Winter cover crop biomass production and water use in southeast Queensland

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Abstract

Cover crops (CC) have the potential to improve fallow efficiency by producing ground cover. Ground cover enhances rainfall infiltration and reduces soil evaporation. However, excessive CC water use can deplete soil moisture, negating any potential benefits. Thus, a delicate balance is required between CC biomass production for ground cover and CC water use. This study investigated biomass production and water use of four winter CC treatments against a bare fallow: 100% common vetch (*Vicia sativa* subsp. *sativa* L.), 100% forage oat (*Avena sativa* L.), 100% forage rape (*Brassica napus* L.) and an even three-way mixture of these species. The forage oat, rape and three-way mixture produced two-fold more biomass than vetch. At CC termination, the fallow had significantly ($P < 0.05$) greater plant-available water (101 mm) than the CC treatments. Forage rape used the most water (64 mm) but provided greater water accumulation post-termination (53 mm). Fallow efficiency did not differ significantly ($P > 0.05$) between the treatments. Post-termination, soil water accumulation ranged from 21-53 mm in the CC treatments. The results demonstrate that CCs can improve fallow efficiency subject to adequate rainfall post-termination. Further research is needed to determine the agronomic and economic implications of winter CC biomass production and water use on subsequent summer cash crops under different management options.

Keywords

Fallow, crop rotation, fallow efficiency, ecosystem services, trade-offs.

Introduction

The dryland crop rotations of southeast Queensland (SEQ) utilise the use of fallow periods to recharge soil water and soil mineral nitrogen (SMN) to stabilize crop yield and minimize crop failure in the subsequent season. Recent research has demonstrated that bare fallows are inefficient in conserving water and SMN and can promote soil degradation through depletion of soil organic matter (SOM) (Blanco-Canqui *et al.*, 2013) and soil erosion (Schillinger et al., 2010).

An alternative paradigm to bare fallowing is to intensify the crop sequence by replacing part of the fallow period with non-harvested crops; cover crops (CC) as part of an ecological intensification approach. The potential to reduce the time that land is bare fallowed is an important management issue in semi-arid areas such as SEQ, where crop production is opportunistic, and the risks and economics associated with forecast precipitation and soil storage dictate cropping decisions (Fischer, 2009). Integrating CCs into existing crop rotations has been shown to provide a range of agroecosystem services, such as water conservation (Whish *et al*., 2009), N supply and retention (Wunsch *et al*., 2017), and weed suppression (Daryanto *et al.*, 2018).

The integration of CCs into dryland crop rotations is fraught with risk due to the potential of excessive soil water consumption during CC growth not being compensated post-CC termination by sufficient rainfall and improved soil moisture conservation. Therefore, the management of CCs for fallow replacement requires a delicate balance between CC water use, N supply and retention, and subsequent crop yield. To increase the adoption of CCs in SEQ, it is critical to evaluate how CCs alter soil water dynamics and whether and how CCs reduce soil water for the subsequent crop. This study investigated the water use of different CC types as fallow replacement option. This will support the design of alternative diverse crop rotation systems that are water use efficient and adapted to SEQ.

Methods

A field experiment was initiated during the 2020 winter season at the Gatton campus, The University of Queensland (27°32'05" S, 152°20'24" E, 92 m a.s.l). The soil has plant available water capacity (PAWC) of 200 mm for 0−1.2 m profile and is a self-mulching, seasonally cracking dark brown vertosol. Before trial establishment, soil core samples were collected from across the experimental site and sectioned into five depth strata (0−0.1, 0.1−0.3, 0.3−0.6, 0.6−0.9, and 0.9−1.2 m). These were composited to form a single sample per depth strata and analyzed for physical and chemical properties (Table 1). Sub-samples of the undisturbed samples at CC sowing were taken to determine the soil water characteristics of crop drained upper limit (DUL) and crop lower limit (LL15). The DUL and LL15 were determined using Ceramic Pressure Plate Extractor (Agro-Ecosystems Soil Management Solutions (http://thinksoils.org/). PAW was determined by subtracting the LL15 from the total soil water content and summed for the soil profile.

The fallow replacement CC treatments consisted of common vetch (*cv* Morava), forage oat (*cv* Comet), and forage rape (*cv* Greenland SF). These were planted as monocultures of each of the three species, a pro-rata mixture (at 33 % of monoculture seeding rates of each species), and a bare fallow. Treatments were laid out in a randomized complete block design with four replications. The seeding rates were 40 kg ha^{-1} for forage oat and common vetch and 4 kg ha^{-1} for forage rape, respectively. The plots were incorporated with starter GranulockZ (11 % N, 21.8 % P, 4 % S, and 1% Zn). Seeds were drilled in 8 m × 5 m plots using a 2.7 m double disc planter on 35 cm row spacing. To ensure CC growth during the drought, supplementary irrigation was applied to bring the total precipitation plus irrigation within the 30-year long term average (1989-2019). Cover crops were terminated at forage oat stem elongation, (90 days after sowing), using glyphosate (450 g L^{-1} isopropylamine) at 2.4 L ha^{-1} and Sharpen (700 g kg^{-1} saflufenacil) plus 1% v/v Hasten adjuvant. At CC termination, CC biomass was harvested by cutting plants at a surface level from a 1 m^2 quadrat on the four middle rows of each plot. Samples were oven-dried at 60°C for seven days until constant weight, then weighed and expressed as tons ha^{-1}.

Soil water was measured at CC sowing and termination at 0−1.2 m depth to determine the change in soil water due to cover cropping. Post termination soil water was determined at 70 days after termination (DAT) and 110 DAT (at sowing of the subsequent maize crop) to determine the temporal effects of cover residue decomposition on soil water dynamics. Seasonal cover crop water use (SWU) was estimated as a residual of the soil water balance as expressed in Equation [1]:

$$SWU = (PAW_s - PAW_t) + (I + P) \qquad [1]$$

Where PAW_s and PAW_t are plant available water at sowing and termination (mm), I is irrigation (mm), P is precipitation (mm). The SWU was used together with cover crop aboveground biomass to estimate water use efficiency (WUE; kg ha^{-1} mm^{-1}). Soil water extraction (or accumulation) by the cover crops was determined as the difference between the change in PAW in the cover crop and bare fallow at CC termination and at the end of fallow period (110 DAT).

Table 1. Baseline soil physical and chemical properties at Gatton Crops Research Unit during the 2020 winter season

Soil depth (m)	bulk density (g cm^{-3})	SMN (kg N ha^{-1})	Colwell-P (mg kg^{-1})	Colwell K (cmol^{+} kg^{-1})	Organic Carbon (%)	pH (in water)	DUL (mm^3 mm^{-3})	LL15 (mm^3 mm^{-3})	PAWC (mm)
0.0-0.1	1.2	33	147	1.6	1.8	7.1	0.36	0.19	17
0.1-0.3	1.4	47	95	0.9	1.1	7.3	0.36	0.22	28
0.3-0.6	1.3	53	89	0.5	0.9	7.7	0.4	0.23	51
0.6-0.9	1.3	32	56	0.5	0.7	8.1	0.39	0.23	51
0.9-1.2	1.3	34	51	0.5	0.6	8.2	0.4	0.23	53

Results

Precipitation during the study period was generally below the average of long-term precipitation. The in-CC rainfall (March-June) was 81 mm. This represents about 79% of the long-term average precipitation (1989-2019) and was therefore supplemented with 125 mm of irrigation (Figure 1a). This provided conditions for quantifying biomass production and water use across a range of fallow replacement cover crops.

Biomass production differed significantly ($P < 0.05$) between the cover crop treatments (Table 2). The forage rape and mixture produced the most biomass (> 6 t DM ha^{-1}), which was more than three-fold of the biomass produced by the common vetch treatment (1.7 t DM ha^{-1}). Forage oat produced 4.9 t DM ha^{-1}, which was statistically equivalent to the forage rape and mixture treatments.

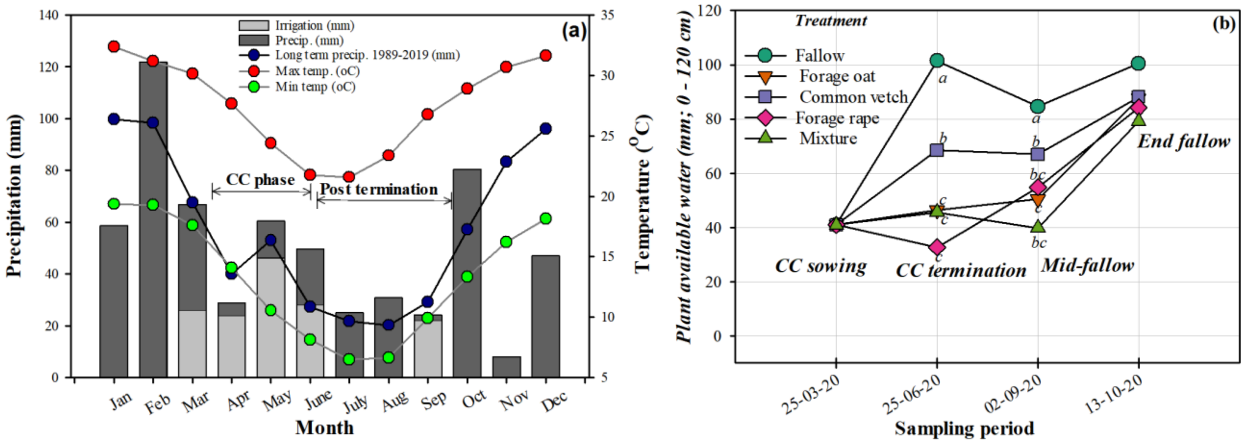

Figure 1. ***(a)*** **Precipitation, irrigation (mm), air minimum and maximum temperatures (°C) during the cover crop growing season and the post-termination period in 2020,** ***(b)*** **Changes in plant available water (mm; 0 – 1.2 m) from planting cover crops to the end of fallow.**

Plant-available soil water (0–1.2 m) at cover crop sowing averaged 40 mm. Following termination of the cover crops, PAW in the bare fallow control treatment was significantly higher than after cover crop treatments (Figure 1b). The mixture and the forage oat had similar PAW at termination, while the forage rape has the lowest PAW (36 mm). Soil water extraction at termination differed significantly between the treatments and the forage rape extracted the most water (64 mm). No significant difference ($P > 0.05$) was observed between the cover crop treatments at the end of fallow. At the end of fallow, PAW did not change significantly in the bare fallow treatment (Table 2). Water accumulation following recharge post-termination was greatest in forage oat and rape (53 mm) and lowest in common vetch (21mm). Fallow efficiency did not differ significantly between the treatments as there was no significant reduction in soil water at the end of fallow.

Table 2. Cover crop water extraction (mm) relative to bare fallow, accumulated fallow water (mm), seasonal water use (mm), and water use efficiency (kg ha^{-1} mm^{-1}) of the different treatments. SE - standard error of means (*n* = 4). Means within a column not connected by the same letter(s) are significantly different ($P < 0.05$) using Tukey HSD test

Cover crop treatment	Aboveground biomass (t ha^{-1})	Water extraction relative to fallow (mm)	Accumulated PAW during fallow (mm)	Seasonal water use (mm)	Fallow efficiency (%)	WUE (kg DM ha^{-1} mm^{-1})
Fallow	-	-	-1	222^{a}	25	-
Forage oat	4.9^{a}	-52.9^{ab}	42	167^{b}	19	29.9^{a}
Common vetch	1.7^{b}	-37.6^{a}	21	189^{b}	20	9.1^{b}
Forage rape	6.3^{a}	-63.9^{b}	53	153^{a}	18	41.3^{a}
Mixture	6.2^{a}	-45.3^{ab}	35	166^{b}	21	37.8^{a}
SE ±	0.43	4.28	10.4	6.2	2.5	3.57

At CC termination, bare fallow had greater PAW because of less water use due to lack of growing crop. The common vetch similarly had higher PAW than forage oat, forage rape, and mixture, likely due to less biomass production and lower water extraction. Although water accumulation was achieved post-termination of cover crops due to reduced evaporation rates by cover crop residue, there was generally insufficient water recharge to compensate for cover crop water use during the cover crop phase. Cover crops that had higher biomass production provided the greatest water accumulation and water use efficiency. This study demonstrated that grass and brassicas are superior to legumes in the provision of biomass input, and the mixture was not superior to the monoculture of forage oat and forage rape in biomass production and water accumulation. Using experiment and crop simulation, Whish et al. (2009) and Wunsch et al. (2017) reported greater benefit of grass cover crop in biomass production and groundcover provision than legumes. In this study, forage oat proved a better winter cover crop choice in the SEQ due to high biomass production, lower water extraction, and greater water accumulation post-termination. Although forage rape produced a significant amount of biomass, it extracted a large amount of soil water and had the lowest fallow efficiency, possibly due to rapid decomposition of its residues. This suggested a greater water use risk with forage rape than with forage oat.

Conclusion

The decision to either plant a winter CC or to winter fallow prior to the sowing of the main summer cash crop will largely depend on the possible water use cost of the cover crop and the management practices. Our results demonstrate that winter CCs may be grown in SEQ without causing a significant reduction in PAW at sowing of the main summer cash crop. Additionally, the CC mixture did not provide greater agronomic benefits than single species forage oat or forage rape. This provided evidence that CC can be grown in place of bare fallow with minimal water cost at the same time offsetting the negative effects of bare fallow by providing additional organic carbon stock, reducing N fertilizer requirement and potentially improve the productivity of the subsequent summer cash crop. Further research is needed to explore the short- and long-term agronomic and economic implications of cover cropping and how cover crops best fit within the dryland cropping system of SEQ.

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