



Nitrogen, weed management and economics with cover crops in conservation agriculture in a Mediterranean climate

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ABSTRACT

Cover crops have been successfully integrated into conservation agriculture systems in many parts of the world. They are primarily used to provide surface cover as well as to improve soil fertility and suppress weeds. Black oat (*Avena strigosa* Schreb.) is a widely used cereal cover crop with a rapid growth and high biomass production. It is being trialled as a cover crop for conservation agriculture systems in south-western Australia, which has a Mediterranean climate with a short winter growing season and where terminal drought is common. Only one crop can be grown in a year and, as such, the long term benefits of including a cover crop in this system must outweigh the loss in income by not growing a cash crop.

This study, which was part of a larger conservation agriculture cropping systems trial, examined the effect of different crop sequences, which included oat cover crops and grass pasture, on soil nitrogen mineralisation and weed control. A related paper in this Special Issue examined the effect of cover crops on the soil water balance. We hypothesised that the inclusion of high-biomass oat cover crops in a cereal-dominated cropping system would (i) result in less immobilisation of soil nitrogen compared with that of harvested cereals, and (ii) significantly improve the weed control. We show that soil N mineralisation following oat cover crops was similar to that following wheat and barley. Therefore, cash crops grown after oat cover crops would require similar levels of nitrogen to those grown after harvested cereals. Oat cover crops and grass pasture were found to be very effective in controlling weeds, even in continuous cereal rotations. Two consecutive years of cover crop were required for good annual ryegrass (*Lolium rigidum* Gaud.) control in a predominantly cereal rotation. Timing of when the cover crops were killed by herbicide was crucial for good weed control, as failure to prevent weed seed set resulted in significantly reduced weed control. Also, late killing of the cover crop reduced soil water storage. The inclusion of an oat cover crop in the rotation reduced the three-year average gross margin; however, the profitability of these crops needs to be evaluated over a longer period. To date, managed pasture, with herbicide control of weed seed set, appears to be a better option than oat cover crops because of the relatively low cost and increased soil water storage.

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1. Introduction

Cover crops are grown primarily to produce large amounts of biomass and provide soil cover; they are not grown for market purposes (Fageria et al., 2005). These crops are well suited to conservation agriculture systems as they provide soil cover and smother weeds. Planting cover crops in a rotation can reduce erosion through greater levels of soil cover (Langdale et al., 1991) as

well as improve weed control (Derpsch, 1990; Creamer et al., 1996; Creamer and Baldwin, 2000), soil fertility (Kuo and Jellum, 2002; Cavigelli and Thien, 2003) and water content (Creamer et al., 1996). Various benefits and disadvantages of cover crops were reviewed by Fageria et al. (2005). Black oat (*Avena strigosa* Schreb.) is the predominant cereal cover crop in southern Brazil and Paraguay and has also shown some potential in the USA (Bauer and Reeves, 1999; Reeves and Price, 2005). It has mainly been used because of its rapid growth, high biomass production and weed control potential (Zibilske and Makus, 2009; Santos et al., 2010). Also, being a cereal, it has a high carbon to nitrogen ratio (C:N) (Derpsch, 1990). Some concern has been raised about possible immobilisation of soil N following some cereal cover crops (Karlen and Doran, 1991; Francis et al., 1998; Bauer and Reeves, 1999; Creamer and Baldwin,

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2000; Fageria et al., 2005). Although, in some instances the residues were incorporated into the soil (Francis et al., 1998), which would increase the likelihood of immobilisation.

The use of cover crops in a rotation is well suited to situations where more than one crop is grown in a year, because the economic impact is minimised. In the south-west of Western Australia, cereals, particularly wheat, grown under conservation agriculture (no-tillage), dominate the cropping systems (Robertson et al., 2010). The Mediterranean climate, with a short, cool growing season and terminal drought (Siddique et al., 2001), precludes the use of cover crops grown in the same year as a cash crop in most of this area. The inclusion of cover crops, therefore, replaces one of the main crops grown in the rotation. Research in Queensland, Australia, showed the impact of millet (*Panicum miliaceum* L.) cover crops grown in a 14-month fallow period could be minimised if they were killed when 50% cover had been achieved (Whish et al., 2009). The effect of cover crop growth on the soil water balance in Western Australian conservation agriculture systems is discussed in a related paper in the Special Issue on Conservation Agriculture in Dry Areas.

In order for cover crops to be used by local farmers the long term environmental and economic benefits in the conservation agriculture system must be established. The reduction in soil erosion from increased levels of residue cover has been well documented (Findlater et al., 1990; Whish et al., 2009). In Western Australia, 50% ground cover by crop residue is recommended for effective control of erosion, where soil loss approaches a value of 10% of the erosion from an unprotected soil. This equates to approximately 1 and 2 t ha⁻¹ of cereal and lupin residue, respectively (Findlater et al., 1990; Leonard, 1993). However the effect of cover crops on soil fertility, weed control and yield under local conditions has not been established. The aim of this research was to test the hypotheses that (i) oat cover crops with a high biomass will immobilise less soil nitrogen than harvested cereals, and (ii) the inclusion of oat cover crops in a cereal rotation can significantly improve weed control in a conservation agriculture system. The comparative profitability of using such cover crops is also discussed.

2. Materials and methods

2.1. Sites, soils and treatments

Two long-term conservation agriculture cropping system experiments were started in 2007, one on a farm near Mingenew (115°17'E, 28°56'S) and the other at the Cunderdin College of Agriculture (117°14'E, 31°38'S) in Western Australia. The soil at Mingenew was deep yellow sand with about 50 g kg⁻¹ clay, 6 g kg⁻¹ organic carbon, 0.5 g kg⁻¹ total nitrogen and 17 mg kg⁻¹ phosphorus (Colwell) in the top 10 cm of soil. Soil pH (0.01 M CaCl₂) decreased from 5.4 in the top 10 cm to 5.0 at 60 cm depth. The Cunderdin soil was red sandy clay loam with about 220 g kg⁻¹ clay, 10 g kg⁻¹ organic carbon, 0.8 g kg⁻¹ total nitrogen and 29 mg kg⁻¹ phosphorus in the top 10 cm of soil. The soil was alkaline at depth with calcium carbonate concretions visible below 40 cm. The soil pH at Cunderdin increased from 6.6 in the top 10 cm to 7.9 at 60 cm. Soil fertility, including organic carbon, was assessed at both sites to 40 cm depth in 10 cm increments at the start of the experiment and after every three years. There were few differences in organic carbon after the first three years and the data is not discussed here. At the start of the experiment the Mingenew site had large numbers of weeds, mainly annual ryegrass that was estimated to be in excess of 600 plants m⁻². Low initial weed numbers of less than about 30 plants m⁻² were present at Cunderdin, although there was a greater diversity of weeds including annual ryegrass, wild oats (*Avena fatua* L.), barley grass

Table 1
Treatment philosophies.

Philosophy	Description
P1 – Maximum carbon input	• Low crop diversity with maximum residue retention. • Three year cereal rotation with every phase presented every year: Cereal [P1/S1]^a–Cereal [P1/S2]–Cereal [P1/S3] • Crops can include any winter cereal such as wheat, barley, oat (including black oat). Changes in the rotation (inclusion of a different cereal or change to management practice such as brown manure or slashing) can only occur once every three years, when the three year cycle is complete. A cereal cover crop must be grown at least once in the first three years of the project (to rapidly increase soil cover levels) and then at least one every six years, subsequently • Crops seeded with a minimum-disturbance disc opener • No burning or tillage
P4 – Maximum profit	• Current farmer practice with low residue retention • Three year rotation with every phase presented every year: Cereal [P4/S9]–Cereal [P4/S10]–Legume [P4/S11] • Maximum residue retention not a priority so burning, straw removal etc. are allowed • Crops sown with a higher-disturbance tine and knife-point no-till seeder • Burning and tillage allowed

^a Square brackets indicate philosophy/crop sequence number (e.g. [P1/S1]=Philosophy 1/Sequence 1) that is constant, based on the first year of the experiment i.e. 2007. See Tables 2 and 3 for detailed information on the crops grown and dates of seeding, killing of cover crops or grain harvest, respectively, for each philosophy/crop sequence number from 2007 to 2010.

(*Hordeum leporinum* Link.), wild radish (*Raphanus raphanistrum* L.) and mallow (*Malva parviflora* L.).

The two experiments had similar designs, although different crop types and cultivars were used because of the different soil and environmental conditions. The treatments were based on four different cropping philosophies titled “P1 – maximum carbon input”, “P2 – maximum diversity”, “P3 – controls” and “P4 – maximum profit”. Only the P1 and P4 philosophies are considered in this paper. Both of these philosophies had a three-year rotation with each phase presented every year, giving six crop sequences each replicated three times in a randomised complete block design. The crop sequence labels were kept constant over the years for all treatments and were based on the first year of the experiment, with the sequences S1–S3 representing the three rotational phases of the P1 philosophy and S9–S11 corresponding to the phases of the P4 philosophy (Tables 1 and 2).

All plots were 40 m × 80 m, including a 2-m wide buffer along each side of the plots, providing a 4-m guard between plots. The first three-year rotation for sequences S1–S3 at Mingenew from 2007 to 2009 included black oat cover crop–wheat (*Triticum aestivum* L.)–barley (*Hordeum vulgare* L.) and this was changed in the next three-year phase, 2010–2012, to oat cover crop (*Avena sativa* L.)–wheat–wheat. These sequences at Cunderdin were black oat cover crop–barley–barley and for the next three years wheat–wheat–wheat (Table 2). The oat cover crop was still included for the second three years at Mingenew to further reduce the weed population. Sequences S9–S11, the maximum profit or farmer practice, at Mingenew consisted of barley pasture–wheat–lupin (*Lupinus angustifolius* L.) in the first three years and then wheat–volunteer grass pasture–lupin in the next three years. Such pasture would normally be grazed by sheep or, in the absence of sheep, left fallow with tactical weed control. The pasture at Mingenew more closely represented the latter situation as it was mown and then later killed by herbicide to control weeds; details are included in the next section. Grazing of the pasture was not included because a number of farmers have no sheep and the large logistical issues and costs associated with animal

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