biological wax degradation in water repellent soils are maintained (Roper 2005; Hoyle & Murphy 2006). Residue retention also provides protection for the soil surface against raindrop impact and subsequent erosion (by both wind and water) and degradation of soil structure (Hillel 1971; Cantero-Martinez et al. 2006). In our research, residue retention resulted in ground cover of at least 60% in each year, compared with ground cover of around 40% in the burned plots. A difference of this magnitude could decrease runoff by more than 50% (Lang 1979).

The results presented in this research demonstrate that consistent residue removal, over just three years, can lead to significant changes in soil water characteristics. Residue removal by burning has become common in southern Australia, largely to assist with weed control and to facilitate seeding operations (Scott et al. 2010). Residue may also be removed by grazing, or for export as hay, or for bioenergy production (Lal 2005), and consistent removal under these circumstances is also likely to lead to changes in the water holding characteristics of the soil.

Conclusions

Surface ground cover removal on a water repellent sand resulted in significant loss of soil water over dry summers in a Mediterranean-type environment. Although the data was collected on a non-wetting sand, it is likely that the mechanisms observed here will apply to a wider range of soil types. Maintenance of soil water may have significant impacts on soil microbial function and general soil health.

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