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Rainfall, rotations and residue level affect no-tillage wheat yield and gross margin in a Mediterranean-type environment

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ABSTRACT

Wheat yield was obtained over nine years (2007–15) of a long term experiment in a Mediterranean-type climate, to understand the effects of rotation and residue retention on rainfed wheat establishment, yield and gross margin under a no-tillage system. The three treatments were based on increasing levels of diversity in the rotation, from 'monoculture wheat', 'cereal rotation' and 'diverse rotation'. These treatments, except monoculture wheat, were based on three phase (year) rotations with every phase presented every year. Any winter/spring cereal may be grown in the 'cereal rotation' treatment, while the diverse rotation was based on a wheat–legume–brassica sequence. For the period 2007–2010, residue was spread across the plot behind the harvester. The plots were split after 2010 with residue spread on half of each plot, and the other half having the residue windrowed and burnt prior to seeding, which reduced residue levels by 40–66%. This reduction in residue level had a positive effect on wheat yield in years with high levels of cereal residue and had negative, or no effect, when residue levels were relatively low ($< \sim 3000$ kg ha^{-1}). By contrast, the effect of windrow burning of canola residue on following wheat yield was negligible, even at high residue levels. Therefore the effect of crop residue on wheat yield depended on the type and amount of material.

Monoculture wheat and cereal rotation had the highest cumulative 9-year average gross margins, despite the diverse rotation showing higher grain protein concentration in most years and improved wheat yield over time. Lower gross margins in the diverse rotation were associated with poor legume performance in many years and low canola yields in dry seasons. Improving the reliability of these break crops in this growing environment is the key to increasing their uptake by farmers. Cover crops in the rotation negatively impacted gross margins, without any observed yield benefits in the following years, therefore should not be recommended to replace the one cash crop per year in this low rainfall Mediterranean-type environment.

1. Introduction

Conservation agriculture is a well-established cropping system that includes minimal soil disturbance, crop rotation and residue retention as its key components (Hobbs et al., 2008). The system is often promoted with cover crops to provide diversity, soil fertility benefits, additional biomass as well as grazing in integrated crop–livestock systems (Kassam et al., 2012; Conceição et al., 2013; Sulc and Franzluebbers, 2014). The system has been widely promoted with successful adoption in many countries (Derpsch et al., 2010). Nonetheless, implementation of full residue retention has hindered uptake in some regions and questions remain about the optimum level of residue; especially as residue has other uses like feeding livestock (Giller et al., 2009; Baudron et al., 2012; Thierfelder et al., 2015). Also, Piggin et al. (2015) and Govaerts et al. (2005) found partial residue removal had no effect on wheat yields compared with full retention. Indeed, the former also reported that farmers in Syria experienced increased yield without any residue retention, in fields that were heavily grazed. Clearly, some issues with no-tillage are specific to regions, as the global meta-analysis of Pittelkow et al. (2014) showed that no-tillage without residue retention had reduced yields in dry rainfed areas. Similarly the benefits of cover crops have been questioned in some regions (Nielsen et al., 2016).

There has been widespread adoption of no-tillage in the Mediterranean-type climate of southern Australia (D'Emden et al., 2008; Derpsch et al., 2010; Llewellyn et al., 2012). Generally, a pragmatic approach to the system has been adopted, which includes partial removal of crop residues by grazing livestock over summer and

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occasional strategic tillage to overcome problems with hydrophobic soils or herbicide resistant weeds (Kirkegaard et al., 2014). In addition, the practice of concentrating the chaff and straw from the harvester into a narrow windrow, which is then burnt, has been widely adopted as a non-chemical, harvest weed seed control measure (Walsh and Newman, 2007). Narrow windrow burning is far more effective at killing weed seeds than burning whole fields (Walsh and Newman, 2007; Walsh et al., 2013). Indeed, it is seen as one of the key non-chemical management practices for combating herbicide resistance (Stokstad, 2013). However, there is little published information on the impact of windrow burning on total residue amount or crop yield.

The benefits of crop rotation are well established and the importance of using these 'break crops' to follow cereal crops has been emphasised. Nonetheless, cereals, particularly wheat, dominate cropping in the region for economic reasons. Cover crops were suggested as a way to introduce diversity into the rotation and their benefits were tested by Flower et al. (2012), without any economic benefits measured in the first three years when they were used; however, the benefits to subsequent cash crops should be evaluated over a longer period.

In this context we conducted a nine-year no-tillage cropping systems experiment at Cunderdin in Western Australia. The hypotheses were that: (i) a diverse rotation will be more profitable than a cereal rotation or monoculture wheat; (ii) cover crops in the rotation will increase profitability of crop production over a six to nine year period and (iii) that spreading (retaining all residue) will have greater yield and profit than windrow burning (lower residue level). These results will be useful for farmers, advisers and researchers to understand the longer term effect of using different break crops in the rotation as well as the impact of residue management on wheat performance.

2. Methods

This nine year experiment was started in 2007 at the Cunderdin College of Agriculture (117°14′E, 31°38′S) in Western Australia.

2.1. Treatments and trial design

The treatments were based on four different cropping philosophies originally called "P1–Maximum carbon input (cereal rotation)", "P2–Maximum diversity (diverse rotation – cereal/legume/brassica)", "P3–Controls (continuous monoculture wheat and permanent pasture)" and "P4–Maximum profit (cereal/cereal/legume or fallow)" (Flower et al., 2012). The current research only included P1–P3, which were labelled 'cereal rotation', 'diverse rotation' and 'monoculture wheat' (Table 1); the permanent pasture control of P3, was not included. The treatments had three-year rotations with each phase presented every year, except for monoculture wheat. The P4 treatment was not included as it had different management, which included a knife-point no-tillage seeding system and was also split for tillage.

The design was a randomised complete block with three replications. Plots in the same phase within a rotation (i.e. the replicates) were given the same sequence number. The three sequences for the cereal rotation were S1–S3, those for the diverse rotation were S4–S6 and monoculture wheat S7 (Table 1). In the diverse rotation, wheat was always sown after canola, while in the cereal rotation, wheat was sown after either wheat or barley crops depending on the year and phase of the rotation.

At the end of harvest in 2010 the plots in the cereal and diverse rotations were split for full residue retention (i.e. 'spread' behind the harvester) and partial residue retention (i.e. 'windrow burn' – placing the chaff and straw from the harvester in a narrow windrow which was burnt prior to seeding each year). The monoculture wheat plots were not split and maintained full residue retention (i.e. spread). All main plots were 36 m × 80 m, with a 2 m wide buffer along each side of the plots, providing a 4 m guard between plots. The split plots were 18 m × 80 m.

2.2. Weather, soil properties and crop management

The site and soil were previously described by Flower et al. (2012) and are briefly described here. The site has a Mediterranean climate with mild, wet winters and hot dry summers. The most recent 20 year average annual rainfall at a nearby Australian Government Bureau of Meteorology site (Cunderdin Airfield, No. 010035, 3 km from the trial site) was about 310 mm, with about 210 mm falling in the growing season between May and October (winter and spring), and 100 mm between November and April (summer and autumn). A tipping bucket rain gauge was used at the Cunderdin site, along with data collected from the nearby Cunderdin Airfield site. The soil was an alkaline red duplex (Xanthic Ferralsol), sandy clay-loam with about 220 g kg^{-1} clay and 10 g kg^{-1} organic carbon in the top 10 cm of soil. The pH increased from 6.6 in the top 10 cm to 7.9 at 60 cm. The available water holding capacity of the soil was approximately 220 mm, with a crop lower limit of about 210 mm in the top 1.6 m of soil.

The trial was set up with a tramline controlled traffic system, although the wheel tracks did not all match, using 4.5 m wide seeder, 9 m spray boom and commercial harvester with a 9 m cutting front. Therefore, there were two harvester runs through each split plot in approximately the same tracks every year. The seeding tractor had 2 cm accuracy autosteer to allow for seeding between the previous rows of stubble if required. The intention was for full residue retention, so seeding was done with a low soil disturbance 'disc opener' (NDF single

Table 1
Crop rotations and sequences at Cunderdin from 2007 to 2015, with every crop presented every year.

Rotation	Cereal rotation			Diverse rotation			Monoculture wheat
Sequence[†]	S1	S2	S3	S4	S5	S6	S7
07–09[‡]		*Spread*			*Spread*		*Spread*
2007	Oat CC*	Barley	Barley	Wheat	Vetch-oat CC*	Canola	Wheat
2008	Barley	Barley	Oat CC*	Vetch-oat CC*	Canola	Wheat	Wheat
2009	Barley	Oat CC*	Barley	Canola	Wheat	Vetch-oat CC*	Wheat
2010	Wheat	Wheat	Wheat	Wheat	Field pea	Canola	Wheat
11–15[‡]		*Spread/Windrow burn*			*Spread/Windrow burn*		*Spread*
2011	Wheat	Wheat	Wheat	Field pea	Canola	Wheat	Wheat
2012	Wheat	Wheat	Wheat	Canola	Wheat	Field pea	Wheat
2013	Wheat	Wheat	Barley	Wheat	Chickpea	Canola	Wheat
2014	Wheat	Barley	Wheat	Chickpea	Canola	Wheat	Wheat
2015	Barley	Wheat	Wheat	Canola	Wheat	Chickpea	Wheat

[†] The crop sequences show the different rotation phases, with every crop presented every year. Crops kept the same for three years.
[‡] Residue management applied. Note: plots split from harvest 2010 onwards for retain residue (spread behind harvester) or windrow burn, except for monoculture wheat.
* CC = cover crop.