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Soil water conservation and nitrous oxide emissions from different crop sequences and fallow under Mediterranean conditions

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ABSTRACT

Interest in fallowing as the drought adaptation strategy has increased recently due to the occurrence of frequent droughts in cropping areas of Australia. Weed management in a fallow is crucial as it affects the level of soil water and nitrogen conserved by this practice. Increased use of fallow has implications for nitrous oxide emissions as soil moisture is a major determinant of evolution of nitrous oxide. In a two year study, three types of fallow with different weed management were compared with wheat and canola crops in 2010 and the carry-over effects with wheat on all plots in 2011. The weeds in the fallows were managed either by herbicide (chemical fallow) or by tillage (cultivation fallow) and compared to an unweeded fallow (weedy fallow). The chemical fallow conserved most soil water followed by cultivation fallow, with the lowest soil water content in the weedy fallow. In addition, more weeds were observed in the wheat crop following weedy fallow. Low wheat and canola yields were measured in 2010 because of a drought, which also depleted soil water compared to the chemical and cultivation fallows. Therefore, fallow is a potential strategy for increasing crop yield under dry conditions. The results also indicated that weeds had a detrimental effect by reducing soil water content due to lack of timely weed management. To test the compatibility of fallow with climate-change mitigation, the nitrous oxide emissions were compared in the 2011 wheat crop. There was a temporal fluctuation in nitrous oxide emissions with increased rates of emission after top dressing with urea. Importantly, however, the nitrous oxide emission from wheat following fallow was not increased compared with wheat in the continuous cropping sequences. Therefore, this study found that fallowing with good weed control, could be used as a drought adaptation strategy without increasing nitrous oxide emissions in following crops.

1. Introduction

Extreme climatic events like drought are becoming common and have more impact in rain-fed agriculture (Li et al., 2011; Qureshi et al., 2013; Sen et al., 2012; van Asten et al., 2011; van Dijk et al., 2013), sometimes leading to complete crop failure. Farmers respond to such events by adopting drought mitigations strategies (Aggarwal, 2008; Cairns et al., 2012; Falloon and Betts, 2010; Farooq et al., 2009; Fleury et al., 2010). Besides crop improvement for drought tolerance, many agronomic management options are being evaluated for their drought tolerance impact (Jafari et al., 2012; Li et al., 2001; Liu et al., 2013; Selvi et al., 2009; Sommer et al., 2012; Verhulst et al., 2011; Wassmann et al., 2009). It is important that drought management practices are screened for greenhouse gas emission potential, as these practices may increase nitrous oxide emissions from crop fields. Especially, as agricultural fields are thought to be a major contributor of this greenhouse gas (IPCC, 2007), which has a global warming potential that is 300 times more than carbon dioxide (IPCC, 2001).

Fallowing is one of the drought mitigation strategies that is gaining popularity in areas receiving less than 400 mm of rainfall (Oliver et al., 2009; Tanaka and Anderson, 1997). A fallow will improve the moisture status of a paddock and thus improve crop yield in the following cropping season. However, there are many factors that influence the soil water storage efficiency of a fallow. The weed management in a fallow system is a major determinant affecting the efficiency of a fallow system (Nielsen et al., 2005; Smika and Wicks, 1968; Wicks and Smika, 1973). The weeds in fallow are usually managed by herbicides or by tillage. Other factors that affect the soil moisture storage of a fallow include soil residue cover, depth of tillage, soil albedo and reconsolidation of soil aggregates after tillage (Moret and Arrue, 2007; Nielsen et al., 2005; Schwartz et al., 2010; Wicks and Smika, 1973).

Although fallow has many advantages, it's economic and climate change implications need to be carefully considered. A fallow would reduce the crop acreage and thereby reduce the crop

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farm income (Oliver et al., 2009). Therefore, the decision to fallow or not is crucial and should primarily be taken based on the expectation of dry conditions. From a climate change perspective, the soil water content following a fallow should be higher than the cropped area; however, conserved moisture might interact with nitrogenous fertilisers leading to relatively higher nitrous oxide emission (Allen et al., 2010; Sirivedhin and Gray, 2006). Therefore this study tests the hypothesis that a previous fallow will reduce weeds and increase soil water storage and crop yield, but will also increase nitrous oxide emission in the subsequent crop compared with a crop grown on previous harvested land. Therefore, in a two year study, we compared different fallow systems and crop rotation sequences in the first year (2010) and wheat on all plots in the second year (2011) for their soil moisture conservation potential (2010–2011) and nitrous oxide emissions (2011). We also estimated the water storage efficacy of different fallow systems with a water balance modelling approach.

2. Materials and methods

The study was conducted at The University of Western Australia Ridgefield farm, near Pingelly (116°59′12.47″ E, 32°29′45.95″ S) during the period of 2010–2011. The Pingelly soil was a duplex with sand over sandy clay loam, with granite at about 1.5 m depth. The long term average rainfall was 446 mm (1891–2011). On the basis of mean values, maximum temperature of this location ranges from 15.2 °C to 31.8 °C and minimum from 5.5 °C to 15.8 °C. The average relative humidity of this location ranges from 44 to 67%. (Bureau of Meteorology, 2013). The mean maximum temperature at Pingelly was 24.6 °C and 24 °C and the minimum temperature was 10.2 °C and 11.5 °C, in 2010 and 2011, respectively (Bureau of Meteorology, 2013).

The treatments were imposed in 2010 winter growing season and wheat was planted in all the plots in the following year (2011) (Table 1). The design was a randomised block with three replications and plots of 1.4 m × 40 m. On 10 June 2010, plots were sprayed with Sprayseed® (135 g L^{-1} paraquat and 115 g L^{-1} diquat) at 2 L ha^{-1} in 85 L ha^{-1} of mix using Jen-Ell Silvan Sprayer with turbo jet nozzles while travelling at a speed of 6 km h^{-1} to control newly emerged weeds. Immediately afterwards, the wheat cultivar Magenta and canola cultivar Cobbler TT were sown at a seed rate of 80 and 3 kg ha^{-1}, respectively at a row spacing of 22 cm using a small plot seeder (1.54 m wide built by the Department of Agriculture Western Australia) with double disc openers and a press wheel behind each opener. The fertiliser Agras No. 1 (16.1% N, 9.1% P, 14.3% S, 0.5% Ca, 0.06% Zn) was band applied below the seed of both crops at the rate of 100 kg ha^{-1}. This was followed by top dressing of 50 kg ha^{-1} of urea at tillering of the wheat and stem elongation stage of the canola. The herbicides Boxer Gold® (800 g L^{-1} prosulfocarb and 120 g L^{-1} S-metolachlor) and Atragranz® (atrazine 900 g kg^{-1}) were applied immediately before seeding the wheat and canola, respectively, both at the rate of 1 kg ha^{-1} of product. The chemical and cultivation fallows were kept weed free throughout 2010. The cultivation fallow was tilled at 12 cm depth using a rotary hoe (Kubota 70 s). Chemical fallow plot was treated with post-emergence herbicide glyphosate on July 15 at the rate of 1.2 kg ha^{-1}. On 17 August 2010, the treatment 'chemical mid' was sprayed with glyphosate 1.2 kg ha^{-1} to determine the effect of late application of herbicides on soil water storage efficiency. The weedy fallow plot remained unweeded during the entire cropping season in 2010 to seeding in 2011.

On 1 June 2011, all the plots were sprayed with glyphosate at 2 L ha^{-1} to control newly emerged weeds. On the same day, plots were planted with wheat variety Magenta at a seed rate of 80 kg ha^{-1} and at a row spacing of 22 cm with a no-tillage seeder using tines and knife points. The fertiliser Agras No. 1 (16.1% N, 9.1% P, 14.3% S, 0.5% Ca, 0.06% Zn) was band applied at the rate of 110 kg ha^{-1} at about 10 cm depth, at the time of planting. This was followed by top-dressing of 30 kg ha^{-1} of urea at the tillering stage (2 July 2011). Prior to planting, the herbicide Boxer Gold® was applied at the rate of 1 L ha^{-1} before seeding and lightly incorporated by the tines at seeding. The herbicides Tigrex® (25 g L^{-1} diflufenican and 250 g L^{-1} MCPA) at 1 L ha^{-1} and Topik® (240 g L^{-1} clodinafop-propargyl and 60 g L^{-1} cloquintocet-mexyl-acetate) 0.1 L ha^{-1} were applied to the wheat as tank mix at the tillering stage.

The soil water status was monitored using neutron moisture meter (NMM) (Campbell Pacific Nuclear International Inc. Hydroprobe Model 503DR). One PVC access tube was installed in each plot to a depth of 1.5 m and moisture was monitored at depths of 0.1, 0.3, 0.5, 0.7, 0.9, 1.1, 1.3 and 1.5 m at major crop growing phases from September 2010 to December 2011. The NMM was calibrated using gravimetric soil water and bulk density measurements. To do this, undisturbed soil columns of 1.5 m were sampled at depths centred on 0.1, 0.3, 0.5, 0.7, 0.9, 0.11, 0.13 and 0.15 m using a hydraulic push probe (Geoprobe®, www.ecoprobe.com.au). These samples were weighed, dried in an oven at 105 °C for 72 h for gravimetric soil water content and bulk density calculations. On the same day, moisture meter readings were taken at these depths using the NMM. The relationship between volumetric water content (Θ) and neutron probe count ratio (CR) was: ($\Theta = 8.0921 \times CR + 5.11$, $R^2 = 0.81$, $n = 22$).

2.1. Nitrous oxide emission from treatments

A closed PVC chamber was used for nitrous oxide flux measurements with two replicate chambers in each plot (Harris et al., 2013). The two chambers in each plot were placed randomly at about 20 m apart, to represent the whole experimental plot. The chambers were placed one day prior to sampling and removed after sampling to avoid interference with seeding, spraying and fertiliser application. The chambers were made out of PVC pipes (325 mm length and 250 mm diameter) and were pushed 5 cm into the soil. The chamber was made gas tight using a screw-on lid with a rubber O-ring at the time of gas sampling. A one-way pressure release valve was installed on the side of each chamber to maintain a constant pressure once the lids were closed for gas measurement. The lids had three-way stopcocks, with needle and syringe attachments, for drawing gas samples. A computer fan with 9 V rechargeable battery and an iButton temperature logger were suspended from the lids for air circulation and to monitor temperature once the chamber is

Table 1
Different crop rotations and fallow systems during 2010 and 2011 at Pingelly.

2010 Treatment	2011 Treatment
Wheat (cultivar Magenta)	Wheat (Magenta)
Canola (cultivar Cobbler TT)	Wheat (Magenta)
Fallow – cultivated (weed free using shallow tillage)	Wheat (Magenta)
Fallow – chemical (weed free with herbicides)	Wheat (Magenta)
Fallow – weedy	Wheat (Magenta)
Fallow – chemical mid (weedy until mid-Aug then sprayed with herbicides)	Wheat (Magenta)