Final Technical Report

Quantifying the effectiveness of cover crops to increase water infiltration and reduce evaporation in the northern region

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Abstract

Effective capture and storage of rain are major challenges for grain and cotton growers in the northern region where only 20-40% of rainfall is typically transpired by dryland crops, with 60% of rainfall lost to evaporation, and 5-20% lost in runoff and deep drainage. Recent research showed cover crops and increased stubble loads could reduce evaporation, increase infiltration and provide net gains in stored soil water over traditional fallow periods.

This project ran 13 experiments on low-cover fallows around Yanco, Parkes/Canowindra and Goondiwindi. The best cover crop treatments recovered the 40-60 mm water deficit taken to grow them by the end of the fallow in most experiments, which modelling suggests may happen ~70% of years at Goondiwindi. While some cover crops stored up to 38mm extra plant available water, others lost water in some very dry seasons. It seems that cover crops can protect the soil from erosion in low cover fallows and maintain stored water in a majority of years.

The amount of stubble required to achieve major reductions in erosion is relatively low and easily achieved. Cover crops that produced 1 t/ha dry matter were predicted to reduce long-term erosion by up to 82%, 2 t/ha by 96% and 3 t/ha by 99%. In dry years, the feed value of cover crops that were grazed easily exceeded the loss of grain yield from the water lost from the fallow. Interestingly, cotton and wheat yield increases were larger than expected from this stored water alone and deserve further investigation to understand the underlying causes and potential across the northern region.

Executive Summary

Cover crops are not new. They can protect the soil from erosion, supress weeds, boost nitrogen levels when legume species are included, and maintain soil organic matter for healthy soils that support greater biological activity. They have been most widely used by organic and low input farmers.

Plant Available Water (PAW) is ‘king’ in northern farming systems where dryland crops use only 20-40% of the rainfall; approximately 60% lost to evaporation and 5-20% lost as runoff and drainage. So, growing crops that do not produce grain or fibre is typically considered ‘wasteful’ of both rainfall and irrigation. However, recent research has supported grower experience that cover crops may provide their benefits with little or no loss of soil water.

Consequently, Queensland’s Department of Agriculture and Fisheries, NSW Department of Primary Industries and CSIRO recently joined forces with funding from the Grains (GRDC) and Cotton (CRDC) Research and Development Corporations to assess the impact of cover crops on the net soil water accumulation of fallows for grain and fibre crops. This research went beyond the previous limited on-farm research, and focused on the following research question(s) using rigorous soil water measurement across cover crops in low-cover fallows and the subsequent ‘cash’ crops:

1. *Can cover crops increase the net water accumulation (Plant Available Water) in grain and cotton systems with low ground cover (<30%) in the northern region?*
    - *What is the net water cost to grow the cover crops?*
    - *What is the net water gain to subsequent grain/cotton crops (fallow & early crop growth)?*
    - *What is the impact on the yield of the subsequent grain/cotton crops?*

2. *Can cover crops improve fallow efficiency and accumulate 20 mm more Plant Available Water?*

The project was conducted across three dry to very dry seasons with some sites experiencing the driest fallows on record; a real test for cover crops that use valuable stored water. However, the best cover crop treatments across the project’s 13 experimental sites typically recouped their water deficits at termination to finish the fallows with similar or better soil water levels than the Control treatments. There were several experiments where the best cover crop treatments ended the fallow with less stored soil water than the Control.

With support from simulation modelling to ‘stretch’ the findings and develop general insights, the project has shown that:

1. Yes; cover crops can increase the net water accumulation of Plant Available Water in grain and cotton systems with low ground cover in the northern region…but not always! Regional, seasonal and industry differences with dryland and irrigated systems led to a range of results;

    - The net water cost to grow cover crops is between 40-60 mm for well-managed crops terminated by anthesis for maximum biomass. The deficit depends on the species selected, the timing of termination and the seasonal conditions with rainfall during the cover crops growth. Mismanagement to let cover crops grow longer than required for the level of cover needed in the intended fallow led to soil water deficits over 100 mm,

    - The net water gain at planting of the subsequent grain and cotton crops from these well-managed cover crops with appropriate species and termination timings for the planned fallow ranged from -30 mm to +38mm. Soil water used to grow the cover crops was recovered at five sites, with net losses at three sites and net gains at three others.

      Simulation modeling based on the Bungunya data, and using a water deficit of 20 mm/t DM produced by the cover crops (this is at the highest end of the experimental data), predicted 1 t DM/ha cover crops (~ early termination, first node) would recover or better the net water accumulation of the low-cover fallows in 70% of years and the 3 t DM/ha (~ mid-termination, flag leaf) in 45% of years with a mean gain of 15-17 mm, and

    - Yield trends in the subsequent wheat and cotton crops reflected the trends in soil water; more water generally meant more subsequent yield. Yield losses of up to 1.5 t/ha in dryland wheat were experienced in the 2019 drought year at Canowindra. However, there were also yield gains of up to 1.4 t/ha of dryland wheat at Bungunya and 3-4 bales/ha in irrigated

cotton at Yelarbon. These gains far outweighing expectations for extra stored water alone, and while better establishment may explain some of this difference at Bungunya, there is scope for future research to understand other possible contributors.

2. Yes; cover crops can improve fallow efficiency and accumulate 20 mm more Plant Available Water in some years, but not others. The 17 mm mean extra water accumulation noted above is close to the targeted 20 mm, and while both are at the extremes of statistical significance for our data, at a Water Use Efficiency of 15 kg/mm equates to 255 kg/ha wheat, right in the middle of the Bungunya collaborator's long-term cover cropping expectation of a 200-300 kg/ha yield benefit.

The large body of work conducted and presented across the northern region over the last three years has provided valuable quantitative data at a time of need for the grain and cotton industries; during a prolonged drought when many growers have faced low-cover situations and difficult decisions. The importance and value of the research is evident in invitations to present results that can help industry make decisions to over 2200 growers and agronomists in the last 2 years, at GRDC updates; Crop Solutions, CottonInfo and Crop Consultants Australia groups; RDE agency reviews and other regional meetings. These invitations with their supporting papers and feature articles in GRDC Groundcover, Australian Grain/Cotton Grower, The Land and ABC radio confirm the project's value and the continuing interest in the potential of cover crops.

Ultimately, the project data suggest that cover crops can protect the soil from erosion, and maintain or increase accumulated soil water storage in 45-70% of years in low cover fallows. When conditions are not extremely wet or extremely dry, cover crops can provide average net benefits of 15-17 mm for short and long fallows respectively. The amount of stubble required to achieve major reductions in erosion is relatively low and easily achieved. Cover crops that produced 1 t/ha dry matter were predicted to reduce long-term erosion by 82%, 2 t/ha by 96% and 3 t/ha by 99% at the Bungunya site.

Consequently, the decision to use cover crops will rely on the topography of the paddock, whether existing levels of cover will go below 30%, individual crop sequencing strategies, whether there is sufficient stored moisture to simply plant an appropriate cash crop, and the season climate forecasts. There was no apparent additional value from multi-species cover crops with cereal providing the best results, so the subsequent decisions will be based on termination timings to suit short (early termination) or long (mid-termination) fallows.

Importantly, the project has measured much larger yield impacts at some dryland grain and irrigated cotton sites; up to three times larger than can be explained by differences in soil water alone. These responses appear to be due to better establishment, increased in-crop infiltration, better water extraction, and perhaps improved soil biology. All results come from a series of dry and extremely dry seasons, so there is a need to confirm findings and model predictions with field experiments in more favourable years to build confidence for on-farm recommendations across the northern region.

There is still much to learn from continued research into cover crops and their contribution to closing our 'systems yield gap' for the enduring profitability of our farming systems.

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Background

Cover crops have been used to protect the soil from erosion and increase infiltration in low stubble situations, return biomass to maintain organic matter and biological activity, and to fix nitrogen when legumes are used. On-farm research in southern Queensland and Northern NSW also suggests that short-term cover crops can also reduce evaporation, increase infiltration and even provide net gains in Plant Available Water over the traditional fallow periods (Price et al. 2007).

More effective capture and storage of rainfall remains a major challenge for grain and cotton growers in the northern region, where only 20-40% of rainfall is typically transpired by dryland crops, with up to 60% of rain lost to evaporation, and 5-20% lost in runoff and deep drainage.

Ground cover is key to soil water storage, protecting the soil from raindrop impacts and so improving infiltration to store more water in the soil with less erosion. Consequently, growers have used cover crops to overcome the lack of stubble following low-residue crops (e.g. chickpea) or following skip-row sorghum with uneven stubble and exposed soil in the 'skips'.

Millets and sorghum have been sown and sprayed out within ~60 days to allow recharge in what are normally long fallows across the summer to the next winter crop. Allowing these millet 'cover crops' to grow through to maturity led to significant soil water deficits and yield losses in the subsequent winter crops. However, only small deficits (and even water gains) accrued to the subsequent crops when the millets were sprayed out; with average grain yield increases of 0.36 t/ha (Price et al 2007), valuable productivity gains for more profitable and more sustainable grain and cotton systems.

Conventional wisdom is that increased stubble loads can also slow down the initial rate of evaporation, but that these gains are short-lived and lost from accumulated evaporation after three to four weeks (Bond and Willis 1969). However, further rain within this period provides the opportunity to reduce total evaporation and to accumulate more Plant Available Water across the whole fallow (Photo 1). Indeed, each 10 mm more (or less) Plant Available Water may increase (or reduce) grain yields by about 150 kg/ha, with analogous benefits also expected for cotton growers

This project was established by the Queensland Department of Agriculture and Fisheries, NSW Department of Primary Industries, and CSIRO with support from both GRDC and CRDC to assess the effectiveness of cover crops to increase soil water accumulation in fallows in the northern region.

Photo 1. The stubble effect three days after ~30 mm of rain at Bungunya, with a rolled cover crop in the foreground and a low-cover fallow plot behind it. The stubble reduces evaporation and keeps the soil surface wetter for 3-4 weeks, so more water will be stored if rain falls in that time (A. Erbacher, 24/04/2018)

Project objectives

The project was focused on the impacts of cover crops on the water dynamics of grain and cotton systems. It aimed to provide rigorous data on the gains and losses of soil water from cover crops to complement farmers' anecdotal evidence and initial data from on-farm studies with large strips on commercial farms. The focus was to quantify the impact of different stubble loads on the accumulation of rainfall, the water required to grow a range of cover crops that provide sufficient stubble loads, the net water gains/losses across the fallows with these different cover crops, and the impacts on the growth and yield of the subsequent cereal and cotton 'cash' crops. Specifically, to answer the following key research questions:

1. *Can cover crops increase the net water accumulation (Plant Available Water) in grain and cotton systems with low ground cover (<30%) in the northern region?*
    - *What is the net water cost to grow the cover crops?*
    - *What is the net water gain to subsequent grain/cotton crops (fallow & early crop growth)?*
    - *What is the impact on the yield of the subsequent grain/cotton crops?*

2. *Can cover crops improve fallow efficiency and accumulate 20 mm more Plant Available Water?*

Answers to these questions will allow growers and their advisers to assess the likely costs, benefits and risks of using cover crops to manage soil water in their own farming systems.

Methodology

Thirteen (13) experiments were conducted to quantify the impact of cover crops in irrigated cotton and dryland grain cropping systems. The experiments targeted the scenarios in which cover crops are currently being used by cotton and grain growers: For cotton, short-fallows in back-to-back cotton systems, and long-fallows following low cover crops like chickpea before going back into cotton; For grains, long-fallows after skip-row sorghum (Photo 2) and again following low-cover crops such as chickpea; or in prolonged drought. Each year there were two cotton and two grain experiments.

Queensland experiments targeted cover crops in individual fallows and legacy effects on the next grain or cotton 'cash' crop. NSW experiments complemented that, targeting sequences across two years in which the different cover crops were repeated as part of the cropping system (Table 2).

Photo 2. Example of variable cover left after skip-row sorghum at Yagaburne). Some stubble from the previous wheat remained in the otherwise bare skip-row (A. Erbacher, 20/11/2017)

Experiments had up to 13 treatments and five replications in 6x20 m plots with summer and winter cereals, legumes, brassicas, and multi-species mixture cover crops to suit the season and location (Photo 3). Three termination timings were typically used to 'spray-out' cover crops crops at key growth stages; establishing a greater range of dry matter production, groundcover and water use than commercial practice before the fallow recharge phase for the subsequent 'cash' crops (e.g. Table 1):

- Early-termination at first node (Z31) after ~40 day when the crop begins stem development;
- Mid-termination at flag leaf emergence (Z41) after ~50-60 days as reproductive phase begins;
- Late-termination at anthesis (Z65) after ~70 days for peak biomass production.

The NSW cereal sites used later termination timings to suit their conditions and systems, typically 50 days, 80 days and 110 days after sowing.

Measurements aimed to capture water dynamics across the fallow, dry matter and cover levels, and the water use by the cover and cash crops. Soil water was estimated with soil cores (gravimetric) at key times across the fallow and subsequent 'cash' crops, along with Neutron Moisture Meters (NMM) and EM38 readings in each plot. These NMM and EM38 readings, biomass and the percentage ground cover were recorded every two-to-four weeks while the cover crops were growing, and every four weeks in the fallow once all cover crops were terminated. Soil water measurements continued every four weeks in the growing crop until a final assessment when the 'cash' crops were harvested.

Table 1. Example of typical cover crop treatments (Yagaburne, Qld prior to planting wheat)

Treatment No.	Cover crop and termination timings
1	Bare (Control, < 10% cover)
2	Wheat; Early spray-out
3	Wheat; Mid spray-out
4	Wheat; Late spray-out
5	Wheat; Late spray-out + rolled
6	Winter Multi-species (wheat, vetch, radish); Mid spray-out
7	White French millet; Early spray-out
8	White French millet; Mid spray-out
9	White French millet; Late spray-out
10	White French millet; Late spray-out + rolled
11	Sorghum; Mid spray-out
12	Summer Multi-species (millet, lab lab, radish); Mid spray-out

Photo 3. Example of cover crop plots; White French millet, Tillage radish and the low-cover control treatments in a fallow at Bungunya (Andrew Erbacher, 20/11/2017)

Location

Table 2. Location and focus of individual experiments

	Latitude (decimal degrees)	Longitude (decimal degrees)
Trial Site #1	-28.6381	150.5164
Nearest Town	Yelarbon (winter cover crops on a short fallow for pivot irrigated back-to-back cotton)	
Trial Site #2	-28.1268	149.8749
Nearest Town	Bungunya (summer cover crops on a long fallow for dryland wheat after skip-row sorghum)	
Trial Site #3	-28.4030	150.1521
Nearest Town	Goondiwindi (winter & summer cover crops after chickpea before irrigated cotton & grain; not planted)	
Trial Site #4	-28.0669	150.4754
Nearest Town	Yagaburne (winter & summer cover crops before wheat)	
Trial Site #5	-28.1011	150.3320
Nearest Town	Billa Billa (summer cover crop & wheat stubble comparison before wheat)	
Trial Site #6	-28.1087	150.0450
Nearest Town	Lundavra (wheat stubble loads & heights versus cover crops)	
Trial Site #7	-29.1059	150.3411
Nearest Town	Croppa Creek (barley cover crops before overhead irrigated cotton; not planted)	
Trial Site #8	-32.8851	148.0290
Nearest Town	Parkes (short fallow systems with summer cover crops for grain)	
Trial Site #9	-32.8851	148.0290
Nearest Town	Parkes (long fallow systems with summer cover crops for grain)	
Trial Site #10	-33.4620	148.7267
Nearest Town	Canowindra (short fallow systems with summer cover crops for grain)	
Trial Site #11	-33.4620	148.7267
Nearest Town	Canowindra (long fallow systems with summer cover crops for grain)	
Trial Site #12	-34.6084	146.4140
Nearest Town	Yanco (system study cover crop sequences under flood irrigation for cotton)	
Trial Site #13	-34.6084	146.4140
Nearest Town	Yanco (Spray-out timing study of winter cover in flood irrigated cotton beds; to match other locations)	

Table 3. Applicable GRDC agro-ecological zones and regions for the project's research

Research	Benefiting GRDC Region	Benefiting GRDC Agro-Ecological Zone (see link: http://www.grdc.com.au/About-Us/GRDC-Agroecological-Zones) for guidance about AE-Zone locations	
All experiments	Northern Region	☒ Qld Central ☒ NSW NE/Qld SE	☒ NSW Central ☒ NSW NW/Qld SW

The project was conducted during an extremely dry period that included one of our worst droughts on record, precluding sowing of some sites due to insufficient stored soil water and irrigation supplies. Droughts are one scenario for using cover crops. However, the prolonged drought means results also reflect some of the worst case scenarios for recharging soil water following cover crops.

Results

The following is a summary of key findings from the project's 13 experiments, illustrated with selected results. Details of specific experiments are in attachments loaded onto the GRDC portal.

Cover crop biomass and ground cover

The cereal cover crops were most effective in producing and maintaining ground cover. They produced more dry matter and ground cover than the brassica and legume treatments that were slower to grow cover and faster to breakdown. The cereals established between 2,500-4,000 kg/ha of dry matter (DM) for the mid-termination treatments typically used in commercial plantings, the late terminations between 4,000-5,000 kg/ha, and the 'very late' crops and those grown through to harvest produced up to 10,000 kg DM/ha (Figure 1). The exceptions were two severely 'droughted' plantings, such as the Yagaburne experiment that only grew between 100-500 kg DM/ha for the winter cover crops and 500-2,500 kg DM/ha for the summer cover crops. However, all experiments successfully increased ground cover levels from ~10% in the control treatments, to over 50% in the 'droughted' sites trials, and between 60-95% in the other locations (Figure 2).

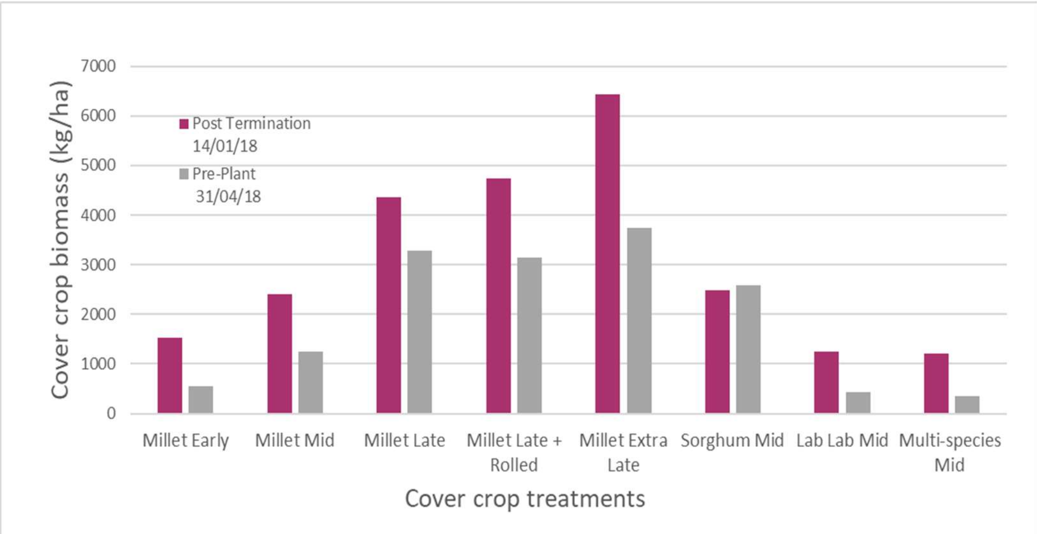

Figure 1. Above-ground biomass from termination of cover crops to the end of the fallow (Pre-plant of the cash crop) at Bungunya

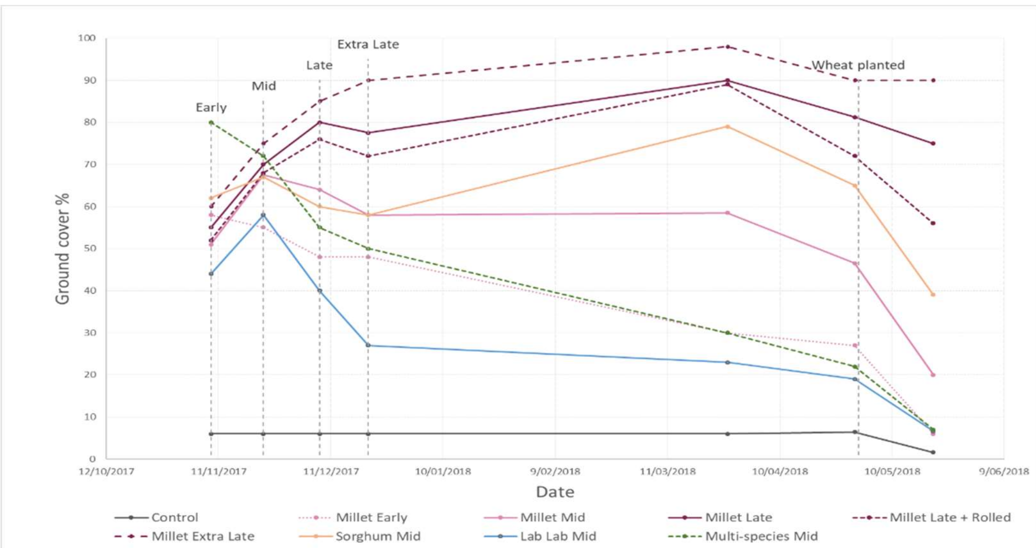

Figure 2. Ground cover assessments at Bungunya show good and resilient cover with cereal treatments

Fallow water dynamics

Fallow water accumulation was the focus of the project. Critically, the best cover crop treatments typically recouped their water deficits at termination to finish the fallows with similar or better soil water levels as the Control treatments (Table 4). However, there were several experiments where the best cover crop treatments still ended the fallow with less stored soil water.

In most cases, the differences in soil water to 150 cm were below, or at the extremes of those needed for statistical significance of the key cover crop treatments (between 12 and 40 mm for each experiment, P=0.05). Extreme treatments that used more water or did not maintain cover (e.g. very late termination, harvested cereals, terminations without subsequent fallow rain, some tillage radish treatments,) did finish the fallows with significantly less stored soil water (P=0.05). The natural variation in soil water made it difficult to confidently measure differences; something commonly seen in soil water studies. Analyses of the focal 0-90 cm depth reduced variation. However, the differences for the key commercially relevant treatments were still at the limit of significance (P=0.1).

Despite these limitations, the trends in the results were very consistent across sites and treatments, and reflected expectations from theories of soil water storage and use. The results, best illustrated for summer cover crops at Bungunya (Figure 3) and Yelarbon (Figure 4), matched simulation/modelling case studies.

The soil water trends at each site were clearly reflected in almost all the crop yields, ultimately building confidence that observed treatment effects were real. These net water trends for the focal (commercial) cover crop treatments across sites were: a net loss of stored soil water at three sites (Parkes, Canowindra, Billa Billa summer cover crops); recovery to similar net water storage at four sites (Yanco systems study, Yagaburne, Goondiwindi, Croppa Creek), and net water gains at three sites (Bungunya, Yelarbon, Yanco sprayout timing trial).

Lundavra was established to compare management of traditional wheat stubble loads and harvest height to a range of cover crops. Ultimately, the cover crops were not planted due to drought. The wheat stubble treatments stored just 23 mm from harvest until the end of February and 1 mm net fallow accumulation until the monitoring concluded in June the following year.

Table 4. Summary of fallow water storage for 'Control' (~10% cover) and the cover crop treatments

Cover crop experimental sites	Fallow water storage (Control)	Fallow water balance compared to the Control	
		Best cover crop	Worst cover crop
Yelarbon: (winter cover crops, short fallow for pivot irrigated back-to-back cotton)	56 mm	+38 mm	-4 mm
Bungunya (summer cover crops, long fallow for dryland wheat after skip-row sorghum)	42 mm	+31 mm	-5 mm
Goondiwindi (winter/summer cover crops after chickpea before wheat/irrigated cotton): Not planted; lack of irrigation water	30 mm	+10 mm	-8 mm
Yagaburne (winter & summer cover crops before wheat)	14 mm	+6 mm	-19 mm
BillaBilla (summer cover crop after chickpea vs wheat stubble before a return to wheat)	28 mm	0 mm	-55 mm
Lundavra (wheat stubble loads & heights versus cover crops): Not planted, too dry	-	-	-
Croppa Ck (barley cover crops before pivot irrigated cotton): Not planted; lack of water	11 mm	+20 mm	0 mm
Parkes (short fallow systems with summer cover crops for grain)	24 mm	-5 mm	-63 mm
Parkes (long fallow systems with summer cover crops for grain)	79 mm	-14 mm	-41 mm
Canowindra (short-fallow system, summer cover crops for grain)	6 mm	+8 mm	-16 mm
Canowindra (long-fallow system, summer cover crops for grain)	-42 mm	+14 mm	+3 mm
Yanco (cover crop systems under flood irrigation for cotton)			
Yanco (winter cover crops, short fallow flood irrigated cotton beds)	12 mm	-6 mm	-37 mm

Soil water deficits to grow cover crops

The net-water-deficit (cost) at termination of the cover crops varied with the growth stage, the species, their water use and the cover provided, and the season with differing amount and timing of rain while they grew (Figure 3, Figure 4). The typical net-water-deficit to grow the cover crops for early-termination was ~40 mm (range 0-50 mm) and mid-termination ~50 mm (range 20-70 mm); late termination ranged from 30-120 mm, showing that timely removal is critical to avoid dramatic losses.

Net fallow water accumulation

The recovery of soil water from these deficits after termination was equally dramatic and consistent across the project. The drier soil profiles and extra cover boosted infiltration and storage of water for the rest of the fallows in-line with theory. The millet cover crop at Bungunya (Figure 3), was planted on ~120 mm of Plant Available Water, used 50-60 mm more water than the control fallow through to late-termination but, had an overall fallow efficiency of 17% for the whole fallow compared to 14% for the bare fallow. This was due to its very high fallow efficiency (>70%) in the shorter period once the cover crop was sprayed out.

Similar results across sites saw most treatments recover the deficits on the next major rain events and then finish with similar levels of soil water by the end of the fallow (see attachments). Exceptions included the late terminations that were too late for their larger deficits and so took longer or did not fully recover, and some legume and brassica cover crops without the resilient cover to last the whole fallow. The other exceptions were when the most appropriate cover crop treatments (early termination for short fallows; late terminations for long fallows) finished with more stored water than the traditional fallow, presumably as more cover protected the soil from raindrop impacts and soil micro-pores and roots channels helped water movement.

Simulation modelling from the Bungunya experiment, using a water deficit of 20 mm/t DM produced by the cover crops (this is at the highest end of the experimental data), showed little benefit from cover crops in the very wet and dry seasons (Figure 5a). In the wettest 5% years, all systems were predicted to finish with similar moisture levels, albeit with significant erosions risks. Whereas the driest years saw net water losses in 10% of years for early terminations and up to 50% of years for late terminations with at least 3 t/ha of biomass. This conservative analysis means cover crops can recoup or improve soil water storage in a wide range of conditions (Rainfall percentiles 25-95%, 70% of years) for early terminated crops producing ~ 1 t DM/ha and a smaller set of years (Rainfall percentiles 50-95%, 45% of years) for later terminations producing 3 t DM/ha. For these later years with in-fallow rainfall of 200-500mm, net soil water accumulation was predicted to increase by 17mm on average; close to the 20 mm sought in the project's second research question.

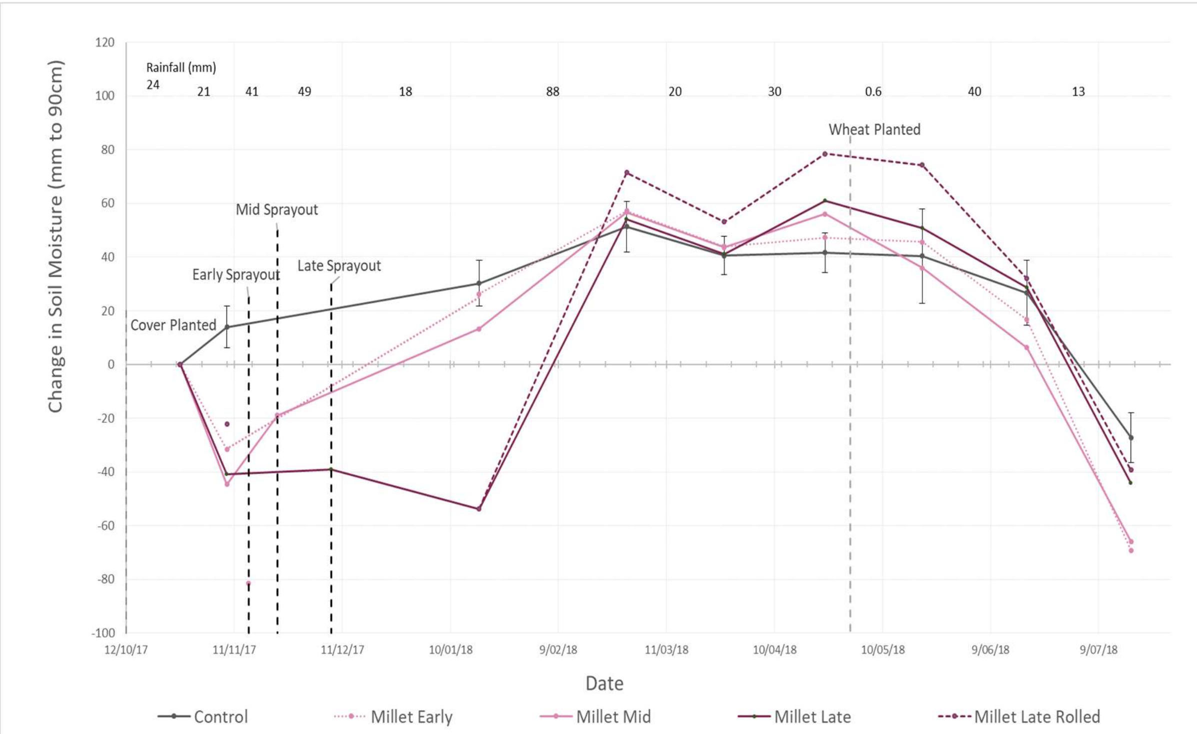

Figure 3. Changes in soil water to 90 cm after planting summer cover crops until canopy closure of the subsequent dryland wheat crop at Bungunya (with standard error bars on Control treatment)

Additional insights from irrigated cotton systems

Irrigated cotton was planted after cover crops at both Yelarbon and Yanco. At both sites, infiltration rates in the early stages of the crop were higher with cover crops. At Yelarbon this occurred even when cover crops had higher soil water levels (Figure 4). At Yanco, the late spray-out cover crops had increased infiltration from longer irrigation run-times for the first irrigation to flush up the dry sown cotton, presumably from drier soil after the larger cover crop, but also from extra cover directly slowing the water flow, leading to these plots having higher soil water levels in later stages of the experiment.

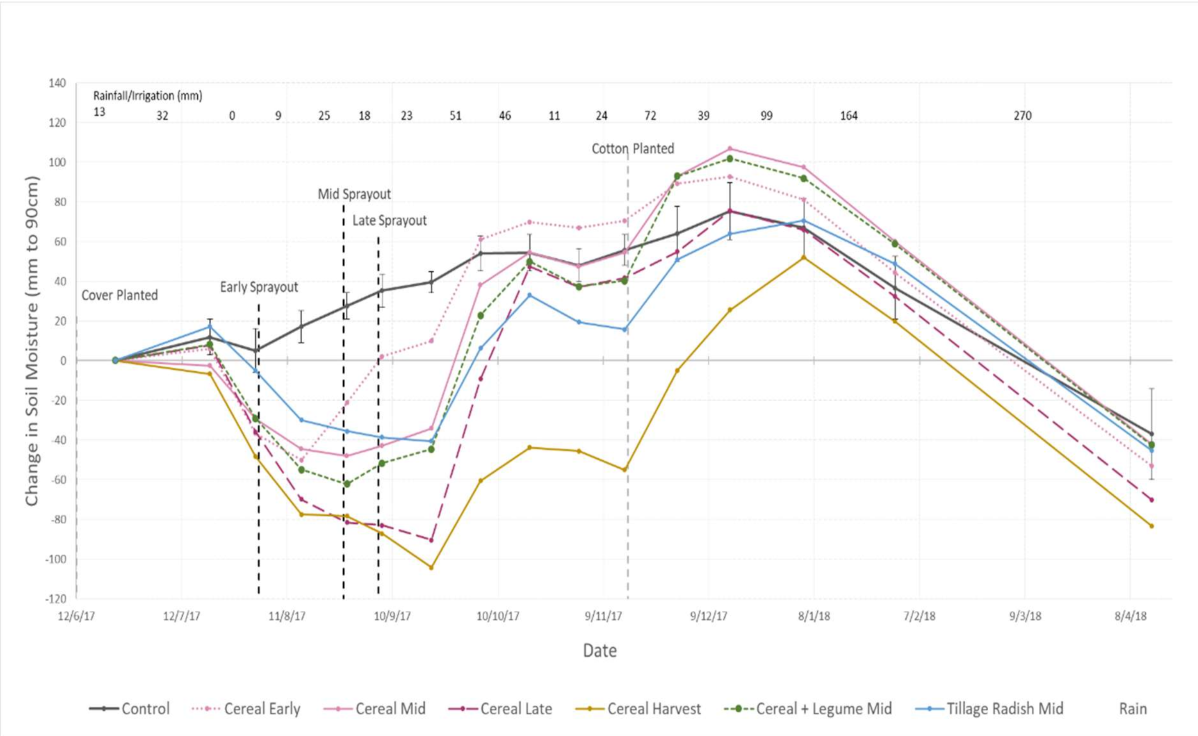

Figure 4. Changes in soil water to 90 cm after planting winter cover crops until defoliation of the subsequent pivot irrigated cotton crop at Yelarbon (with standard error bars on Control treatment)

Yield of subsequent 'cash' crops

Grain and cotton cash crop yield impacts reflected the general soil water trends across dryland and irrigated sites; more soil water typically produced more yield. Yields closely followed Water Use Efficiency figures at some sites (e.g. 12 kg grain/mm water at Billa Billa). However, other factors affected the relationship at other sites.

The cover crop systems that targeted both infiltration and soil improvements with sorghum and winter cover crops at Yanco increased irrigated cotton yields by over 1.0 bale/ha (P=0.05) compared to long fallows without cover crops that yielded poorly with 5.7 bales/ha.

Dryland yield losses in wheat at Canowindra and Parkes matched expectations of cover crops in an extreme drought. While the 50 mm variation across treatments at Canowindra was not significant (P=0.05), yield losses of up to 1.5 t/ha of wheat (0.6 t/ha at Parkes) reflected increased water stress. In contrast, yield responses in wheat at Bungunya (Table 5) were well beyond any direct impact of water alone. Applying Water Use Efficiencies of 15 kg/mm to measured benefits in stored soil water may have provided ~200 kg/ha extra yield for the mid-terminated millet and ~280 kg/ha for the later terminated millet, matching the host farmer's long-term expectation of 200-300 kg/ha yield increases. However, measured yield responses were four to five times higher. These responses beyond stored water effects are likely from establishment that increased dramatically with cover from better surface soil moisture at planting.

The irrigated cotton yield responses at Yelarbon were equally dramatic. The Control with limited ground cover was the poorest performer with at least 2.6 bales/ha lower yield, lower infiltration in early growth stages, and less water extracted late in the crop than treatments with cover crops. This was despite the early termination treatment being the only one to have more soil water at planting (Table 6). The cover from the short fallow cover crops was clearly beneficial for infiltration early in the following cotton crop. However, further research on other possible contributing factors in these situations is warranted.

Table 5. Net change in water storage over the life of the fallow (relative to the Control) and final wheat yield for each cover crop treatment at Bungunya

Treatment	Cover crop	Termination	Water gain (c.f. control)	Wheat yield (kg/ha)
1.	Control (bare fallow) Starting water ~120mm PAW		42mm (fallow gain)	1436[f]
2.	Millet (White French)	Early	+5 mm	2223 [cd]
3.	Millet (White French)	Mid	+14 mm	2386 [bc]
4.	Millet (White French)	Late	+19 mm	2897 [a]
5.	Millet (White French)	Late + Roll	+36 mm	2565 [b]
6.	Sorghum	Mid	+17 mm	2634 [ab]
7.	Lablab	Mid	-4 mm	1795 [e]
8.	Multi-species (millet, lablab, tillage radish)	Mid	+21 mm	1954 [de]

Table 6. Net change in water storage over the life of the fallow (relative to the Control) and final cotton yield for each cover crop treatment at Yelarbon

Treatment	Cover crop	Termination	Water gain (c.f. control)	Cotton yield (Bales/ha)
1.	Control (Bare) Starting water ~100 mm PAW		56 mm (fallow gain)	9.3
2.	Cereal	Early	+14 mm	12.9
3.	Cereal	Mid	-1 mm	12.7
4.	Cereal	Late	-14 mm	11.9
5.	Cereal	Mid + Roll	-2 mm	12.6
6.	Cereal	Harvest	-111 mm	14.1
7.	Cereal + Legume	Mid	-16 mm	11.9
8.	Cereal + Legume	Late	-7 mm	13.9
9.	Tillage Radish	Mid	-40 mm	14.4

A trade-off between soil water impacts and erosion in wet and dry years

Simulations based on the Bungunya data indicate benefits from spring cover cropping for soil water storage in many years when initial PAW is low (5a). In dry years, the simulated benefits of cover crops in improved water retention are not sufficient to overcome the water required to grow the cover crop. This occurs in approximately 10% of years for small cover crops (1 t/ha) or 50% of years for larger cover crops (3 t/ha). In wet years, there is sufficient in-fallow rainfall to fill the soil to its capacity and so there is little benefit of cover crops in approximately 5% of years. However, improved soil water storage from small cover crops can lead to improved soil water for winter planting for a wide range of rainfall conditions between these extremes (Rainfall percentiles 25-95%). Note that the increased water use by larger cover crops reduces this range of net benefit to a smaller set of years (Rainfall percentiles 50-95%).

Cover crops reduce erosion risk during fallows by reducing runoff volumes and sediment concentration in runoff water (5b). Even small stubble levels (1 t/ha) are predicted to eliminate sediment losses in up to 50% of years. While cover crops may have little benefit for water storage in very wet years, higher levels of stubble are predicted to be effective in preserving soils during these years of high erosion risk. The amount of stubble required to achieve major reductions in erosion is relatively low and easily achieved. Cover crops that produced 1 t/ha dry matter were predicted to reduce long-term erosion by 82%, 2 t/ha by 96% and 3 t/ha by 99% at the Bungunya site.

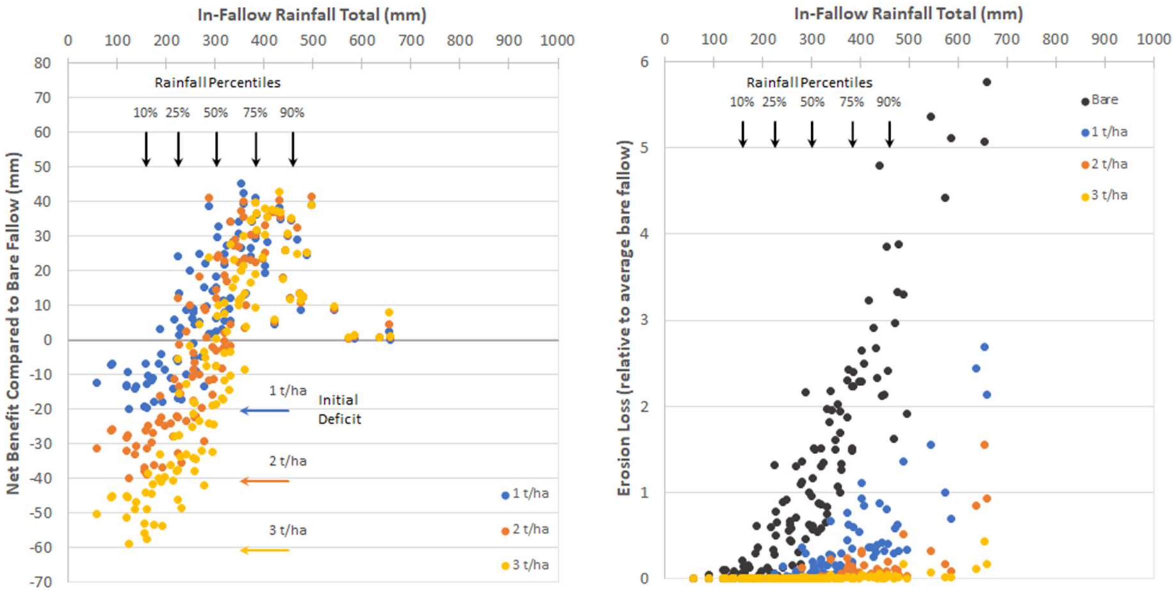

Figure 5a). Net benefit of spring cover crops of varying stubble mass on stored soil moisture for the following winter compared to bare soil fallow with 60mm starting PAW, and 5b). Relative erosion losses due to cover crops during the fallow. Bare soil erosion rates are shown for comparison, as are rainfall percentiles for the fallow, and the initial soil water deficit to grow the cover crops.

Other observations

Other measurements and observations were made across the experiments. These represent costs and benefits that may be important to assess the value of using cover crops for individual managers.

Planting and establishment – Improved surface soil moisture at Bungunya (Photo 1) resulted in better establishment and dramatically higher yields (Figure 6). Again at Yagaburne, treatments with good cover could also have been planted when the bare fallows could not. This potentially valuable planting opportunity was noted. However, the subsequent cash crop was delayed and then watered (after no other planting opportunities arose), to assess any impacts of fallow treatments on the crop. In contrast, the summer cover crop treatments were unable to be planted at Billa Billa without watering-up. This was a lost planting opportunity, albeit following driest fallow rainfall on record at the site.

Nitrogen – Most experiments were conducted on sites with good nitrogen levels. However, some nitrogen deficiency was observed in the cover crop at Bungunya with 'striping' showing the past sorghum rows and 'skips', and late-terminated cereal cover crops with large biomass resulted in reduced mineral nitrogen (up to ~80 kg N/ha) for the cash crops at some sites. Nitrate and mineralisable nitrogen assessments at planting of the cash crop at Bungunya showed recovery of nitrogen for all but the late terminated treatments, with the early terminated cover crop quickly recycling nitrogen to be on-par with the lab lab treatments.

Herbicide use – another key observation was a reduction in fallow herbicide applications required. For example, two less sprays at Bungunya and three less sprays at Yelarbon offset a significant amount of the cost to establish the cover crops.

Soil temperature – Increased stubble from cover crops reduced temperatures at the soil surface (up to 10 ^{0}C) and 0-10 cm (typically 2-4 ^{0}C) where it was monitored; more stubble led to cooler temperatures and less daily variation between minimum and maximums. This may be an advantage for establishment in summer, but equally a disadvantage for spring planting of summer crops if trying to push the planting window earlier.

Soil carbon – Soil organic carbon should increase as systems using cover crops produce more dry matter with less fallows. However, negligible impacts were seen on the single fallows investigated, except in the 0-10 cm layer at Canowindra where organic carbon levels increased where cover crops produced large biomass.

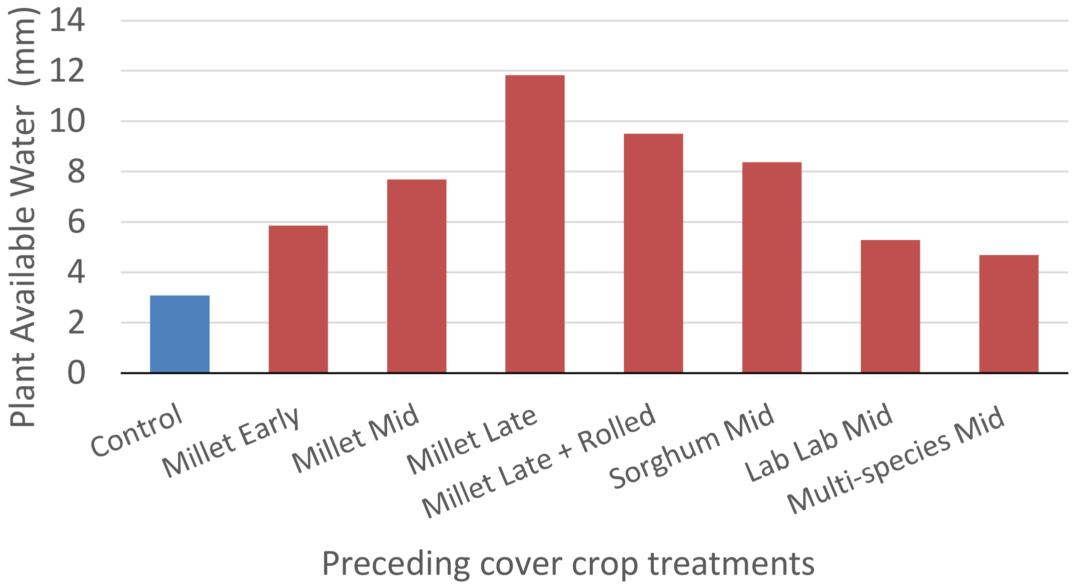

Figure 6. Surface moisture differences (0-10 cm) at planting of wheat following cover crops (Bungunya)

Returns

The cereal cover crops used in Queensland cost ~$70/ha ($50 to establish, $20 to spray out). These sites were planted into fallows within the growers' normal fertiliser program in the fallow, and mineral nitrogen levels generally recovered by planting of the 'cash' crops. Additional costs would accrue if additional fertiliser (e.g. nitrogen) was required. The legume and mixed species cover crops were more expensive with seed costs up to ~$30 more without any additional benefit in the experiments.

Consequently, the net cost of protecting the soil from erosion when there was no water or yield benefit was ~$70/ha for the basic cereal cover crops. However, saving up to 2-3 fallow herbicide applications (@$20/ha) through cover crop competition with weeds, significantly reduced the net cost of introducing these cover crops to between $10-$30/ha.

Yield losses of 1.4 t/ha at Canowindra and 0.6 t/ha at Parkes for mid-terminated sorghum cover crops are clearly costly. In contrast, the yield gains in the dryland wheat crop at Bungunya (~1.5 t/ha), the pivot-irrigated cotton crop at Yelarbon (~3-4 bales/ha) and flood irrigated cotton in the Yanco systems experiment (~1 bale/ha) were all very profitable.

Similarly, the feed provided by the sorghum cover crops at Canowindra and Parkes was estimated to be worth $1051/ha (early termination), $1827/ha (mid termination) and $3716/ha (late-termination) for cross-bred wethers (6-month old, 30 kg liveweight and $3.50/kg gain) utilising 80% of the crops grown. In the drier conditions at Parkes, the values were lower, ranging between $176-$818/ha. The grazing value generated from the cover crops more than compensated for the reduced grain yields at 2019 commodity prices, and would have provided the greatest returns of any treatments.

Discussion of Results

The project has gone a long way to answering its focal research questions…at least across the series of dry to very dry seasons that it was conducted within.

Natural variation in soil water and measurement with neutron moisture meters and gravimetric soil cores on large plot sizes to allow destructive sampling of biomass made it difficult to confidently measure differences. Differences in soil water to 150 cm were below, or at the extremes of the 12 - 40 mm needed for statistical significance (between) for the key cover crop treatments (P=0.05) Analyses of the focal 0-90 cm depth reduced variation. However, the differences for the key commercially relevant treatments were still at the limit of significance (P=0.1). Despite these limitations, the trends in the results were very consistent across sites and treatments, and matched expectations from theories of soil water storage and use, while subsequent trends in crop yields also reflected these trends in measured soil water. With support from simulation modelling to 'stretch' the findings and develop general insights, the project has shown that:

1. Yes, cover crops can increase the net water accumulation of Plant Available Water in grain and cotton systems with low ground cover in the northern region…but not always! Regional, seasonal and industry differences with dryland and irrigated systems led to a range of results;

    - The net water cost to grow cover crops is between 40-60 mm for well-managed crops terminated by anthesis for maximum biomass. The deficit depends on the species selected, the timing of termination and the seasonal conditions with rainfall during the cover crops growth. Mismanagement to let cover crop grow longer than needed for the level of cover needed for the intended fallow led to soil water deficits over 100 mm,

    - The net water gain at planting of the subsequent grain and cotton crops from these well-managed cover crops with appropriate species and termination timings for the planned fallow ranged from -30 mm to +38mm. Soil water to grow the cover crops was recovered at five sites, with net losses at three sites and net gains at three others. There was also continued improved infiltration and soil water gains measured during the early growth of the cotton at the Yelarbon and Yanco spray-timing experiments.

      Simulation modeling based on the Bungunya data predicted 1 t DM/ha cover crops (~ early termination, first node) would recover or better the net water accumulation of the low-cover fallows in 70% of years and the 3 t DM/ha (~ mid-termination, flag leaf) in 45% of years with a mean gain of 15-17 mm. At the same time, these cover crops would reduce long-term erosion by up to 82%, 2 t/ha by 96% and 3 t/ha by 99% respectively, and

    - Yield trends in the subsequent wheat and cotton crops reflected the trends in soil water; more water generally meant more subsequent yield. Yield losses of up to 1.5 t/ha in dryland wheat were experienced in the 2019 drought year at Canowindra. However, there were also yield gains of up to 1.4 t/ha of dryland wheat at Bungunya and 3-4 bales/ha in irrigated cotton at Yelarbon. These gains far outweighing expectations for extra stored water alone, and while better establishment may explain some of this difference at Bungunya, there is scope for future research to understand other possible contributors.

2. Yes, cover crops can improve fallow efficiency and accumulate 20 mm more Plant Available Water in some years, but not others. The 17 mm mean extra water accumulation noted above is close to the targeted 20 mm, and while both are at the extremes of statistical significance for our data, at a Water Use Efficiency of 15 kg/mm equates to 255 kg/ha wheat right in the middle of the Bungunya collaborator's long-term cover cropping expectation of 200-300 kg/ha extra yield.

Ultimately, the project data suggest that cover crops can protect the soil from erosion in nearly all years, and maintain or increase accumulated soil water storage in 45-70% of years. When conditions are not extremely wet or extremely dry, cover crops can provide average net benefits of 15-17 mm for short and long fallows respectively. The decision on whether to use cover crops will rely on the topography of the paddock, whether existing cover levels will go below 30%, individual crop sequencing strategies, whether there is sufficient stored moisture to plant an appropriate cash crop, and seasonal forecasts. There was no apparent additional value from multi-species cover crops; cereals provided the best with lower seed costs for establishment, so subsequent decisions will be based on termination timings to suit short (early termination) or long (mid-termination) fallows.

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Conclusion and Implications

The large body of work conducted and presented across the northern region over the last three years has provided valuable quantitative data at a time of need for the grain and cotton industries; during a prolonged drought when many growers have faced low-cover situations and difficult decisions.

The importance and value of the research is evident in invitations to present results and help over 2200 growers and agronomists to make decisions in the last 2 years through GRDC updates; Crop Solutions, CottonInfo and Crop Consultants Australia groups; RDE agency reviews and other regional meetings. These invitations with their supporting papers and feature articles in GRDC Groundcover, Australian Grain/Cotton Grower, The Land, and ABC radio confirm the project's value and the continuing industry interest in the potential of cover crops.

The project's charter was to assess the water balance and dynamics in line with its focal research questions. Initial modeling of these results has predicted, at least in southern Queensland, that cover crops with at least 1 t DM/ha can reduce long-term soil erosion by between 82% and 99% without losses of water across fallows in up to 70% of years; not the 5% wettest or the 25% driest. Indeed, cover crops producing 3 t DM/ha (between mid and late terminations in the project) were predicted to recover or better the fallow water storage on low cover fallows in 45% of years with an average of 15-17 mm extra water stored on long and short fallows. Of course, these 'odds' can be improved further and avoid wasting stored soil water with informed decision making that accounts for the planned fallow period, starting moisture levels, and the seasonal climate outlook.

The project consequently developed a simple static spreadsheet model (Freebairn, summary sheet uploaded to portal) to help people assess the water impacts for their own situations. Furthermore, the project has used the ADOPT program to assess the potential impact of the work and cover crops in the northern region with extension support. Assuming water impacts on yield only, not the much greater yields that were measured in some experiments, the ADOPT analysis suggests a peak adoption of 27% in year 10, with a cumulative farm gate impact of $41 million and ~ $80 million for the wider economy. This was based on 20% of the 7.5 million ha cropped in the region that will have low-cover after chickpeas, lentils, skip-row sorghum, cotton and drought each year, the average water gains of 17 mm observed on farms and predicted in modeling for 45% of the years.

Importantly, the project has measured much larger yield impacts at some dryland grain and irrigated cotton sites; up to three times larger than can be explained by differences in soil water alone. These responses appear to be due to better establishment, increased in-crop infiltration, better water extraction, and perhaps improved soil biology. All the results come from a series of dry and extremely dry seasons, so there is a need to confirm findings and model predictions with field experiments in more favourable years to build confidence for on-farm recommendations across the northern region.

Finally, the collaborating grower group at Canowindra wanted a grazing treatment implemented as part of the project. The large predicted grazing value ($/ha) generated from the resulting sorghum cover crops more than compensated for the grain yield reduction based on recent commodity prices.

There is still much to learn from continued research into cover crops and their contribution to closing our 'systems yield gap' for the enduring profitability of our farming systems.

Recommendations

Future RDE

1. *Research across a range of better seasons* - The current research has been conducted in a period of below average and well below average rainfall. While cover crops have recovered and even bettered soil water storage from ongoing low-cover trials, a better reflection of their true potential and confidence for on-farm practice recommendations requires further research that includes the same experiments across periods with average and above average rainfall years.
2. *Remaining research questions on soil water accumulation from drought affected sites*
   - At what stubble cover level are cover crops valuable for soil water storage? Can cover crops on low-cover fallows after pulses store as much soil water as fallows with good wheat stubble? The current project focused on fallows with ~10% cover. However, will cover crops have any soil water benefit once the starting cover levels reach 15%, 30% or 50%? The Billa Billa and Lundavra sites targeted these critical questions and a range stubble management options (stubble height, spreading, rolling). However, both were affected by severe drought; and
   - What is the legacy of 'one-off' cover crops on subsequent fallow water accumulation and cash crops? Will systems with repeated cover crops accrue additional soil water benefits? Continuing research over a longer period is needed to assess any legacy effects of one-off cover crops and repeated cover crops in growers' systems.
3. *The wider systems impact of using cover crops in regional farming systems?* The current project has shown yield responses that greatly exceed any direct soil water accumulation impacts. While it has highlighted the potential for additional planting opportunities, reduced herbicide use from crop competition, possible better water extraction at depth in the following cash crop, the greater production of dry matter in systems with cover crops will also ultimately boost soil organic matter and impact on soil biology through AMF, nematodes and other soil pathogens. While the current project did not identify any real benefits in multi-species cover crops in single fallow studies, these may emerge with longer-term use in systems. Assessing the costs and benefits of using cover crops and their impact on the overall system performance as an ongoing part of modern farming systems is important and of prime interest to growers across the region. The impact of long-term use cover crops in the farming system on soil health, soil biology and subsequent crop performance is a key area of interest for future RDE. Key questions include:
   - What are the long-term impacts of cover crops on soil carbon, soil biological activity and system resilience?
   - Do multi-species cover crops provide extra benefits over time (compared to cereals only)?
   - What are the disease, weed and pest impacts of incorporating cover crops into cotton and grain systems?
   - Can cover crops reduce the reliance on herbicides (e.g. glyphosate) and synthetic fertilizer with the inclusion of legumes?
   - What is the grazing value of cover crops? How much cover should be left after grazing? What are the impacts of grazing on subsequent grain production?
4. *On-farm monitoring with growers testing cover crops in their systems* – There is a great opportunity to support growers who are now interested in cover crops. With so many growers and agronomists interested in testing cover crop options in their local conditions, a great deal of valuable data can be collected across the region by supporting them with rigorous monitoring of their crops. By leaving several strips unplanted in their cover crops, or spraying out areas large enough to minimise runoff from bare areas into the crop, there is the opportunity to provide replicated and professional sampled data to inform future decisions across multiple regions, systems and soils.

Scientific publications

GRDC update papers (15 venues)

- March 2019 (Spring Plains, Goodndiwindi) Cover crops can boost soil water storage and crop yields. Andrew Erbacher, David Lawrence, David Freebairn, Neil Huth, Brook Anderson and Graham Harris
- August 2019 (Surat, Dalby, Quirindi, Warialda, Walgett) & November 2019 (Capella, Moura) Cover crops can boost soil water and protect the soil for higher crop yields. David Lawrence, Andrew Erbacher, David Freebairn, Neil Huth, Brook Anderson, Graham Harris and Nikki Seymour
- February/March 2020 (Wagga Wagga, Dubbo, Corowa, Lake Cargelligo) Summer cover crops in short fallow - do they have a place in central NSW? Colin McMaster, Allan Stevenson and Stuart Strahorn
- March 2020 (Mungindi, Gulargambone) - Cover crops improve ground cover in a very dry season. Andrew Erbacher, David Lawrence, David Freebairn, Neil Huth, Brook Anderson and Graham Harris

Conferences

Paper & presentation

- Erbacher A, Lawrence D, Freebairn D, Huth N, Anderson B & Harris G (2019) Net water benefit of cover crops in northern grains production. Farming water with ground cover. Proceeding of the 2019 Agronomy Australia Conference. August 2019, Wagga Wagga

Abstract & presentation

- Hagan J, Erbacher A & Lawrence D (2020) Economics of cover cropping in the northern grains region. Australia Agricultural and Resource Economics Society Conference. February 2020, Perth.

Journal articles (Abstracts for articles in preparation)

1. Working title: Cover crops protect farming systems with improved ground cover, rapid recovery of stored soil water and increased crop yields in southern Queensland

Andrew Erbacher, David N. Lawrence, David M Freebairn, Brook A. Anderson and Neil I. Huth

Abstract

In Queensland (Qld) and northern New South Wales, dryland crops are grown with a significant dependency on soil water stored in the fallow. In fallows with low ground cover evaporation and run-off of rainfall is often increased, resulting in a reduction in fallow rainfall captured (Fallow Efficiency).

Six field experiments were established around Goondiwindi in Queensland to investigate whether cover crops can be grown to increase ground cover and whether the resultant increase in fallow efficiency would store enough water to be of a net benefit to the following crop. Cover crops were established in low cover fallows and sprayed out with glyphosate at different growth stages, to create fallows with different stubble amounts and types and different fallow lengths. Soil water was monitored regularly throughout the fallow and following crop to assess the net water impact of growing more ground cover. The yield of the following crop was also measured as an indicator of cover crop value.

Cover crops were successful in increasing ground cover over the fallow in all experiments. Across the six experimental sites cover crops had on average 40 mm less water than the bare fallow (range of 0 to 100 mm) at termination of the cover crop. Cover crops improved fallow efficiency after termination,

so the best cover crop had more water than bare fallow at three of four sites when the following cash crop was planted. The improved ground cover provided by cover crops increased soil moisture in the top ten cm of soil at planting of two dryland sites resulting in an extended planting window at these sites and a more even crop establishment at the site deep planted to wheat. Two sites established more even crops that were able to extract more soil water to maturity, so had a yield benefit greater than the measured water benefit following cover crops. The two sites that had trickle irrigation applied to aid establishment of wheat produced differences in measured grain yields related to differences in soil water available at planting.

This demonstrates the potential for cover crops to improve water capture by the soil, which can then be used by crops for improved yield. To do this careful planning and management is necessary to match the cover crop duration (water use, stubble volume and stubble type produced) to the fallow length until the next planned crop (how long does the stubble need to last and how much extra water does it need to recover).

2. **Cover crops increase soil water storage and reduce soil erosion in a southwest Queensland rainfed cropping system.**

Brook A. Anderson[1], Neil I. Huth[1], Andrew Erbacher[2] and David N. Lawrence[2]

[1]CSIRO Agriculture and Food, P.O. Box 102, Toowoomba, Queensland 4350, Australia

[2]Department of Primary Industry and Forestry, P.O. Box 102, Toowoomba, Queensland 4350, Australia

Abstract:

For many years, cover crops have been recognised for their role in increasing water infiltration, protecting soil from runoff and erosion and suppressing weeds in dryland agricultural systems where water is limiting. However, cover cropping does not always lead to a net benefit, and in the context of extreme seasonal variability, knowing when and how to incorporate cover crops into a crop rotation is vital. In this study, we employed a simulation modelling approach using the Agricultural Production Systems Simulator (APSIM) to understand the conditions under which cover crops provide benefits to storage of soil water and soil conservation. The model was parameterised using soil and cover crop data collected at three South East Queensland experimental sites located at Bungunya, Yelarbon and Yagaburne from 2018 to 2020. We simulated fallow conditions over 120 years (1900-2020) for bare soil and for fallows after cover crops providing up to 3 t/ha of surface stubble with initial plant available water (PAW) of 60mm or 120 mm. According to the model, cover crops provide erosion control and facilitate increased water storage when weather conditions are not extremely wet or dry, providing average net water storage benefits of 17mm and 15mm for short (6 month) and long (12 month) fallow periods respectively. During dryer years (< 200mm), cover crops offer little benefit, as erosion risk is inherently low, and the water used in growing the cover crop is not replenished by rainfall. During wetter years (> 500mm), cover crops provide effective erosion control, substantially reducing sediment loss compared to bare fallow, but provide little moisture benefit as rainfall is sufficient for maximum soil water storage. Our results show that through understanding how and when to incorporate cover crops into a crop rotation, growers can more effectively utilize cover crops to increase soil water storage and soil preservation using seasonal forecasts and estimates of stored soil water.

3. **A further paper from NSW (Colin McMaster) is also likely on using cover crops in mixed farming systems where crops can be grazed**

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Bond JJ, Willis WO (1969) Soil water evaporation: Surface residue and placement effcets. Soil Science Society of America Proceedings 33:445-448

Price L, Cooper J, Smith L, Castor P, Thorn S (2007) Millet as a ground cover in low stubble systems. Eastern Farming Systems Technical Report 2007. Queensland Department of Primary Industries, Toowomba. 52-66.

Appendix 1. Extension presentations and media summary

These activities have highlighted the ongoing research, the emerging results and impacts on soil water storage, erosion and crop yields, their context in a wider range of seasons, and their implications for industry. To date we have not focused on recommendations for practice and how agronomist/growers can assess cover crop performance on their own farms

Presentations

2017

- Yelarbon site walk: CottonInfo with local cotton growers
- Yelarbon site walk: Conservation Farmers bus tour

2018

- Regional Research Agronomy Updates (Goondiwindi, Mungindi, Dalby, Jambin, Moura, Kilcummin, Orion)

2019

- GRDC Updates - March (Spring Plains & Goondiwindi)
- GRDC Updates - August (Surat, Dalby, Quirindi, Warialda, Walgett)
- GRDC Updates - November (Capella, Moura)
- Focus on Food and Fibre (St George)
- Regional Research Agronomy Updates (Mungindi, Roma, Pittsworth)
- Crop Consultants Australia/CottonInfo Soil Health (Jondaryan, Moree)
- Australian Cotton Production Manual
- Australian Agronomy Conference (Wagga Wagga)
- Northern Weeds Researchers (Gatton)
- Cowra preseason grower meeting
- Canowindra trial site walk
- Carbon for profit forum
- Parkes show
- Canowindra spring field day
- Yanco Cotton research update
- CottonInfo Soil Health (Parkes)

2020

- GRDC Updates – February/March (Mungindi, Gulargambone, Wagga Wagga, Corowa, Dubbo, Lake Cargelligo)
- Delta Agribusiness agronomist conference (Griffith)
- Australasian agricultural and resource economists society (Perth)
- Canowindra preseason grower meeting
- GRDC Regional crop solution groups (Greenthorpe, Marrar)

Press

GRDC GroundCover

- Issue 136 (2018) Cover Feature article: *Cover crop project seeks more ways to capture water*
- Issue 140 (2019) *Millet shows its worth as a versatile cover crop*
- Issue 143 (2019) *A plus for water*
- Issue 146 (2020) *Weigh up cover risks*
- Issue 146 (2020) *A test for new tactics (farmer story linked to trials)*
- Issue 149 (2020) *Increase in PAW dramatically increases yields*

Others (did not keep an exhaustive list)

- Grain central: April 2019 *Water storage bonus from cover cropping boosts yields*
- The Land: June 2020 (R Freebairn) *Summer cover crops*
- The Land: Oct 2019 (R Freebairn) *Increase your soil water: a short fallow crop can be helpful*
- General press release: April 2019 (T Somes) picked up by local papers: *Researchers gain ground on soil water storage*

ABC Radio following several GRDC update presentations (details not recorded).

Other articles (did not keep an exhaustive list)

- DAF Queensland Grains research (1 in 2017-18; 2 in 2018-19; 4 in 2019-20)- uploaded to GRDC portal
- GRDC Update proceedings 2019 & 2020 (4 articles presented at 15 venues)
- Australian Agronomy Conference 2019
- Australian Grain (August 2019): *Cover crops: old ideas reborn for modern farming systems*
- Australian Cottongrower (July 2019): *Cover crops: old ideas reborn for modern farming systems*
- CRDC Research summaries 2019
- Australasian agricultural and resource economists society 2020 (Perth)

GRDC video story

- Colin McMaster has also recently done a video with/for GRDC on cover crops in NSW, their benefits and costs

Appendix 2. Recommendations for practice

Well managed cover crops improve infiltration in low-cover fallows when subsequent seasonal conditions are not extremely wet or extremely dry.

The cost to grow a cereal-based cover crop is approximately $70/ha (to plant and spray out), plus any required fertiliser.

The net water cost to grow cover crops is typically 40-60 mm. However, the additional cover protects soils in low cover fallows from erosion, and the rapid soil water recharge from the cover crop will maintain or even increase overall soil water accumulation for the next crop in 45-70% of years. Average net water benefits of 15-17 mm can be expected in these years for short and long fallows respectively.

In the other years, there will be no extra water storage if it is very wet (erosion control will be the main benefit), and water storage will be lower in very dry years that have little or no rainfall once the cover crops are sprayed out.

The amount of stubble required to achieve major reductions in erosion is relatively low and easily achieved. Cover crops that produced 1 t/ha dry matter were predicted to reduce long-term erosion by 82%, 2 t/ha by 96% and 3 t/ha by 99% at Bungunya in southern Queensland.

Consider cover crops when ground cover will drop below 30%

Consider cover crops when groundcover is low, or will be, by the end of your planned fallow; certainly below 10% and possibly below 30%.

These situations may comprise ~20% of the 7.5 million ha cropped in the northern region. They are typically in fallows following chickpeas, lentils, wide-row sorghum, cotton and during prolonged droughts. In these situations, cover crops will be most valuable when:

- Stored soil water levels are too low for a profitable grain crop
- Going into an extended fallow to prepare for a high value crop (cotton)
- Long-fallowing to change between summer and winter cropping systems

Cover crops may also be beneficial in mixed farming enterprises when cover is low and the grazing value is high enough (e.g. droughts) to compensate for soil moisture losses. Care will be needed to ensure 30% cover is left after grazing.

Other potential benefits

- Increased infiltration and water storage for early growth of the subsequent crop
- Increased soil organic carbon from greater dry matter production
- Greater biological activity (including AMF) from higher crop intensity and organic matter
- Lower fallow herbicide costs and herbicide resistance
- Cooler soil temperatures in summer
- Improved planting conditions with better surface moisture for longer after rain
- Protection from wind erosion

Other potential costs

- Additional nitrogen fertiliser if soil mineralisation is low
- Higher seed costs if mixed species (legume, brassica) cover crops are used
- Additional disease/pest risk from some cover crop species
- Reduced establishment of subsequent cash crops from stubble blockages (e.g. Cotton)
- High water deficits if cover crops are not removed on time

Cover crop decisions on the species used, the timing of removal, and the supporting agronomy will be determined by aim of the fallow and the subsequent crop. For example, longer fallows will require higher cover levels and more resilient cover to protect the soil and maximise infiltration until the subsequent grain/cotton crop.

Species selection

- Use cereal to maximise net water storage; They are quick growing, use water efficiently and provide resilient cover.
- Select cereals with dense/erect stems (e.g. wheat, barley) rather than leafy prostrate growth habits (e.g. prostrate oat varieties) will have better resilience and machine trafficability for planting the subsequent crop.
    - Winter - quick erect varieties of wheat or barley
    - Summer - White French millet or sorghum.
- Legumes may fix/contribute nitrogen but will require cereal species to be included for resilience in longer fallows. These nitrogen benefits may be valuable for low input systems, or in mixed farming systems where the cover crop may be grazed. However, both legumes and brassicas are slower growing, use more water and breakdown faster after being sprayed-out to provide less soil protection unless cereals are included. Further research is needed to assess any long-term benefits of multi-species cover crops (e.g. soil health and biology).

Removal timing

- Match cover crop spray-out timing to the fallow length requiring cover (the resilience needed) and the time required to recharge soil water storage
    - Short fallows (<3-4 months): spray-out at stem elongation
    - Long fallows (5-6+ months): spray-out at flag leaf to ensure long-term cover. Termination of the cover crop at anthesis may be suitable where extended fallows (e.g. prior to cotton) provide more time to recharge soil water storage
- Do not delay spray-out timing. Water use by the cover crop increases dramatically from flag leaf onwards. A typical net water deficit of 40-60 mm can rapidly grow to 100+ mm and be hard to recover in all but very wet seasons when spray-out is delayed too long.

Agronomic recommendations

- Plant as soon as possible in the new fallow period to maximise the time available to recharge the soil water after the cover crops are removed.
- Cover crops were typically 40-60 mm drier than the bare Control at termination, so having at least 50 mm Plant Available Water at planting will improve the reliability of the cover crop.
- Maintain high planting rates and narrow row spacings where possible to gain fast cover.
    - For example, wheat or barley at 1M plants/ha, millet at 1M plants/ha and sorghum at 300k plants/ha. Use forage or hay planting rates for other species.
    - Plant on the narrowest row spacing available to minimise the growing time required for the cover crop to reach canopy closure and maximise stem distribution of decaying stover.
    - Plan carefully for difficult to establish crops like cotton, use of GPS guidance and/or widening cover crop row spacing around (future) plant rows to aid even crop establishment (e.g. Use GPS positioning to offset cover crop row from cotton row, or leave out a row where the cotton is to be planted if very narrow row spacing is used).
- Maintain good nitrogen levels for rapid growth to minimise the time to produce the critical biomass for the fallow, and to ensure max time to recharge soil water levels. Nitrogen deficient cover crops will be less water efficient.
- Use sorghum on hard setting soil or marginal conditions where millet establishment may be difficult. Sudan x sudan varieties may provide more resilient stem than standard grain varieties.

Cover cropping articles only

Queensland grains research 2018-19

Regional Research Agronomy

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Summer cover crops can increase stored soil water in long fallows and improve wheat yields—Bungunya

Andrew Erbacher and David Lawrence
Department of Agriculture and Fisheries

Research Questions: *Can summer cover crops increase the net water accumulation (plant available water) in dryland systems with low ground cover (<30%) in the Northern Region?*

- *What is the net water cost to grow summer cover crops?*
- *What is the net water gain to subsequent grain crops (fallow and early growth periods)?*
- *What is the impact on the yield of the grain crops?*

Key findings

1. Summer cover crops can be very profitable; improving ground cover and increasing fallow water storage in long fallows to improve grain yields and boost returns in northern farming systems.
2. A later spray-out produced additional levels of a cover that is more resilient and stored more water in the longer fallow. Delaying spray-out too long reduced fallow water storage considerably.
3. Using a summer cover crop saved two fallow herbicide sprays and dramatically improved establishment of the subsequent wheat crop.
4. Yields and returns were increased by the cover crops, and yields were well in excess of those expected from the increased soil water storage alone.

Background

Cover crops can protect the soil from erosion in low stubble situations, return biomass that helps maintain soil organic matter and biological activity, and provide additional nitrogen (when legumes are used). However, cover crops may also offer opportunity to increase infiltration and fallow moisture storage for higher yields and more profitable grain and cotton crops.

Advances in agronomy and support from commercial agronomists have resulted in better use of available soil water to improve individual crop performance. However, effective capture and storage of rainfall across the whole farming system remains a major challenge for grain and cotton growers in the Northern Region, where dryland crops typically transpire only 20-40% of rainfall. Up to 60% of rainfall is lost to evaporation and a further 5-20% lost in runoff and deep drainage. Indeed, every 10 mm of extra stored soil water available to crops is worth up to 150 kg/ha extra yield for grain crops.

Farming systems projects funded by the Grains Research and Development Corporation (GRDC) are assessing ways to improve the use of our total rainfall, with the aim of achieving 80% of the water and nitrogen-limited yield potential in our cropping systems. Past research from GRDC's Eastern Farming Systems and Northern Growers Alliance projects suggests that cover crops and increased stubble loads can reduce evaporation and increase infiltration to provide net gains in plant available water over traditional fallow periods. Consequently, cover crops may be a key component of improved farming systems; providing increased productivity, enhanced profitability and better sustainability.

Scientific rationale

Stubble and evaporation

Retained crop stubble protects the soil from rainfall impacts and so improves infiltration to store more water in the soil. Past research also shows that increased stubble loads can slow down the initial rate of evaporation, but that these gains are short-lived and lost from accumulated evaporation after about three weeks. However, further rain within this three-week period provides opportunity to reduce total evaporation and so accumulate more plant available water (Photo 2).

Cover crops are used in Southern Queensland and Northern New South Wales to overcome a lack of stubble and protect the soil from rainfall impacts following low residue crops (e.g. chickpea, cotton), or following skip-row sorghum with uneven stubble and exposed soil in the 'skips'.

Growers typically plant White French millet and sorghum, and spray them out after 6–10 weeks to allow recharge in what are normally long fallows across the summer to the next winter crop. Allowing these 'cover crops' to grow through to maturity can lead to big losses of stored soil water and low yields in the subsequent winter crops. However, the Eastern Farming Systems project showed only small deficits (and even water gains) accrued to the subsequent crops when millets were sprayed out within six weeks, with average grain yield increases of 360 kg/ha. Furthermore, the Northern Growers Alliance suggested that the addition of 5-40 t/ha extra stubble (hay) after winter crop harvest reduced evaporation; initial studies showed 19-87 mm increases in plant available water that could increase yields by up to 1300 kg/ha. These gains will be valuable if validated in further research and captured in commercial practice.

Our current project is monitoring sites intensively to quantify the impact of different stubble loads on the accumulation of rainfall, the amount of water required to grow cover crops with sufficient stubble loads, the net water gains/losses for the following crops and the impacts on their growth and yield. This paper reports on the first 'grain' site in Southern Queensland, which will be used in simulation/modelling later in the project to assess the wider potential and economic impacts of cover crops in both grain and cotton production systems.

What was done

The Bungunya experiment was in a long-fallow paddock following skip-row sorghum. The sorghum was harvested in early February 2017, deep phosphorus was applied in August 2017, and the paddock was 'Kelly-chained' in September 2017 to level the surface. The paddock subsequently had little cover for the planned wheat crop.

Eight cover crop treatments were established on 11 October 2017 with ~120 mm of Plant Available Water in the soil (Table 1, Photo 1), while the rest of the paddock was sown to a White French millet cover crop by the host grower. Each treatment had five replicates to monitor for ground cover, dry matter (DM) production and fallow soil water until the subsequent wheat was planted on 1 May 2018.

Table 1. Cover treatments applied at the Bungunya site included millet, sorghum and lablab.

Cover crop treatment	Terminated	Biomass (kg/ha)
Control (bare fallow)		
Millet (White French)	Early	1533
Millet (White French)	Mid	2327
Millet (White French)	Late	4365
Millet (White French)	Late + Roll	4737
Sorghum	Mid	2481
Lablab	Mid	1238
Multi-species (millet, lablab, tillage radish)	Mid	1214

Three planned termination times matched key growth stages of the main cereal treatments:

- Early-termination at first node (Z31) when stem development began;
- Mid-termination at flag leaf emergence (Z41) when the reproductive phase began; and
- Late-termination at anthesis (Z65) for peak biomass production.

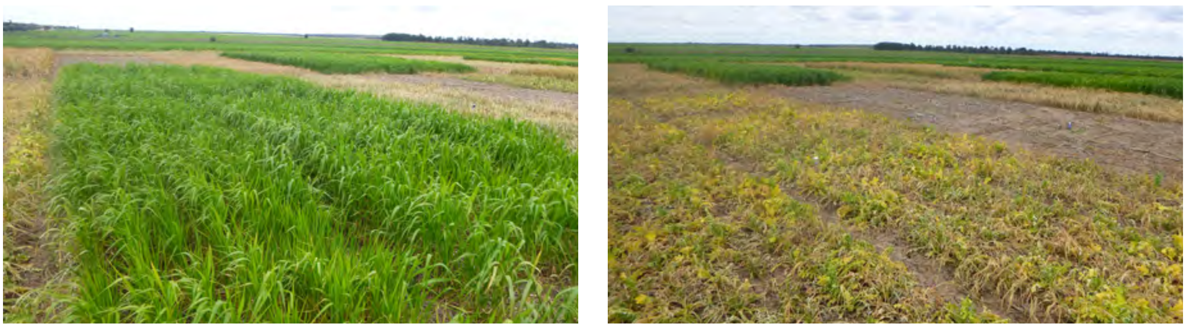


Photo 1. A range of summer cover crops were planted and sprayed out at different times at Bungunya to assess their impact on the soil water storage during a long-fallow period after skip-row sorghum, prior to planting wheat.

One millet plot was 'missed' when spraying the late-termination; its removal two weeks later provided additional unreplicated biomass data and water use figures for an 'extra late' termination.

Soil water was estimated using soil cores to measure gravimetric soil water at key times across the fallow and the subsequent wheat, along with regular neutron moisture meter (NMM) and EM38 readings in each plot. These NMM and EM38 readings and the percentage ground cover were recorded every 2–4 weeks while the cover crops were growing, and every four weeks in the fallow once all cover crops were terminated. These soil water measures continued every four weeks in the growing crop until canopy closure, with a final soil water measure at harvest. Wheat yields were estimated with hand-cuts on 12 October and mechanical harvesting on 26 October 2018.

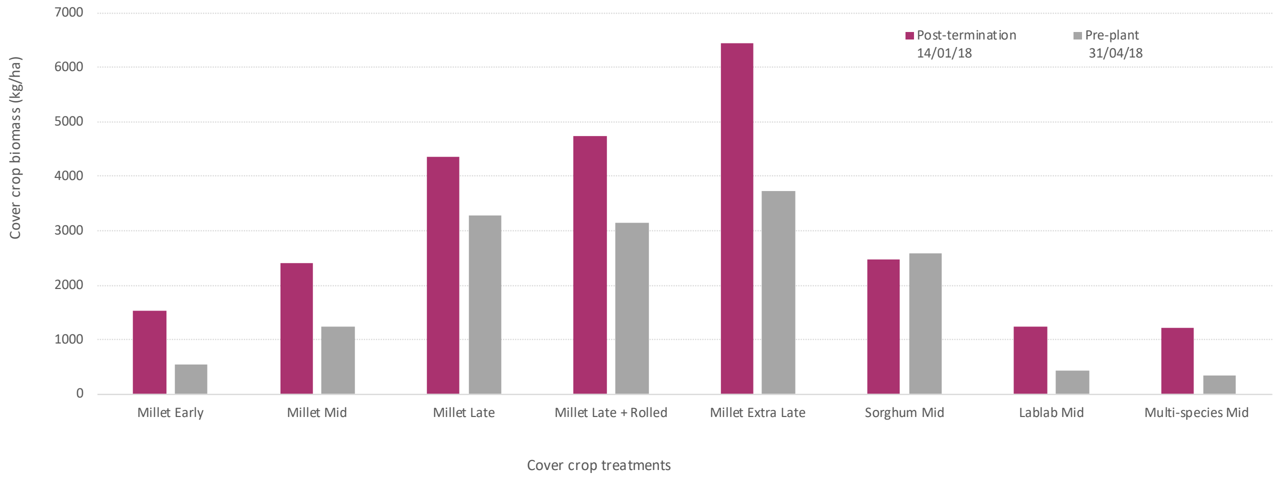


Figure 1. Above-ground biomass accumulation for the cover crop treatments at Bungunya show reduced biomass level by the end of the fallow.

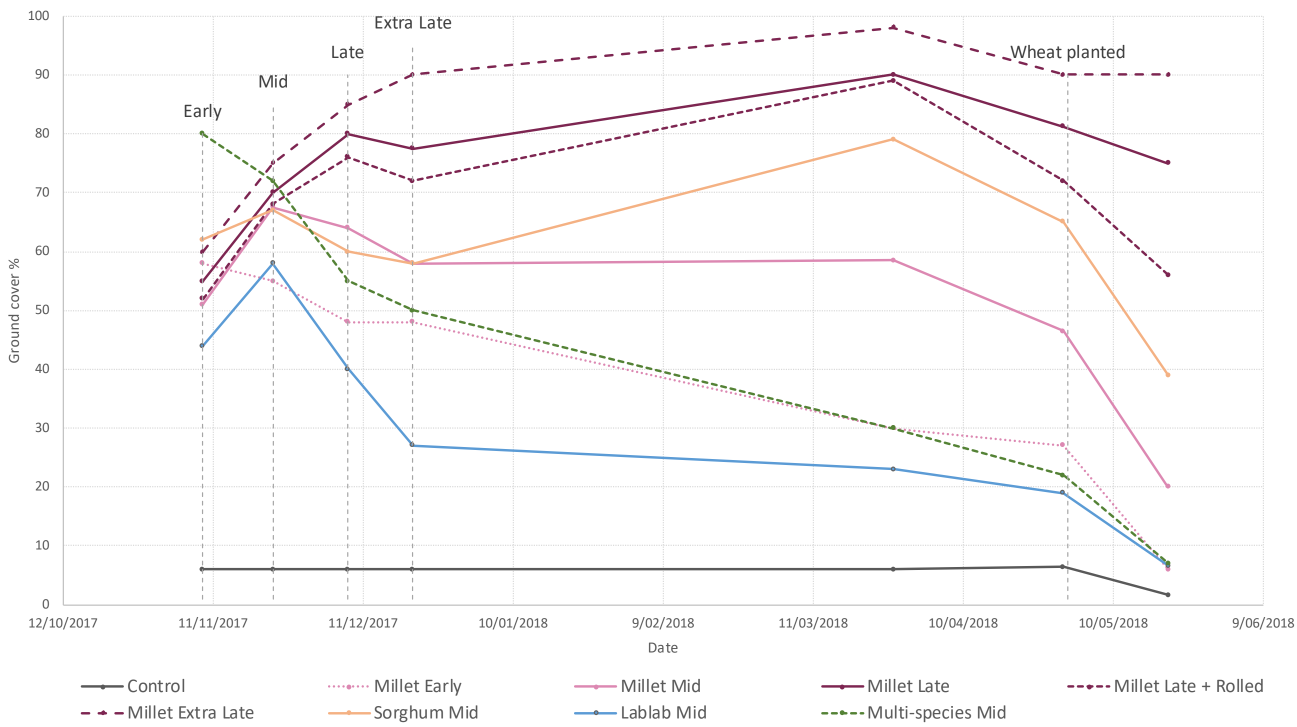


Figure 2. Visual assessments of ground cover over time at Bungunya also show reduced cover over the fallow, especially for lablab.

Results

Biomass and ground cover

Biomass of the millet cover treatments ranged from 1533 kg DM/ha for the early-termination, up to 4737 kg DM/ha for the late-termination. The lablab and multi-species treatments produced less dry matter than the cereals, and biomass fell below 1000 kg DM/ha prior to planting wheat in the early terminated millet, the lablab and the multi-species treatments (Figure 1). These three treatments also fell to only 20-30% ground cover by the end of the fallow (Figure 2).

Soil water

The water cost of growing the millet cover crops, relative to the Control treatment in the early stages of the fallow was ~50 mm for the early-termination, ~40 mm for the mid-termination and ~60 mm for the late-termination treatment (Figure 3). The lablab mid-termination treatment also cost ~60 mm to grow, relative to the Control treatment (Figure 4).

The unreplicated 'extra' late termination (two weeks later) used an additional 55 mm of water.

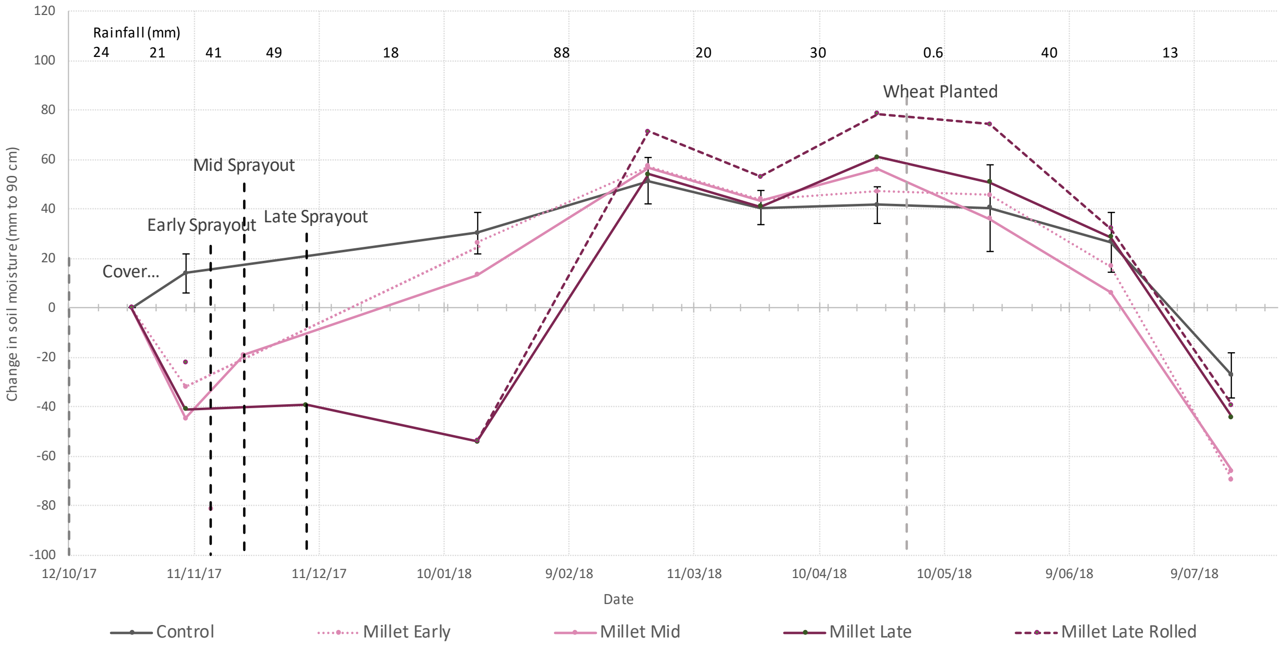


Figure 3. Changes in soil water (mm to 90 cm) from planting of millet cover crops to canopy closure of the subsequent wheat crop at Bungunya show that stored water can be increased over the fallow.

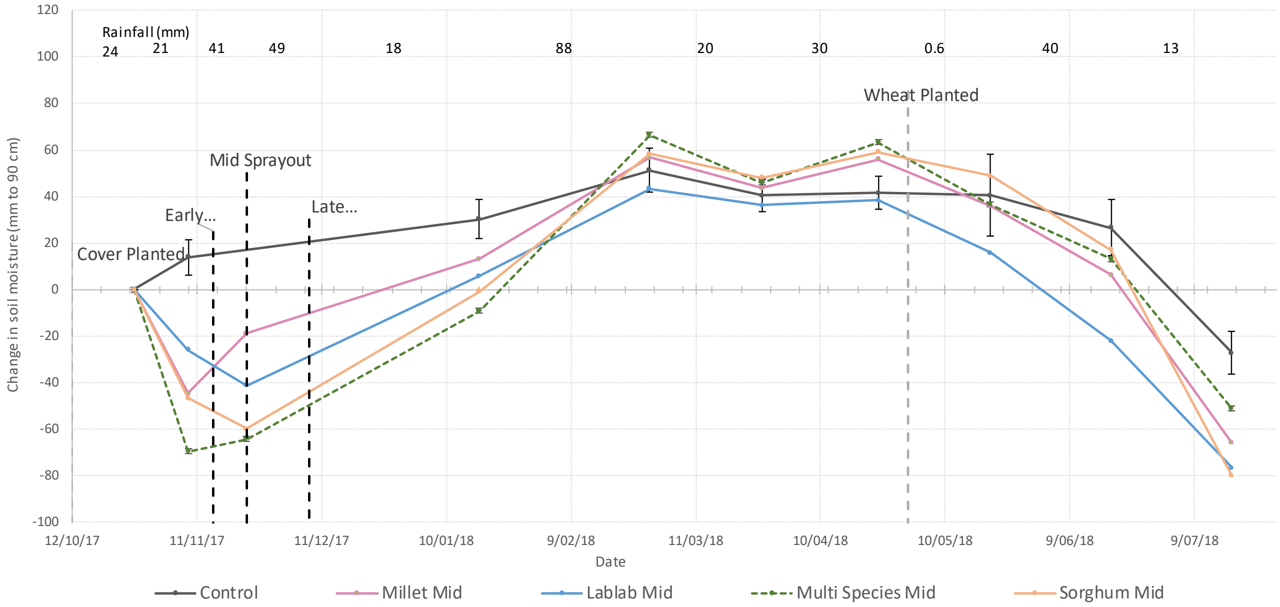


Figure 4. Changes in soil water (mm to 90 cm) after planting cover crops until canopy closure of the subsequent wheat crop at Bungunya show that soil stored less water under legume stubble than cereal stubble.

These results reflect additional rainfall and different rates of infiltration achieved in each treatment (some of which were still growing) between the soil water measurements:

- Plant of cover crops to Mid-termination, 86 mm in four events (11/10/17 to 22/11/17)
- Mid-termination to plant of wheat, 205 mm in 11 events (22/11/17 to 1/5/18)
- Plant to maturity 41 mm in 3 events (1/5/18 to 5/10/18)
- Maturity to post harvest soil sample 72 mm in 7 events (5/10/18 to 5/11/18).

Between mid-termination and early March 2018, 175mm of rainfall had fallen in 10 events, and the millet treatments had regained similar soil water levels to the Control, except the late terminated (rolled) treatment (Photo 2), which now had ~20 mm more stored water.

When the subsequent wheat crop was planted, the mid-terminated millet had ~14 mm more soil water than the Control treatment, the late terminated millet ~19 mm more, and the late terminated and rolled millet ~36mm more soil water (Table 2). Interestingly, water extraction by the wheat crop was greater from all of the millet cover crop plots than the Control, which had poorer establishment and lower yields, and probably reduced root development.

Crop performance

All cover crop treatments increased the yield of the final wheat crop (Table 2). They also required two less fallow weed sprays, a saving of ~$40/ha.

Photo 2. This photo shows the stubble effect three days after ~30 mm of rain at the site. A Late + Rolled treatment is in the foreground with a Control plot visible behind it. The theory is that stubble reduces evaporation and keeps the soil surface wetter for ~21 days, so if more rain falls in that time, more water will be stored.

However, the biggest yield increases were from the cereal cover crops, especially the late-terminated millet and the sorghum. The water differences at end of the fallow may explain some of the observed yield differences. However, the establishment of the wheat crop was also dramatically better after the cover crops, especially where cereals were used (Photo 3).

The expected yield increases from the higher fallow water storage alone would typically be ~200 kg grain in wheat (assuming 15 kg grain/mm water) for the mid-terminated millet (worth ~$50/ha), ~280 kg grain for the late millet (worth $75/ha) and ~540 kg grain for the late +rolled millet (worth $150/ha). These gains would represent net returns of $20/ha, $45/ha and $120/ha respectively. However,

Table 2. Net change in water storage over the life of the fallow (relative to the Control) and final wheat yield for each cover crop treatment at Bungunya shows cover crops can increase stored water.

Cover crop treatment	Terminated	Water gain (cf control)	Wheat yield (kg/ha)
Control (bare fallow) Starting water ~120 mm PAW		42 mm (fallow gain)	1436 f
Millet (White French)	Early	+5 mm	2223 cd
Millet (White French)	Mid	+14 mm	2386 bc
Millet (White French)	Late	+19 mm	2897 a
Millet (White French)	Late + Roll	+36 mm	2565 b
Sorghum	Mid	+17 mm	2634 ab
Lablab	Mid	-4 mm	1795 e
Multi-species (millet, lablab, tillage radish)	Mid	+21 mm	1954 de

the measured yield gains for these same three treatments were 950 kg/ha, 1461 kg/ha and 1129 kg/ha respectively, representing increased returns of between $250 and $380 /ha.

Implications for growers and agronomists

These results show that cover crops can indeed help increase net water storage across fallows with otherwise limited ground cover. How often these soil water results will occur across different seasons will be explored with further experiments and simulation modelling.

More dramatically, these 'initial' results and the impact on the subsequent wheat crop (and cotton at Yelarbon, page 69) are dramatic, and provide big dollar returns; far beyond what could be expected from the increases in net soil water storage across the fallows. Improved establishment of the following wheat crop is an obvious contributor in this experiment. However, there was also greater water extraction from some treatments (especially at depth) in the 'sister' cotton experiment at Yelarbon. How much of the responses can be attributed to these factors, how often such results might occur, and the contributions of different factors remains to be explored.

Acknowledgements

We very much appreciate the support of the trial co-operator and consultants for their effort and contributions to the project, along with our project team members in CSIRO (Neil Huth, Brook Anderson), David Freebairn, and the DAF Biometry, Technical and Research Infrastructure staff that supported the heavy management and monitoring loads of these experiments. Thanks also to the Grains Research and Development Corporation, Cotton Research and Development Corporation and the Department of Agriculture and Fisheries for funding the project (DAQ00211).

Trial details

Location:	Bungunya
Crop:	Wheat long-fallowed from skip-row sorghum with White French millet and other cover crops
Soil type:	Brigalow, Brown Vertosol
Rainfall:	332 mm (291 mm Cover/Fallow and 41 mm in wheat)

Bare fallow

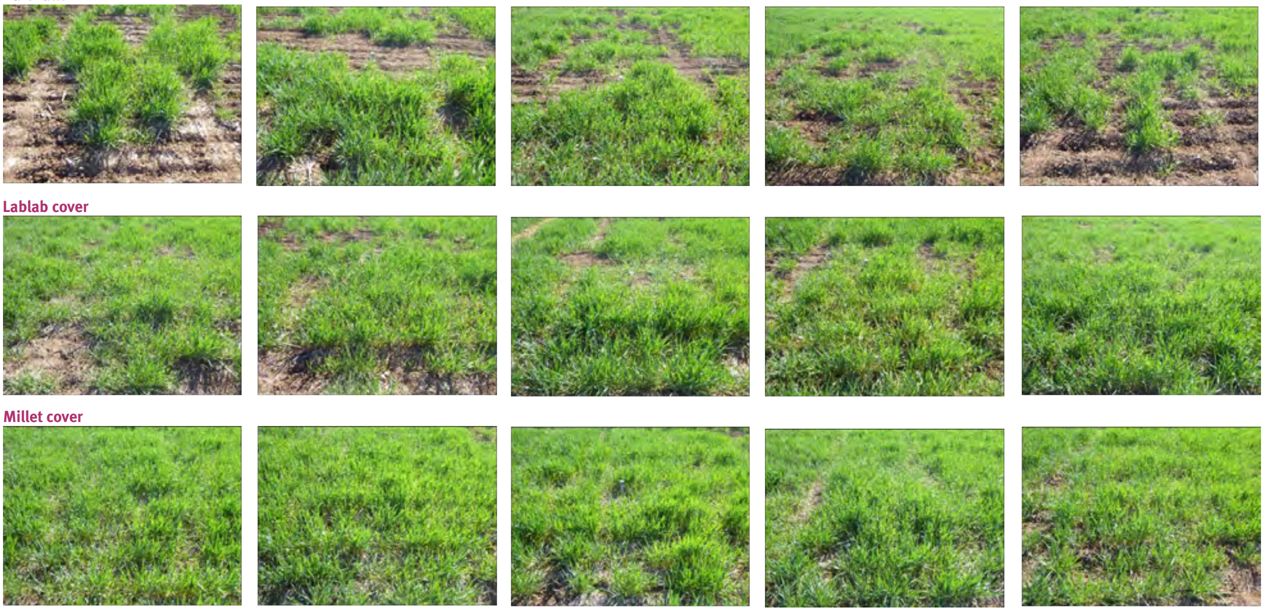
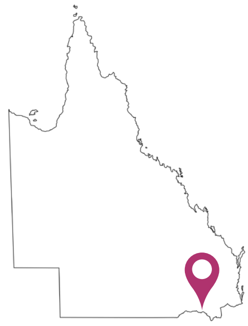


Photo 3. These photos show the poor establishment of the wheat crop following a normal low-cover fallow (Control) and a lablab cover crop, compared to a White French millet cover crop (five photos/reps of each).

Winter cover crops can increase infiltration, soil water and yields of irrigated cotton—Yelarbon



Andrew Erbacher and David Lawrence
Department of Agriculture and Fisheries

***Research Questions:** Can cover crops increase infiltration and <u>net</u> water accumulation in pivot-irrigated cotton systems with low (<30%) ground cover?*

- *What is the net water cost to grow winter cover crops?*
- *What is the net water gain to subsequent cotton crops?*
- *What is the impact on the yield of the subsequent cotton crops?*

Key findings

1. Winter cover crops can improve ground cover, increase plant available water and improve subsequent cotton yields in pivot-irrigated systems.
2. The early spray-out treatment was the best cover crop for storing water over the short fallow in this study where cover did not have to last very long. However, the extra cover in the mid-terminated cover treatment continued to boost infiltration in the cotton's early growth stages.
3. All cover crop treatments improved the yields of cotton by approximately 3 bales/ha; well in excess of any gains expected from the increased fallow soil water storage.

Background

Approximately 60% of rainfall in northern farming systems is lost to evaporation, with transpiration through plants typically only 20-40%. Cover crops are good for protecting the soil from erosion, building soil organic matter and maintaining soil biological activity. However, not being harvested for grain or fibre, they are considered 'wasteful' of rainfall; widely seen to be our most limited resource in dryland farming systems.

Recent research now suggests that cover crops may provide these benefits with little or no loss of plant available water. Therefore, there is renewed interest in cover cropping to use some of this 'lost' water and help develop systems that are more productive, profitable and sustainable.

For example, we know that cotton crops can leave the soil dry and unprotected with low ground cover after picking. This reduces infiltration and makes it difficult to rebuild soil water levels for the next crop. Consequently, dryland growers plant winter cereals post-cotton to get cover back on the ground and protect the soil; the crops may be harvested in good seasons, or be sprayed-out after 6-10 weeks just to provide the necessary ground cover to maintain infiltration.

However, efficient water use is also important for irrigated cotton growers; especially overhead irrigators who are interested in cover to maximise infiltration when they are watering-up and during the early growth stages of the cotton when they may have trouble getting enough water into the soil to keep up with the later crop demand. Any additional cereal stubble will also protect the young cotton plants from hot summer winds after planting.

Our project has intensively monitored crop experiments from Goondiwindi (Qld) to Yanco (NSW) to quantify the impact of cover crops on fallow water storage and crop growth. That is, how much water is required to grow cover crops with sufficient stubble, how these stubble loads affect accumulation of rainfall, the net water gain/loss for following crops and the subsequent impacts on crop growth and yield. This paper reports on an irrigated cotton paddock between Yelarbon and Goondiwindi.

What was done

The Yelarbon experiment was on a pivot-irrigated paddock that grew cotton in 2016/17. The crop was picked and root cut in May 2017, before offset discs were used on 12 June 2017 to pupae-bust and to level wheel tracks of the pivot irrigator. Nine cover treatments (Table 1) with five replicates were planted on the same day using barley (100 plants/m^2), barley and vetch mixtures (30 plants/m^2 each) and tillage radish (30 plants/m^2). Rain that night aided establishment, with the surrounding paddock planted to wheat for stubble cover two weeks later as per the grower's normal practice. The grower normally takes this wheat crop through to harvest and so we included a 'grain harvest' treatment.

Table 1. Cover treatments applied at the Yelarbon site included barley, vetch and tillage radish.

Cover crop treatment	Terminated	Peak biomass (kg/ha)
Control (bare fallow)		
Cereal (barley)	Early	1166
Cereal (barley)	Mid	4200
Cereal (barley)	Late	5104
Cereal (barley)	Mid + Roll	4200
Cereal (wheat)	Grain harvest	8175
Cereal + legume (vetch)	Mid	4928
Cereal + legume (vetch)	Late	4149
Tillage radish	Mid	4692

Three termination times matched key growth stages of the main cereal treatments:

- Early-termination at first node (Z31) when stem development began;
- Mid-termination at flag leaf emergence (Z41) when the reproductive phase began; and
- Late-termination at anthesis (Z65) for peak biomass production.

The subsequent cotton crop was planted on 15 November 2017. Importantly, the grower's 'grain harvest' treatment was used to determine the irrigation schedule for the wider paddock and our experimental plots.

Above-ground biomass was monitored across the growth of the cover crops until termination and through the subsequent fallow. Establishment counts were taken on each plot and hand cuts used to estimate cotton yields.

Soil water was estimated using soil cores to measure gravimetric soil water at key times across the fallow and the subsequent cotton, along with regular neutron moisture meter (NMM) and EM38 readings in each plot. These NMM and EM38 readings and the percentage ground cover were recorded every 2–4 weeks while the cover crops were growing, and every four weeks once all cover crops were terminated through to canopy closure of the following cotton. Final EM38 and NMM water measurements were done at cotton defoliation.

Results

Biomass and ground cover

Biomass of the barley cover crops ranged from 1166 kg DM/ha for the early-termination, up to 5104 kg DM/ha for the late-termination and 8175 kg DM/ha for the grain harvest treatment (Table 1). The cereal/legume mix and the tillage radish produced less dry matter than the cereals. Only the early-terminated cereal (barley) fell to below 1000 kg DM/ha, with ground cover down to 35% by the time the cotton was planted with the short fallow at this site (Figure 1).

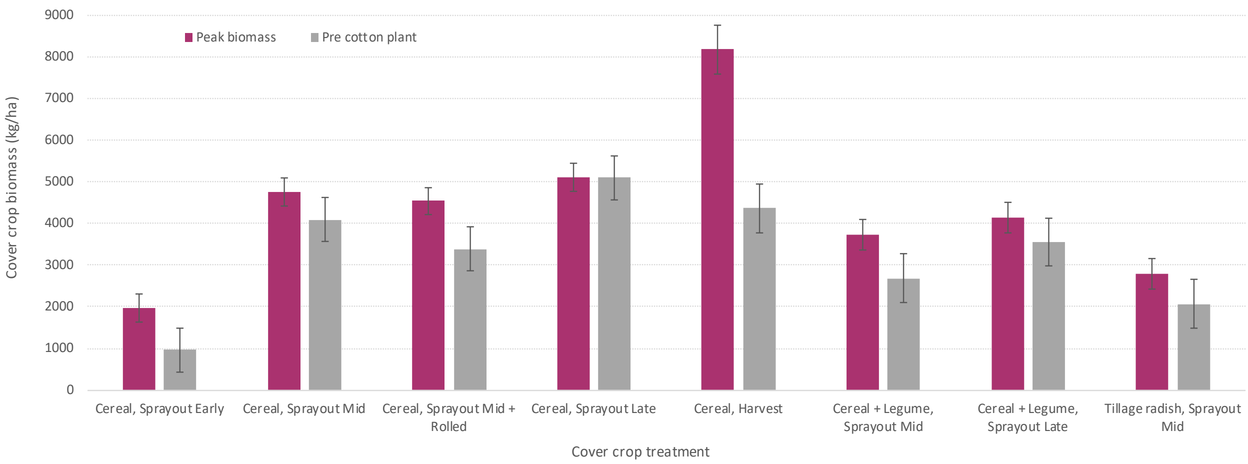


Figure 1. Above-ground biomass accumulation for each cover crop treatment (excluding old cotton stubble) showed small reductions by the end of the short fallow.

Ground cover in the tillage radish fell dramatically to ~20% ground cover, which would be of little value for infiltration in the early stages of the crop (Figure 2). Rolling had no effect on the breakdown of biomass during this short fallow.

Soil water

The 'water cost' of growing the barley cover crops, relative to the Control treatment in the early stages of the fallow was ~40 mm for the early-termination, ~70 mm for the mid-termination and ~120 mm for the late-termination treatment (Figure 3).

However by the end of the fallow, and a subsequent 170 mm of rainfall/irrigation in eight events from mid-termination to cotton plant, the mid-termination treatment caught up to the control, and the early-termination had accumulated an additional 14 mm of water. Not surprisingly, this early-termination proved to be the best cover crop treatment on the short fallow to cotton planting; it did its job and maintained over 30% ground cover until planting. However, the mid-terminated cereal maintained over 50% cover, which presumably led to it accumulating more moisture throughout the early stages of the following cotton.

The 'cover' crop that continued through to grain harvest was ~145 mm behind by the end of the fallow. Again, this treatment mirrored the wider paddock that set the pivot irrigation schedule.

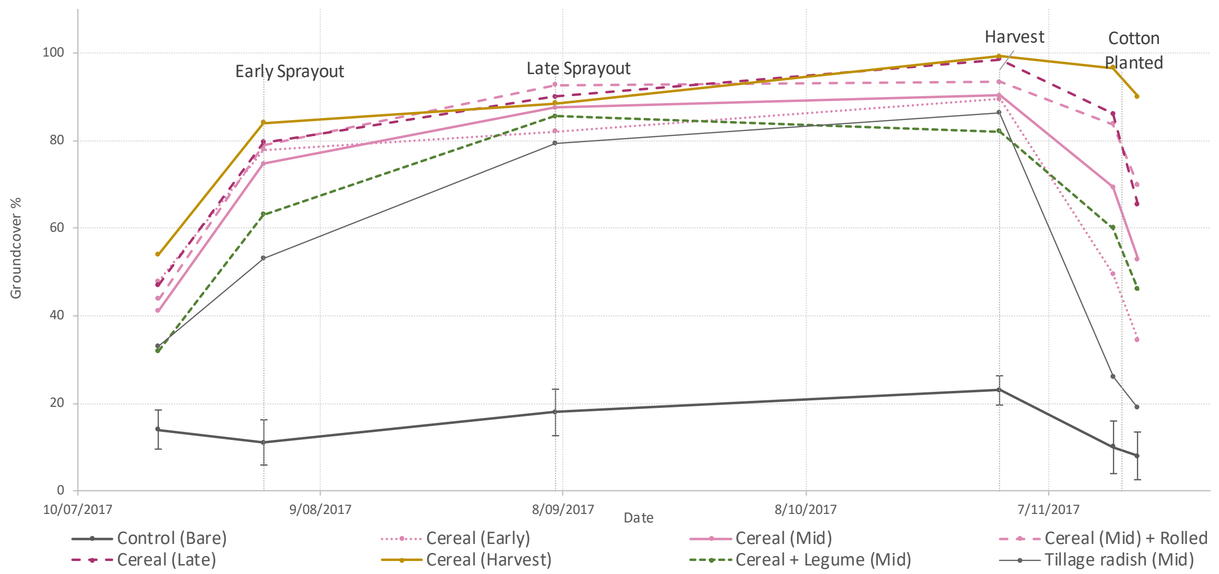


Figure 2. Ground cover assessments showed the largest decline under the tillage radish treatment.

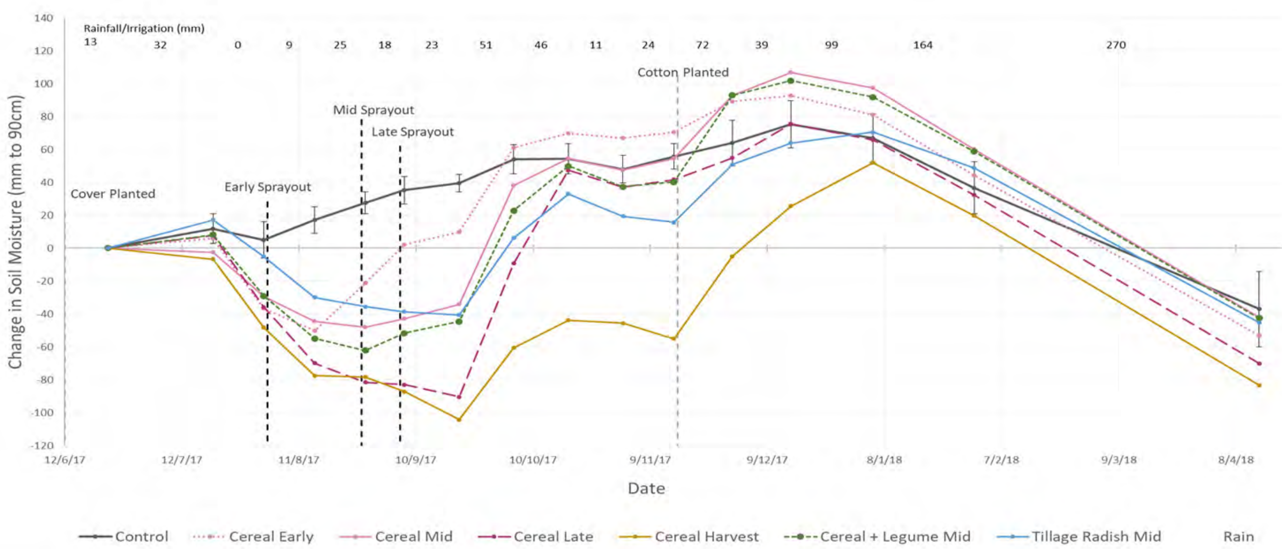


Figure 3. There were large changes in soil water (mm to 90 cm) from planting of the winter cover crop treatments and defoliation of the subsequent cotton crop at Yelarbon.

Crop performance

Matching the irrigation schedule to the harvested crop appears to have provided more than adequate water across the cover crop treatments; yields for all cover crop treatments were similar. However, the Control with limited ground cover was the poorest performer with at least 2.6 bales/ha lower yield, lower infiltration in early growth stages, and less water extracted late in the crop than treatments with cover crops.

The costs to plant the cover crops (~$50/ha) and to spray them out (~$20/ha) almost matched the savings from three less weed sprays during the fallow (~$60). Consequently, the measured cotton yield responses were very profitable, and appear to have been due to more than water alone.

For people who also grow grain, the 14 mm of extra stored water from this early-termination cover crop would typically produce ~200 kg grain (assuming 15 kg grain/mm water). This is worth ~$50/ha (at $270/t) for a net return of ~$40/ha.

Table 2. Net change in water storage over the life of the fallow (relative to the Control) and final cotton yield for each cover crop treatment at Yelarbon ranged from -111 mm to +14 mm.

Cover crop treatment	Terminated	Water gain (cf control)	Cotton yield (bales/ha)
Control (bare fallow) Starting water ~100 mm PAW		56 mm (fallow gain)	9.3
Cereal	Early	+14 mm	12.9
Cereal	Mid	-1 mm	12.7
Cereal	Late	-14 mm	11.9
Cereal	Mid + Roll	-2 mm	12.6
Cereal	Harvest	-111 mm	14.1
Cereal + legume	Mid	-16 mm	11.9
Cereal + legume	Late	-7 mm	13.9
Tillage radish	Mid	-40 mm	14.4

Implications for growers and agronomists

The project results show that cover crops can indeed help increase net water storage across fallows that have limited ground cover. How often these soil water results will occur across different seasons will be explored with further experiments and simulation modelling.

The yield results for the subsequent cotton crop (and the wheat crop at Bungunya, page 63) are dramatic. These very large responses represent big improvements in returns; far beyond what could be expected from the increases in net soil water storage across the fallows. There also appears to have been greater water extraction in some cover crop treatments in this Yelarbon experiment.

While wheat establishment was dramatically better after cover crops at Bungunya, the trial planter configuration and the alignment of plots in the paddock at Yelarbon led to the cotton rows crossing over rows of cover crop stubble, making establishment hard to assess. The grower ensures his cover crop planter bar and row alignment is configured so that the cotton is planted between the rows of stubble to ensure good establishment. How much of the final responses can be attributed to these factors, how often such results are likely, and the contributions of other factors to these gains remains to be explored.

Acknowledgements

We very much appreciate the support of the trial co-operator and consultants for their effort and contributions to the project, along with our project team members in CSIRO (Neil Huth, Brook Anderson), David Freebairn, and the DAF Biometry, Technical and Research Infrastructure staff that supported the heavy management and monitoring loads of these experiments.

Thanks also to the Grains Research and Development Corporation, Cotton Research and Development Corporation and the Department of Agriculture and Fisheries for funding the project (DAQ00211).

Trial details

Location:	Yelarbon
Crop:	Cover crops, cotton
Soil type:	Brigalow, Grey Vertosol
In-crop rainfall and irrigation:	895 mm (253 mm Cover/Fallow and 642 mm in cotton)

Cover cropping articles only

Queensland grains research 2019-20

Regional agronomy (research)

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Queensland Government

Cover crops: Soil water was not reduced on a long fallow during a drought—Yagaburne

Andrew Erbacher and David Lawrence
Department of Agriculture and Fisheries

Research Questions: *Can summer cover crops increase the net water accumulation in dryland systems with low ground cover (<30%) in the northern region?*

- *What is the net water cost to grow summer cover crops?*
- *What is the net water gain to subsequent grain crops (fallow and early growth periods)?*
- *What is the impact on the yield of the grain crops?*

Key findings

1. Cover crops continue to provide soil and water security in the Goondiwindi district with little if any downside risk of losing stored moisture across long fallows.
2. The net water deficit of both mid-terminated summer and winter cover crops was approximately 40 mm; in-line with all past experiments in this project.
3. Despite a record dry season, all cover crop treatments recovered to within +/- 10 mm plant available water by the end of the fallow.
4. Ground cover from the cover crops created a planting opportunity in 2019 that was not available where cover crops were not used; a valuable opportunity in most seasons.

Background

Advances in agronomy and commercial agronomist support have seen growers better use their available soil water and improve individual crop performance. However, more effective capture and storage of rainfall across the whole farming system remain as major challenges for northern grain and cotton growers where only 20-40% of rainfall is typically transpired by dryland crops, up to 60% of rainfall is lost to evaporation, and a further 5-20% lost in runoff and deep drainage. Every 10 mm of extra stored soil water available to crops could increase dryland grain yields for growers by up to 150 kg/ha, with corresponding benefits to dryland cotton growers as well.

Grains Research and Development Corporation (GRDC) funded farming systems projects (DAQ00192/CSA00050) are assessing ways to improve this system water use, and to achieve 80% of the water and nitrogen limited yield potential in our cropping systems. GRDC's Eastern Farming Systems project and Northern Growers Alliance trials both suggested that cover crops and increased stubble loads can reduce evaporation, increase infiltration and provide net gains in plant available water (PAW) over traditional fallow periods. Consequently, cover crops may be a key part of improved farming systems; providing increased productivity, enhanced profitability and better sustainability.

The project has previously demonstrated at Bungunya that it is possible to recoup PAW used by a cover crop in a long fallow between sorghum and wheat, and even increase total water storage in some treatments. Reported in *Queensland grains research 2018-19*, the trial subsequently established a more even wheat population after cover crops, extracted more water at harvest, and increased wheat grain yield by 30%.

Scientific rationale

Stubble and evaporation

Retained stubble provides ground cover, protects the soil from rainfall impacts and so improves infiltration to store more water in the soil. Conventional wisdom is that increased stubble loads can slow down the initial rate of evaporation, but that these gains are short-lived and lost from accumulated evaporation after about three weeks. However, further rain within this period, and the manipulation of stubble to concentrate stubble loads in specific areas, provide an opportunity to reduce total evaporation and to accumulate more plant available water (Photo 1).

Photo 1. The stubble effect visible three days after ~30 mm of rain. The theory is that stubble reduces evaporation and keeps the soil surface wetter for ~21 days, so if more rain falls within that time, more water will be stored.

Dryland grain systems

Cover crops are used in Southern Queensland and Northern NSW to overcome a lack of stubble and protect the soil following low residue crops (e.g. chickpea, cotton) or following skip-row sorghum with uneven stubble and exposed soil in the 'skips'.

Growers typically plant White French millet and sorghum, and spray them out within ~60 days to allow recharge in what are normally long fallows across the summer to the next winter crop. Allowing these 'cover crops' to grow through to maturity led to significant soil water deficits and yield losses in the subsequent winter crops. However, the Eastern Farming Systems projects showed only small deficits (and even water gains) accrued to the subsequent crops when millets were sprayed out after 6 weeks, with average grain yield increases of 0.36 t/ha. Furthermore, the Northern Growers Alliance showed that the addition of extra stubble (from 5-40 t/ha) after winter crop harvest appeared to reduce evaporation, with initial studies showing between 19 mm and 87 mm increases in plant available water. These gains will be valuable if validated in further research and captured in commercial practice.

What was done

The Yagaburne experiment was in a long-fallow zero-till paddock following skip-row sorghum. The sorghum harvest was in early February 2018 and the paddock was left with standing sorghum rows and some wheat stubble in the interrow.

The site was on a poplar box soil that is prone to setting hard in the absence of good ground cover.

There were two times of planting for cover crops and five replications. Winter cover crops were planted on 18 July 2018 with ~70 mm of PAW, with five different cover crop treatments and an undisturbed control (Photo 2).

Photo 2. Residual stubble at emergence of the winter cover crop (and undisturbed on the right).

A further six spring cover crop treatments were planted on 9 October 2018 with ~90 mm PAW. The rest of the paddock was sown to a White French millet cover crop by the cooperator. Cover crop treatments are provided in Table 1.

There were three planned termination times matching key growth stages: Early-termination (sprayout) at first node (Z31) when the crop begins stem development; Mid-termination at flag leaf emergence (Z41) when the reproductive phase begins; and Late-termination at anthesis (Z65) for peak biomass production. All cover crops were terminated to their growth stage. All treatments were monitored for ground cover, dry matter production and soil water until the subsequent grain wheat crop was planted in May 2019.

Soil water was estimated using soil cores to measure gravimetric soil water at key times across the fallow and the subsequent wheat, along with regular neutron moisture meters (NMM) and EM38 readings in each plot.

Table 1. Cover treatments applied at the Yagaburne site prior to planting wheat, biomass* at termination of each cover crop and percentage ground cover at the last termination date and at the end of the fallow period.

Trt#	Cover crop	Planting rate (plants/m² targeted)	Termination (sprayout)	Biomass grown (kg/ha)	Ground cover %	
					5/12/19	2/05/19
1.	Bare (control)			0	8	8
2.	Wheat	100	Early	86	12	11
3.	Wheat	100	Mid	410	26	24
4.	Wheat	100	Late	697	45	42
5.	Wheat	100	Late + roll	718	50	45
6.	Winter multi-species (wheat, vetch, radish)	50, 30, 20	Mid	538	38	31
7.	Millet	100	Early	527	62	37
8.	Millet	100	Mid	1412	89	80
9.	Millet	100	Late	2043	94	87
10.	Millet	100	Late + roll	1945	97	84
11.	Sorghum (sudan hybrid)	65	Mid	2551	96	93
12.	Summer multi-species (millet, lablab, radish)	50, 30, 20	Mid	1117	65	46

* (does not include the 1700 kg/ha of residual stubble, centred mostly on the sorghum row, in all treatments including the 'bare control')

These NMM and EM38 readings and the percentage ground cover were recorded every 2–4 weeks while the cover crops were growing, and every four weeks in the fallow once all cover crops were terminated. These soil water measurements continued every four weeks in the growing crop and a final soil water measure at harvest.

The subsequent wheat crop was planted on 27 May 2019 and harvested in October 2019. With no planting opportunity and no rain predicted, the site was dry planted using the grower's single disc planter (33⅓ cm row spacing) and ~8 mm trickle irrigation applied for crop establishment. While several of the cover crop plots retained better surface moisture and could have been planted earlier in the season, the treatments with little cover could not. So, planting was held off for rain then resorted to irrigation at the end of May to ensure any underlying treatment impacts on the grain yield of the wheat crop could be compared.

Results

Biomass and ground cover

The late planting date of the winter cover crops and the relatively dry conditions restricted dry matter production (biomass) and ground cover. The Early-terminated wheat grew only 86 kg/ha of biomass before termination and did not provide useful levels of cover (Table 1), whereas past trials had early termination biomass levels in cereal cover crop of over 1000 kg/ha and ground cover levels over 50%; equal to the best cover levels from the winter cover cops in this experiment at Yagaburne.

The summer cover crop fared much better. While still relatively low, the millet treatments produced ~500, 1400 and 2000 kg/ha for Early, Mid and Late-termination respectively (Table 1). The Mid-terminated sorghum cover crop was sprayed out on the same day as the Late-terminated millet, used the same water and grew similar biomass.

Soil water

The mid-terminated wheat cover crop had 36 mm less PAW at termination than planting for 400 kg/ha biomass (Figure 1, Figure 2). With 50 mm rainfall in October, the late-terminated wheat was 5 mm drier than at planting with 700 kg/ha of resilient straw. Critically, all winter cover crops had recovered to similar PAW as the control when the summer cover crops were planted.

With an extra 90 days and 75 mm rain in fallow, the summer cover crop had 26 mm more PAW in the soil than when the winter cover crop was planted. The Early, Mid and Late-terminated millet cover crops were 25 mm, 46 mm and 80 mm drier at termination than when they were planted (Figure 1, Figure 2; the balance of water used by the cover crop and the water captured and stored from rainfall).

The subsequent wheat crop

With the dry autumn of 2019, the paddock was assessed on 14 May for the potential to plant wheat across the trial. At ten days after 8 mm rain and 45 days since the last significant rainfall, the conclusion was that only the plots with the highest levels of cover (those above 40%) had enough surface moisture to allow an even establishment of wheat; soil moisture across the plots clearly reflected their cover levels. The four treatments with the best cover (Treatments 8-11; Table 1) had good moisture for planting; three treatments were too dry (Treatments 1-3; Table 1), and the other five treatments were marginal.

With no rain received by the end of May and no forecast rain, it was decided to dry plant and apply trickle irrigation to the seed row for crop establishment.

When the wheat 'cash crop' was planted, the bare control treatment had approximately the same PAW that it had 11 months earlier at the start of the fallow; it was a dry season but there was no net water storage after 240 mm of rain (average annual rainfall for the area is 580 mm). Previous trials have shown variability in sampling of +/- 10 mm, so there was no real difference in PAW at this time with the best cover crop treatments having only 10 mm more and the worst 10 mm less PAW than the control.

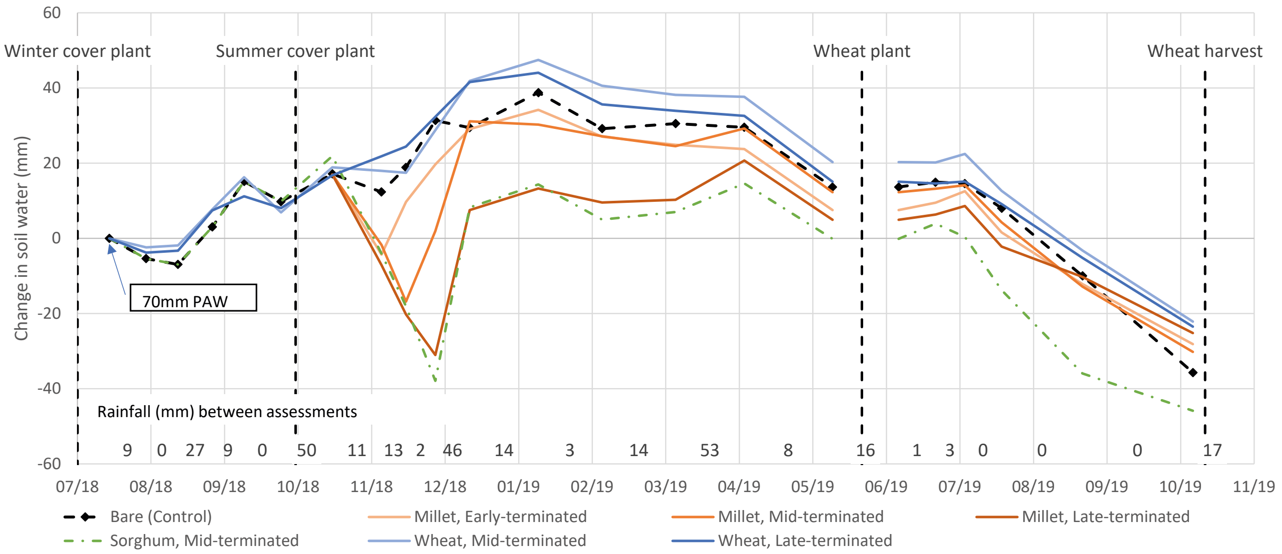


Figure 1. Change in plant available water for a range of cover crops, measured with a neutron moisture meter to 150 cm depth. Grids represent each month and numbers in the bottom row are mm rainfall for that month.

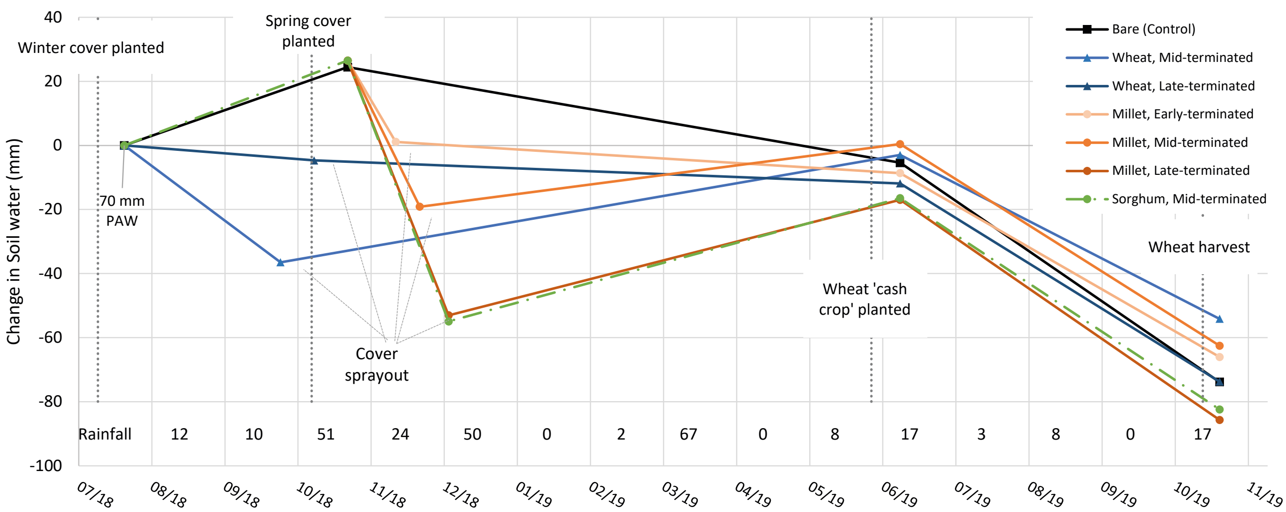


Figure 2. Change in plant available water for a range of cover crops, measured with soil cores (gravimetric) to 150 cm depth at key crop growth stages. Grids represent each month and numbers in the bottom row are mm rainfall for that month.

Volumetric soil water measured post-harvest of the wheat crop had a similar spread as the wheat. The crop extracted an average of 61 mm (net) of PAW from the profile, and with only 17 mm of in-crop rain the wheat yielded 570 kg/ha. There was no treatment effect observed from the cover crop treatments, reflecting the similar soil moisture levels they had at planting.

However, there was a consistent yield increase from the crop over the old sorghum rows, compared to the crop growing in the original 'skip-row' from the previous sorghum crop. After noticing lower EM38 readings in the previous sorghum skips, two plot header runs were taken for each plot: one over the previous sorghum rows and the other over the skip (Figure 1). Across all plots, there was an extra 126 kg/ha yield (25%) measured on the old sorghum rows versus the skip (632 kg/ha vs 506 kg/ha), reinforcing the original rationale for cover crops in the Goondiwindi district; to protect the bare skip-rows from erosion by encouraging infiltration rather than runoff, especially on harder setting and sloping sites.

Implications for agronomists and growers

The trial has provided some clear insights despite the extremely dry season, with its low yields for both the cover crops and the subsequent wheat.

The net water deficit of both the Mid-terminated summer and winter cover crops was approximately 40 mm; in line with all past experiments in this project.

Again in an extremely dry season, by the time the subsequent wheat crop was planted for grain, the water in all treatments had recovered to within +/- 10 mm PAW.

Furthermore, the only plots that had enough surface moisture to be planted (without the aid of trickle tape) were those in which cover crops had increased, and then maintained, at least 40% cover by the end of the fallow. The opportunity for an extra crop could be incredibly valuable in many seasons.

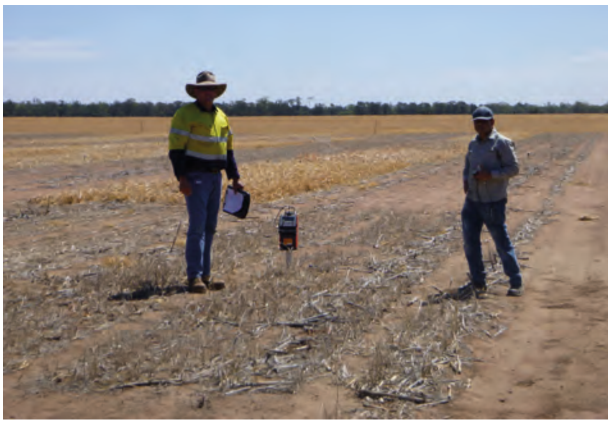
This was a real test for cover crops with a large expected downside risk. However, the results suggest that even in these very dry times, cover crops can be used to protect the soil and maximise the opportunity to capture as much rain as possible, with no significant loss of water across the fallow. Growing the cover crops is an additional cost, however, this cost will be off-set in more normal seasons when infiltration, runoff and erosion are more likely to be problems. In short, cover crops have an understandable role to play when cover levels are low and growers are struggling to get water back into their paddocks.

Acknowledgements

We very much appreciate the support of the trial cooperator and consultants for their effort and contributions to the project, along with our project team members in CSIRO (Neil Huth, Brook Anderson), David Freebairn, and the DAF Biometry, Technical and Research Infrastructure staff that supported the heavy management and monitoring loads of these experiments. Thanks also to the Grains Research and Development Corporation, Cotton Research and Development Corporation and the Department of Agriculture and Fisheries for funding the project (DAQ00211).

Trial details

Location:	Yagaburne
Crop:	Wheat long fallowed from skip-row sorghum with wheat or White French millet and other cover crops
Soil type:	Poplar Box Chromosol
Rainfall:	269 mm (224 mm cover/fallow and 45 mm in wheat)



Taking monthly neutron moisture meter readings.

Cover crops: Soil water was not reduced on a long fallow during a drought—Goondiwindi

Andrew Erbacher and David Lawrence
Department of Agriculture and Fisheries

Research Questions: *Can cover crops increase infiltration and net water accumulation in lateral-irrigated cotton systems with low ground cover (<30%)?*

- *What is the net water cost to grow winter cover crops?*
- *What is the net water gain to subsequent cotton crops?*
- *What is the impact on the yield of the subsequent cotton crops?*

Key findings

1. Cover crops can improve ground cover in fallows without costing plant available water for the next crop.
2. The Early-terminated treatment was the best cover crop for storing water over the short fallow in this study where cover did not have to last very long. However, the extra cover in the Mid and Late-terminated treatments continued to boost infiltration later in the fallow.

Background

Approximately 60% of rainfall in northern farming systems is lost to evaporation, with transpiration through plants typically only 20-40%. Cover crops protect the soil from erosion, build soil organic matter and maintain soil biological activity. However, not being harvested for grain or fibre, they are considered 'wasteful' of rainfall; widely seen to be our most limited resource in dryland farming systems.

Recent research now suggests that cover crops may provide benefits with little or no loss of this plant available water (PAW). Therefore, there is renewed interest in cover cropping to use some of this 'lost' water and help develop systems that are more productive, profitable and sustainable. For example, we know that cotton crops can leave the soil dry and unprotected with low groundcover after picking, reducing infiltration and making it difficult to rebuild soil water levels for the next crop. Consequently, dryland growers plant winter cereals to get cover back on the ground and protect the soil; the crops may be harvested in good seasons, or be sprayed out after 6-10 weeks to provide the necessary ground cover to maintain infiltration.

However, efficient water use is also important for irrigated cotton growers, especially overhead irrigators who are interested in cover to maximise infiltration when they are watering-up and during the early growth stages of the cotton when they may have trouble getting enough water into the soil to keep up with later crop demand. Stubble will also protect young cotton plants from hot summer winds after planting.

This project has intensively monitored crop experiments from Goondiwindi (Qld) to Yanco (NSW) to quantify the impact of cover crops on fallow water storage and crop growth. That is, how much water is required to grow cover crops with sufficient stubble, how will these stubble loads affect accumulation of rainfall, the net water gain/loss for following crops and the subsequent impacts on crop growth and yield. This paper reports on an irrigated cotton paddock north-west of Goondiwindi.

What was done

The Goondiwindi experiment was on a lateral-irrigated paddock that grew chickpea in 2017. Chickpeas were harvested in December and cover crops were planted on the first significant rainfall event after harvest. Nine cover treatments with five replicates were planted in February 2018, and a further two (winter) cover crops in June (Table 1). The commercial area was planted to a wheat cover crop with the aim of growing cotton in 2018/19.

This site had 12 m wide plots with the plan to plant half (6 m) to winter crop after a cover crop in a short fallow and keep the other half for long fallow into cotton.

Table 1. Cover treatments applied in 2018.

Trt#	Cover crop	Termination timing	Planted	Terminated	Termination stage
1	Control (bare)				
2	Sorghum	Early	6 February	15 March	First node (Z31)
3	Sorghum	Mid	6 February	5 April	Flag leaf emergence (Z41)
4	Sorghum	Mid and rolled	6 February	5 April	Flag leaf emergence (Z41)
5	Sorghum	Late	6 February	14 May	Anthesis (Z65)
6	Sorghum	Late and rolled	6 February	14 May	Anthesis (Z65)
7	Millet	Mid	6 February	5 April	
8	Millet & lablab	Mid	6 February	5 April	
9	Millet & lablab	Mid (incorporated not sprayed)	6 February	16 April	
10	Multispecies	Mid	6 February	5 April	
11	Wheat	Mid	7 June	3 September	Booting (Z53)
12	Wheat	Late	7 June	17 September	Milky-dough

Sorghum termination times matched key growth stages: Early-termination when the crop begins stem development; Mid-termination when the reproductive phase begins; and Late-termination at anthesis for peak biomass production. The wheat cover crops were planned for termination at 'mid' and 'late' phenological stages.

The incorporated millet/lablab was not sprayed out, but ploughed with offsets. Sorghum development slowed after Mid-termination with Late-termination occuring 14 weeks post-planting. Mid-termination for the wheat cover crop was at booting (10 days later than planned), and Late-termination two weeks later when the wheat was at milky-dough stage.

The dry spring in 2017 meant the summer cover crop were planted late, and with a dry autumn the Late-termination didn't occur until winter crop planting time. Consequently, the plan to split all plots and plant wheat was not progressed, and the larger plots were maintained to plant cotton in spring 2018. Due to the ongoing dry winter, the farm used the last of their water to grow their cover crop through to yield and did not grow cotton that year.

Soil water was estimated using soil cores to measure gravimetric soil water at key times, along with regular neutron moisture meters (NMM) and EM38 readings in each plot. These readings and the percentage of ground cover were recorded every 2–4 weeks. NMM water monitoring continued until 14 August 2019.

Results

Biomass and ground cover

The millet established very poorly, providing an ineffective cover crop, so the millet and multispecies treatments will not be discussed in any detail.

Biomass of the sorghum cover crops ranged from 2072 kg dry matter (DM)/ha for the Early-termination, up to 3650 kg DM/ha for the Mid and Late-terminated sorghum (Figure 1). The millet established poorly and produced much less biomass than the sorghum, despite being at anthesis (peak biomass) when sprayed. There was very little millet in the millet/lablab cover crops, so these treatments produced considerably less biomass than the sorghum.

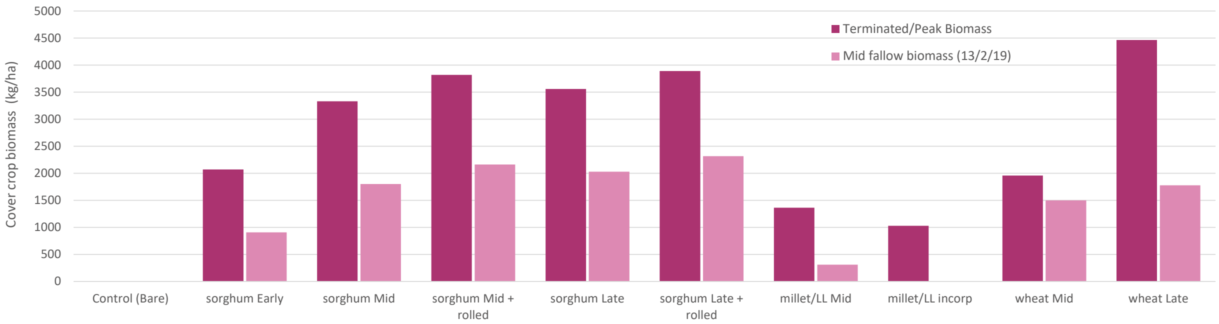


Figure 1. Above ground biomass accumulation for each cover crop treatment (excluding old cotton stubble).

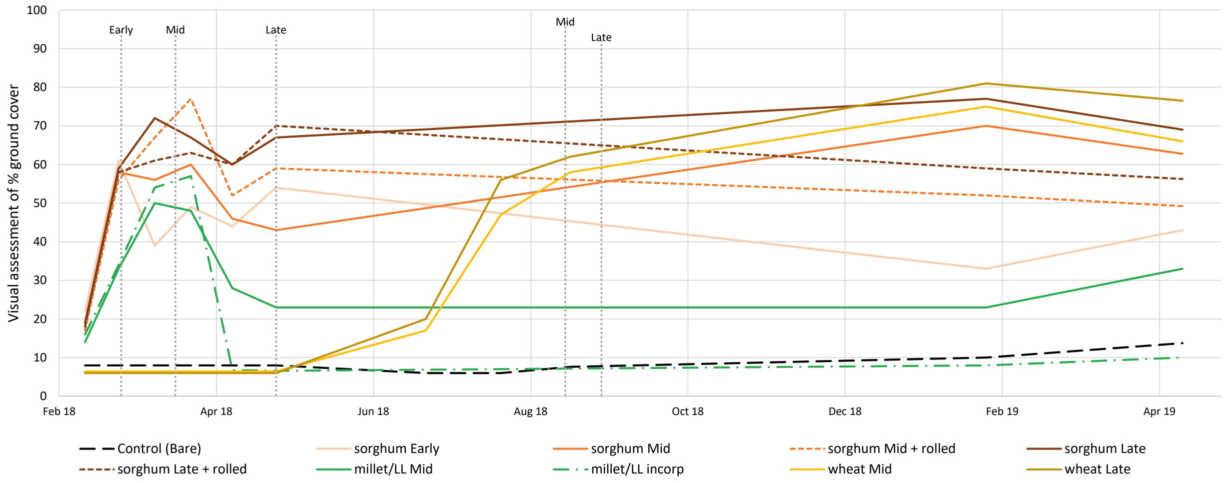


Figure 2. Visual assessments of ground cover for each cover crop treatment over time.

The wheat cover crop produced 1959 kg DM/ha at the Mid-termination, and increased to 4465 kg DM/ha at Late-termination. The change in biomass to February 2019 suggests about 2 t/ha of this increase was grain production.

Ground cover increased rapidly in line with biomass as the cover crops grew. However, the Early-terminated sorghum collapsed across the rows shortly after termination, and increased its initial ground cover to a level higher than the Mid-terminated sorghum. The Mid and Late-terminated sorghum developed stronger stems so remained standing, but rolling the Mid and Late-terminated sorghum had a similar effect in increasing initial ground cover. Early termination and rolling increased the rate of stubble breakdown and overall loss of ground cover for these treatments (Figure 2).

Soil water

The chickpea crop prior to the experiment left the soil profile wet below 90 cm, so the results presented here focus on the top 90 cm of soil.

The cover crop was planted after 50 mm of rain with 30 mm PAW. With another 138 mm of rain in the early stages of the cover crop, the Early-terminated sorghum finished with similar soil water to the bare control.

With little rain after Early-termination, the Mid-terminated sorghum had 30 mm less PAW than the control, and this gap increased to 40 mm PAW at Late-termination (Figure 3). The Late-terminated sorghum used all of the PAW in the top 90 cm.

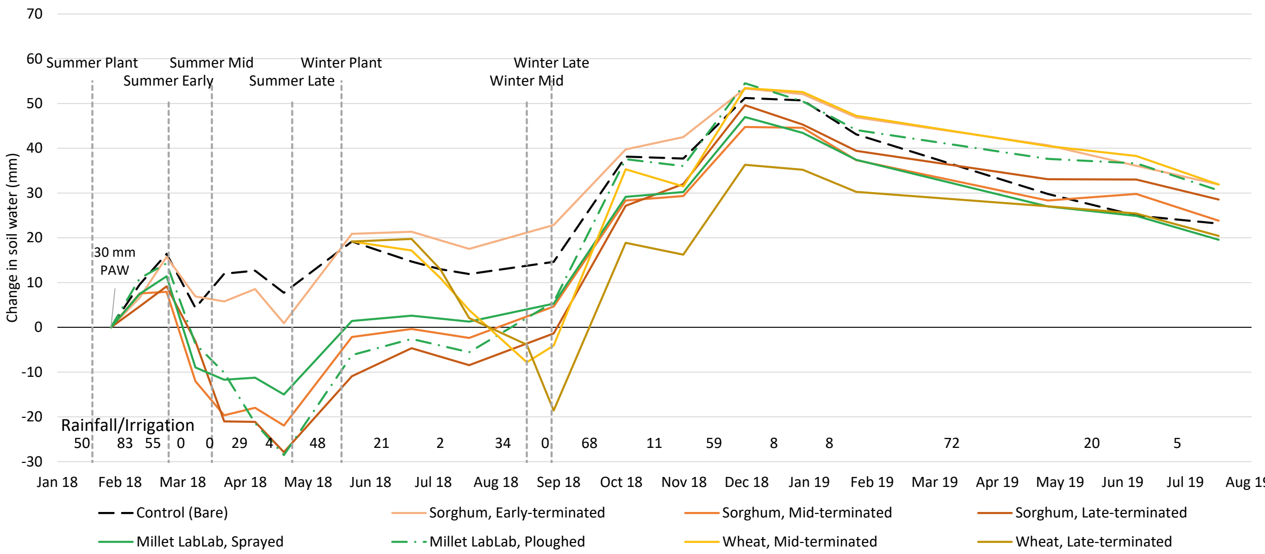


Figure 3. Changes in soil water (mm to 90 cm) from planting of the cover crop treatments to conclusion of monitoring at Goondiwindi. Rainfall and overhead sprinkler irrigation was measured onsite from May 2018, prior values were estimated from a nearby BOM station.

The wheat cover crops had 20 mm more PAW at planting (50 mm). By Mid-termination the wheat was 24 mm drier than the bare control, and 30 mm drier the late-sprayout. The Late-terminated wheat and sorghum were the only treatments to extract water from below 60 cm.

The summer cover crops recovered some of their lost PAW during the winter. However, it was not until after the Late-terminated wheat spray-out and the grower started irrigating the paddock that the treatments recovered the water used to grow the cover crops. By the end of November, most cover crops had recovered PAW differences, only the Late-terminated sorghum and wheat were drier in the 60-90 cm layer.

Rainfall in 2019 was very low, so differences began to emerge and the treatments with low cover dried out in the 0-30 cm layer more than those with more ground cover (i.e. where the lines cross in Figure 3). The exception was the incorporated millet/lablab cover crop, which maintained more surface moisture than the sprayed out millet/lablab, and similar moisture to the sorghum and wheat cover crops that had much higher ground cover. The surface roughness from tillage may have allowed the water to pool and infiltrate over time on this flat site. Closed soil pores then slowed the rate of water loss in the following period.

Implications for growers and agronomists

Terminating the sorghum cover crop early allowed ground cover to be re-established without sacrificing PAW or planting opportunities of the next crop. However, as the crop matured, the later terminations used more water and created a water deficit that took longer to recover in the fallow.

The poor establishment of the millet in the other summer cover crops made them ineffective; they used soil water without producing high levels of ground cover, in a similar fashion to a weedy fallow. These treatments with millet still recovered the soil water used at the same time as the more effective cover crops, but did not provide resilient, long-term ground cover to reduce surface drying in 2019.

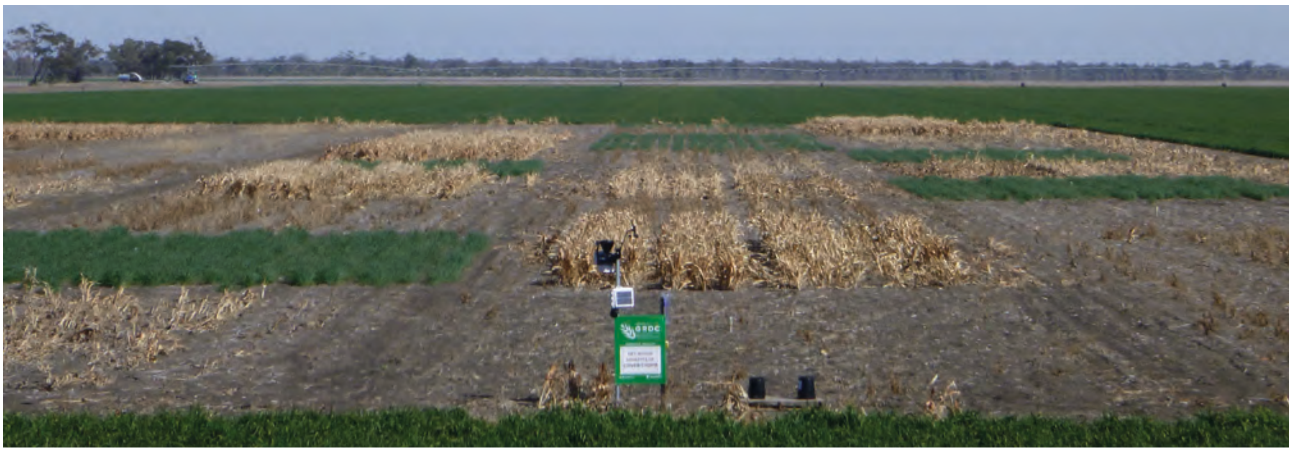
All cover crop treatments in this trial recovered their soil water. However, the site was located in an irrigated system that did not have enough water available to grow a subsequent 'cash' crop and assess the impact of the cover crops on their yield.

Acknowledgements

We very much appreciate the support of the trial cooperator and consultants for their effort and contributions to the project, along with our project team members in CSIRO (Neil Huth, Brook Anderson), David Freebairn, and the DAF Biometry, Technical and Research Infrastructure staff that supported the heavy management and monitoring loads of these experiments. Thanks also to the Grains Research and Development Corporation, Cotton Research and Development Corporation and the Department of Agriculture and Fisheries for funding the project (DAQ00211).

Trial details

Location:	Goondiwindi
Crop:	Cover crops including sorghum, wheat, millet, lablab and tillage radish.
Soil type:	Alluvial, Grey Vertosol
In-crop rainfall and irrigation:	521 mm (February 2018 to August 2019)



Cover crops: Summer cover crops on a short fallow reduced soil water and wheat yield—Billa Billa

Andrew Erbacher and David Lawrence
Department of Agriculture and Fisheries

***Research Questions:** Can summer cover crops increase the net water accumulation in dryland systems with low ground cover (<30%) in the northern region?*

- *What is the net water cost to grow summer cover crops?*
- *What is the net water gain to subsequent grain crops (fallow and early growth periods)?*
- *What is the impact on the yield of the subsequent grain crops?*

Key findings

1. Stubble load and stubble type had no impact on fallow efficiency in this very dry season.
2. Growing cover crops can reduce soil water available at the end of the fallow.
3. Wheat population and evenness of establishment remains critical to maximise water extraction and water use efficiency.

Background

Growers typically use cover crops to protect the soil from erosion in low stubble situations, return biomass that helps maintain soil organic matter and biological activity, and provide additional nitrogen (when legumes are used). However, cover crops also offer an opportunity to increase infiltration and fallow moisture storage for better and more profitable grain and cotton crops across the northern region of New South Wales and Queensland.

Grains Research and Development Corporation (GRDC) funded farming systems projects (DAQ00192/CSA00050) are assessing ways to improve this system water use, and to achieve 80% of the water and nitrogen limited yield potential in our cropping systems. GRDC's Eastern Farming Systems project and Northern Growers Alliance trials both suggest that cover crops and increased stubble loads can reduce evaporation, increase infiltration and provide net gains in plant available water over traditional fallow periods. Consequently, cover crops may be a key part of improved farming systems; providing increased productivity, enhanced profitability and better sustainability.

The 'Cover crop project' (DAQ00211) has monitored sites intensively to quantify the impact of different stubble loads on the accumulation of rainfall, the amount of water required to grow cover crops with sufficient stubble loads, the net water gains/losses for the following crops, and the impacts on their growth and yield.

This project has previously demonstrated at Bungunya that it is possible to recoup PAW used by a cover crop in a long fallow between sorghum and wheat, and even increase total water storage in some treatments. Reported in *Queensland grains research 2018-19*, the trial subsequently established a more even wheat population after cover crops, extracted more water at harvest, and increased wheat grain yield by 30%. In the short fallow between two cotton crops, only the earlier termination timings recouped the PAW used by the cover crops. However, all cover crops treatments had improved capture of the overhead irrigation water in early crop development that led to significant cotton yield benefits.

This current report is on research to explore the possibility of improving ground cover in a short fallow following a chickpea crop, without sacrificing the following wheat crop.

What was done

The Billa Billa experiment was established adjacent to the long-term farming systems trial site. The duplex soil has a loam surface that is prone to setting hard in the absence of good ground cover. The experiment compared the use of a cover crop when cover was low following chickpea, compared to different amounts and heights of traditional cereal stubble. The trial was planted to randomised plots of wheat and chickpea in 2018 to establish the different reference stubble types.

At harvest the wheat stubble was cut at two heights; tall - just below the head (50 cm), and short - half the height of tall (25 cm). Half of the tall wheat was later rolled, and half of the short wheat had the chopped straw raked off the plots, creating four wheat stubble treatments; tall standing, tall rolled, short tops spread, short tops removed. In the chickpea plots, sorghum cover crops were planted on the next planting opportunity post-harvest, with one chickpea treatment left as a bare control (Table 1).

All crops were planted on 40 cm row spacing, using the same planter and GPS guidance each time. This allowed us to plant the cover crop on the chickpea stubble row, and the subsequent wheat crop was planted in the inter-row leaving existing stubble standing in all plots.

Five Sudan hybrid forage sorghum cover crop treatments with six replicates were planted on 26 November 2018, to complement the five reference treatments with different stubble treatments.

Three planned termination times matched key growth stages of the main cereal treatments: Early-termination at first node (Z31) when the crop begins stem development; Mid-termination at flag leaf emergence (Z41) when the reproductive phase begins; and Late-termination at anthesis (Z65) for peak biomass production.

With low in-crop rain, the sorghum stopped phenology development at second node, so Mid-termination was sprayed-out three weeks after Early-termination. The Late-termination was delayed until rain was received, so wasn't sprayed until two months after the Mid-termination. There were two treatments sprayed at each of the mid and late spray dates, with the second treatment left a week for herbicide translocation, then crimp rolled.

Soil water was estimated using soil cores for gravimetric soil water at key times across the fallow and the subsequent wheat, along with regular neutron moisture meter (NMM) and EM38 readings in each plot. The NMM and EM38 readings and the percentage ground cover were recorded every 2–4 weeks in the fallow. These soil water measures continued every four weeks in the growing crop until canopy closure, with a final soil water measure at harvest.

The subsequent wheat was dry-planted on 28 June 2019 and irrigated with trickle tape down the seed row, for establishment. Wheat yields were estimated with hand-cuts on 17 October, and mechanical harvesting on 30 October 2019.

Table 1. Cover treatments applied prior to planting wheat in 2019.

Trt#	Initial crop	Cover treatment
1	Chickpea	Bare (Control)
2	Chickpea	Sorghum Early-terminated
3	Chickpea	Sorghum Mid-terminated
4	Chickpea	Sorghum Mid-terminated + Rolled
5	Chickpea	Sorghum Late-terminated
6	Chickpea	Sorghum Late-terminated + Rolled
7	Wheat	Tall stubble, left standing
8	Wheat	Tall stubble, rolled
9	Wheat	Shorter stubble, tops spread
10	Wheat	Shorter stubble, tops removed

Results

Biomass and ground cover

The chickpea stubble provided 20% ground cover at the start of the fallow. Planting a cover crop increased ground cover rapidly to have 65% cover at early-termination (Figure 1) but did not increase with delayed termination.

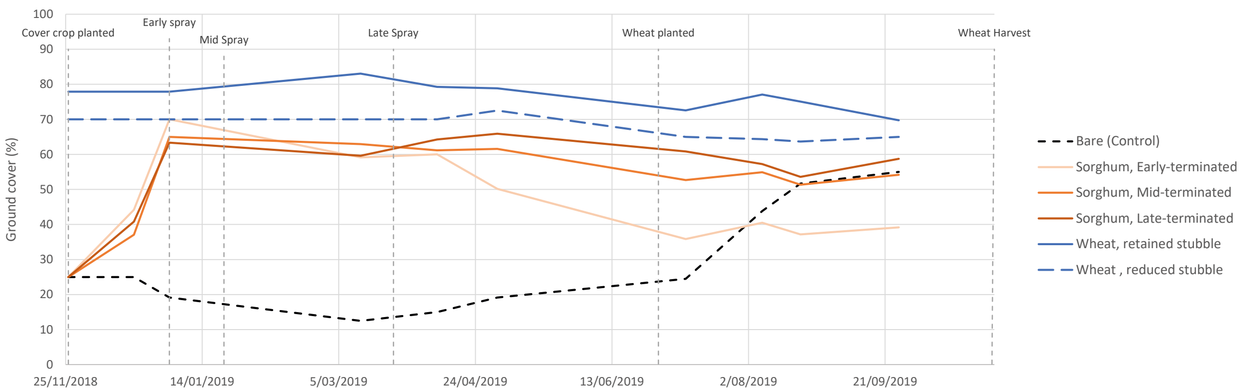


Figure 1. Visual assessment of % ground cover (three retained stubble treatments or +/- rolling were not different, so averaged values are presented).

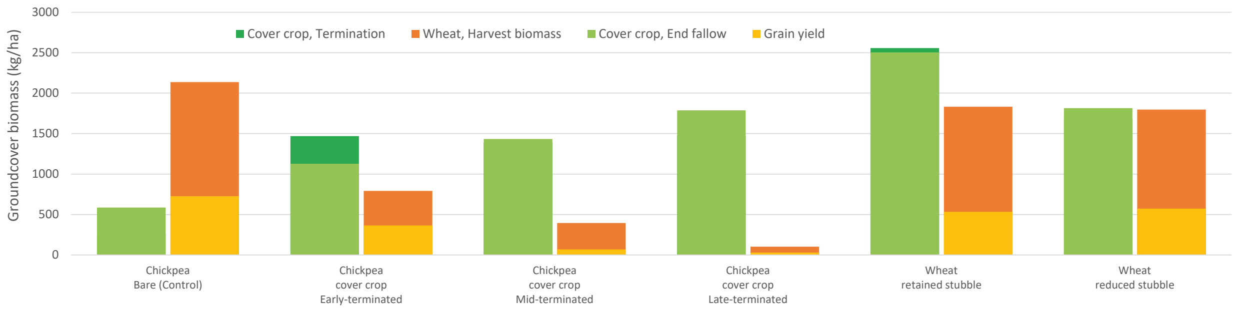


Figure 2. Biomass of ground cover assessed at Late-termination (27 March 2019), overlayed by biomass at the end of the fallow (21 June 2019), and wheat crop biomass overlayed by grain yield.

The three treatments with retained wheat stubble had 80% cover throughout the fallow. Removing the tops of the wheat plant only reduced this cover to 70%.

The chickpea stubble (bare control) provided 0.5 t/ha biomass at the start of the fallow. The sorghum cover crop provided an additional 1.5 t dry matter (DM)/ha at Early-termination, and with no in-crop rain, the sorghum biomass did not increase for the later termination timings. In comparison, there was 2.7 t DM/ha in the tall wheat stubble, while cutting the wheat stubble shorter and removing the tops reduced the biomass to a similar level as the sorghum cover crop (Figure 2).

With the low rainfall received during the fallow period, the wheat and chickpea stubble persisted on the soil surface. Only the Early-terminated cover crop reduced biomass and ground cover over the fallow period, as it was soft and leafy at termination, so broke down with the small rainfall events.

The subsequent wheat crop only increased cover significantly in the bare control. This treatment started from a lower cover level and increased to a similar level to the Mid and Late-terminated cover crops.

The wheat stubble plots started with higher cover levels, so the low yielding wheat crop made little improvement. The subsequent wheat grew poorly following the cover crops, and did not improve the cover in these treatments.

Soil water

The preceding chickpea left 20 mm more plant available water (PAW) on average than the wheat at harvest in 2018. The cover crops were planted on the next rainfall event after harvest with 70 mm plant available water.

At Early-termination, PAW reduced by 40 mm, and by Mid-termination used all of the PAW. The site received 40 mm rainfall in the first half of March, so had 16 mm PAW at Late-termination and received another 43 mm rain in the last week of March (Figure 3).

The rainfall over the fallow period was the lowest on record with rainfall only received in isolated storms. With no follow-up rain, the fallow efficiency was the same for all stubble types and stubble loads. As such the bare control (chickpea stubble) had the most PAW at planting, followed by the wheat stubble (which started the fallow 20 mm drier), and the sorghum cover crops had the least (Figure 3).

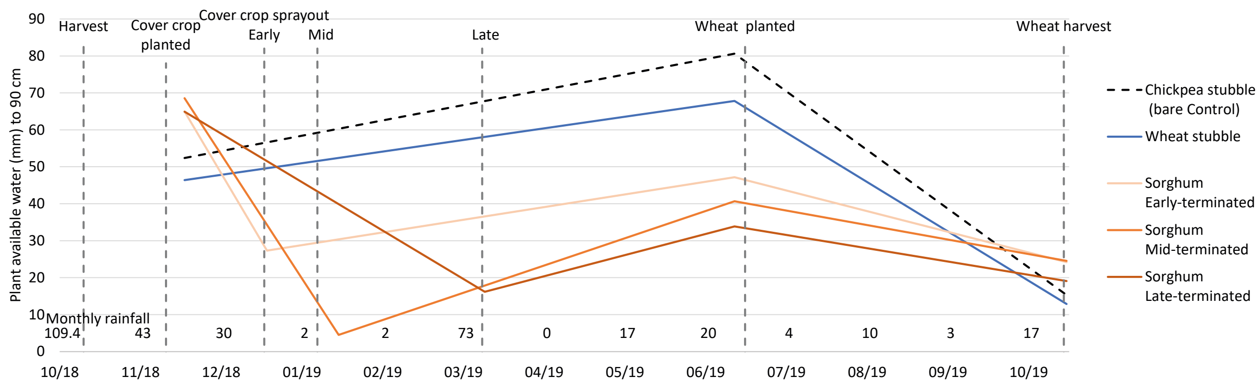


Figure 3. Plant available water measured to 90 cm with gravimetric soil coring at key times. Values on the bottom show the rain received that month. Wheat stubble treatments or +/- rolling Mid and Late-terminated cover crops had no impact on soil water, so averaged values are presented here.

The Early-terminated cover crop had a similar fallow efficiency to the fallowed treatments. The Mid and Late-terminated cover crops had drier soil surface when the site received 73 mm rain in March, which allowed them to capture more of this rainfall and so return a higher post-cover crop fallow efficiency; however, they still had the least PAW when the subsequent wheat crop was planted.

With an even population established in the wheat crop, all treatments dried the profile to a similar level at harvest.

Crop performance

Biomass of the mature crop and grain yield was low across all treatments (Figure 2). Yields were directly related how much soil water was available at planting. Crops across all treatments produced 37 kg/ha biomass or 11.8 kg/ha grain per mm of water over-and-above an initial 44 mm of water required before crops went through to yield (Figure 4).

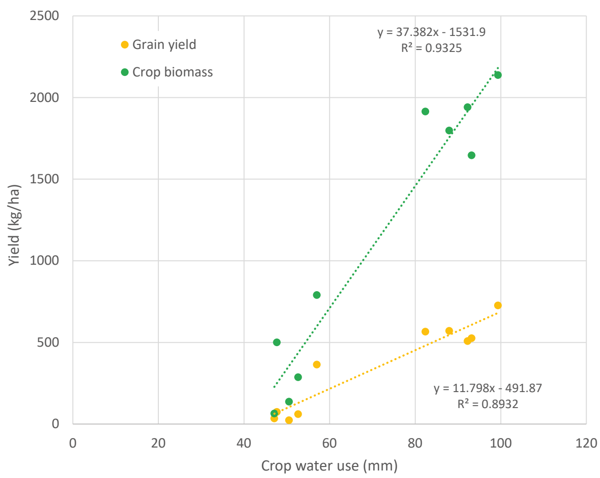


Figure 4. Crop water use and grain yield of the wheat following cover crops at Billa Billa. The point where the lines intercept the x axis is the water use required to produce yield and the slope of the line is the marginal water use efficiency.

Implications for agronomists and growers

This project has previously shown that it is possible to recover the water used by a cover crop, and even accumulate more PAW in a long fallow with little cover. Moreover, the project has measured yield benefits beyond what can be explained by the extra PAW.

However, this experiment showed the opposite. It focused on a shorter fallow period and in a record low rainfall year. Over the fallow, the rain received was in one-off events with no follow-up for up to four weeks. So, it is not surprising that the cover crops did not recover the PAW used to grow them. In this situation stubble loads were of little consequence; any effect extra stubble had on slowing the evaporation of surface moisture had dissipated by the time the next rain fell.

The use of trickle tape irrigation for establishing the wheat crop allowed an even population of 1 million wheat plants per hectare. With this even population the differences in wheat yield was strongly correlated to the soil water at planting that was subsequently used by the crop. From this we can suggest that the PAW left at harvest in the bare control at the Bungunya site (reported in *Queensland grains research 2018-19*) and its associated yield penalty was largely a result of uneven crop establishment.

Acknowledgements

We very much appreciate the support of the trial cooperator and consultants for their effort and contributions to the project, along with our project team members in CSIRO (Neil Huth, Brook Anderson), David Freebairn, and the DAF Biometry, Technical and Research Infrastructure staff that supported the heavy management and monitoring loads of these experiments. Thanks also to the Grains Research and Development Corporation, Cotton Research and Development Corporation and the Department of Agriculture and Fisheries for funding the project (DAQ00211).

Trial details

Location:	Billa Billa
Crop:	Wheat short fallowed from wheat or chickpea with sorghum cover crops
Soil type:	Belah, Duplex
Rainfall:	180 mm (145 mm cover/fallow and 35 mm in wheat).

Cover crops: Cover crops though a very dry then very wet fallow—Croppa Creek

Andrew Erbacher and David Lawrence
Department of Agriculture and Fisheries

Research Questions: *Can cover crops increase infiltration and net water accumulation in pivot-irrigated cotton systems with low ground cover (<30%)?*

- *What is the net water cost to grow winter cover crops?*
- *What is the net water gain (and impact on yield) to subsequent cotton crops?*

Key findings

1. Early-terminated cover crops quickly recovered the soil water they used early in the fallow.
2. Cover had no impact in what was a very dry fallow period.
3. Mid and Late-terminated cover crops had more cover and captured more rain in the wet February late in the fallow, resulting in all treatments finishing with similar plant available water.

Background

This site aimed to replicate the 2018-19 Goondiwindi and 2017-18 Yelarbon sites (*Queensland Grains Research 2018-19*), which grew cover crops in preparation for overhead irrigated cotton. Unfortunately, no cotton was planted due to a water shortage, so no crop effects are reported.

What was done

The Croppa Creek experiment was conducted on a newly converted pivot-irrigated paddock that last flood irrigated cotton in 2017. Initially planted to a barley cover crop, the paddock was surveyed using an EM38 before it was pegged and soil sampled (Image 1). Control treatments were established on 12–13 June 2019 by spraying-out the barley at the 3 leaf stage before six cover crop treatments with five replicates were established (Table 1).

Three termination times matched key growth stages of the barley: Early-termination at first node (Z31) when the crop begins stem development; Mid-termination at flag leaf emergence (Z41) when the reproductive phase begins; and Late-termination at anthesis (Z65) for peak biomass production. The terminations were conducted on 5 July, 4 August, and 6 September 2019. Terminated crops were left for a week to translocate herbicides before soil sampling, biomass cuts and rolling (where applicable) at each timing.

Table 1. Cover treatments applied.

Trt#	Cover crop type	Termination
1	Control (Bare)	
2	Barley	Early
3	Barley	Mid
4	Barley	Mid and Rolled
5	Barley	Late
6	Barley	Late and Rolled

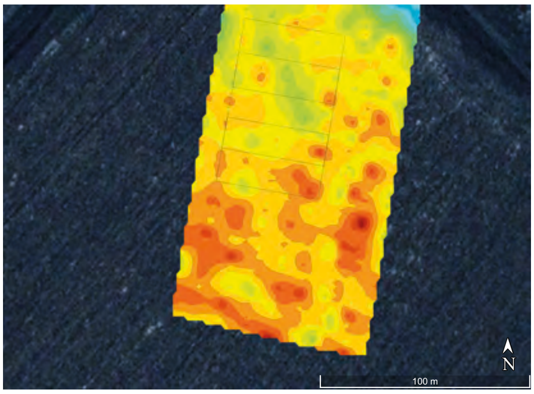


Image 1. EM38 survey (black lines indicate trial area).

Bore water allocations for the district are reviewed mid-year and were reduced for 2019–20. The collaborating grower subsequently decided not to grow cotton but to take the barley cover crop through to grain yield, with 80 mm of irrigation applied in August.

Soil water was estimated using soil cores to measure gravimetric soil water at key times, along with regular neutron moisture meters (NMM) and EM38 readings in each plot. These readings and the percentage ground cover were recorded every 2–4 weeks.

Results

Biomass and ground cover

The Early, Mid and Late-terminated barley cover crops produced 2.6 t/ha, 4.8 t/ha and 10.5 t/ha of dry matter respectively (Figure 1), with peak ground cover levels of 70%, 90% and 100% (Figure 2). Visual assessments of cover continued across the fallow. However, a hail storm on 12 October damaged the stubble and biomass was not reassessed.

Cover in the Early-terminated barley reduced rapidly once sprayed out, and fell below 30% by October 2019.

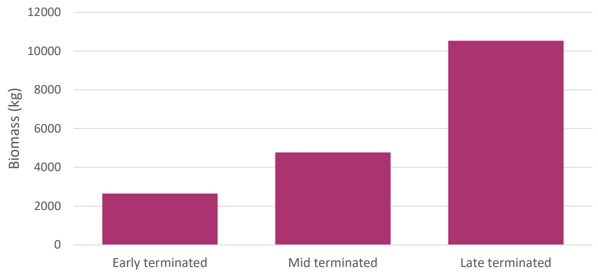


Figure 1. Above ground biomass accumulation for each cover crop treatment (excluding old cotton stubble).

The Mid-terminated barley produced more stubble that was also was more resilient, maintaining 50% cover until March 2020 when the trial concluded. There was no difference between the rolled and standing stubble treatments. Continuing to a Late-termination again produced more stubble that was also more resilient, maintaining 75-85% cover. In previous experiments, rolling stubble has increased stubble breakdown, but with the soil surface remaining dry for most of the trial, both the standing and rolled Late-terminated treatments maintained very high groundcover. The Late-terminated standing barley suffered a 20% cover reduction from a hail storm in October, whereas the rolled barley retained cover in this period (Figure 2).

Soil water

The site had approximately 120 mm of PAW when the trial was established, which remained static in the bare Control until August. The Early-terminated barley had 20 mm less plant available water (PAW) than the bare Control when sprayed-out. This deficit increased to ~50 mm for the Mid-terminated barley and 100 mm for the Late-terminated barley (Figure 3).

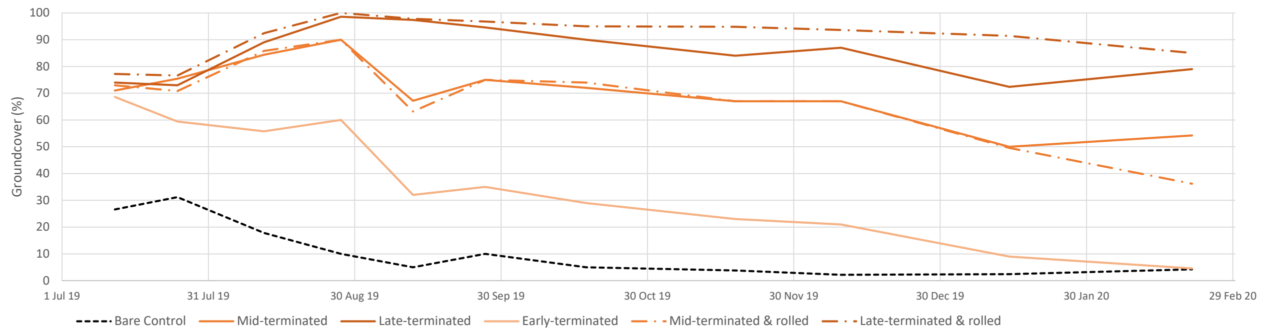


Figure 2. Visual assessments of ground cover for each cover crop treatment over time.

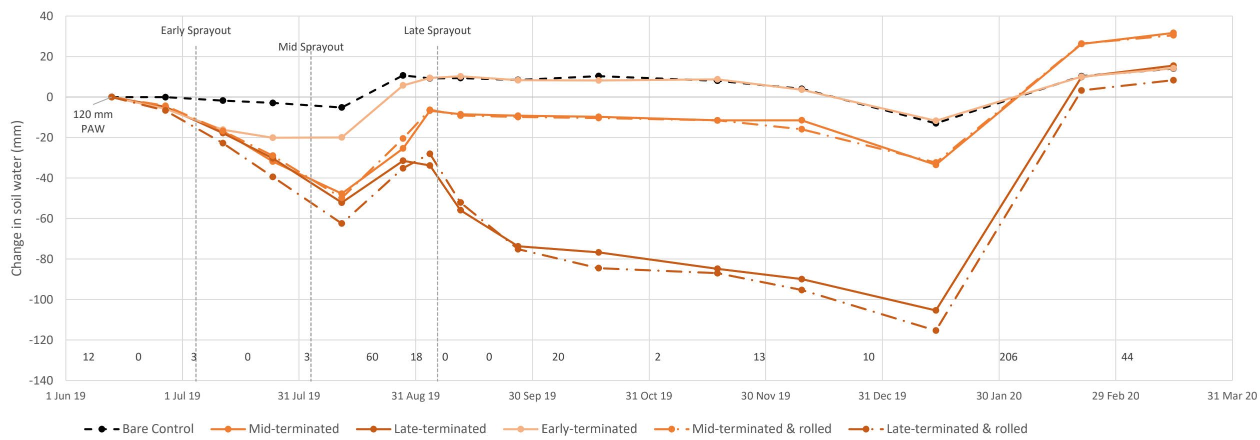


Figure 3. Change in soil water estimated using neutron moisture meters.

The 80 mm of irrigation applied to the paddock in August allowed all treatments to accumulate PAW. The bare Control increased 10 mm, while the Early-terminated cover crop increased by 30 mm to the same PAW as the bare Control. These two treatments maintained the same PAW for the remainder of the trial.

The Mid-terminated crop increased by a similar amount to reach a 20 mm deficit. The late terminated cover crop also recovered ~30 mm during this irrigation, but was still actively growing and continued to use this water. It had a deficit of 100 mm PAW when sprayed out to begin its fallow period.

All treatments maintained PAW at approximately the same levels until December 2019 when they began to decrease. The season changed early in 2020, with 206 mm rainfall in January and February. The bare Control captured 20 mm of this rainfall to have a net storage of 10 mm more PAW than the start of the trial. The Mid-terminated cover crop captured more of this rainfall, and finished with ~20 mm more PAW than the bare Control. Similarly, the Late-terminated cover crops had much higher fallow efficiency during this period and recovered from their 100 mm deficit to finish the trial with a similar PAW to the bare Control.

There was no difference in PAW between the rolled and standing stubble treatments in this trial.

Packing up the soil sampling truck after establishing the trial site.

Implications for growers and agronomists

The impacts of the cover crops on subsequent cotton yields were unable to be measured in this trial when a water shortage prevented the cotton being planted. However, the recovery of the water deficits to grow the cover crops was clear; all treatments finished the fallow with similar soil water levels.

Growers going into fallows with little ground cover can expect that well managed cover crops, sprayed out at the appropriate growth stage for the intended fallow length, can recharge their lost water as long as there is a period of reasonable rainfall at some stage in the fallow. Past research suggests that a deficit of 40-60 mm of soil water can be expected. High fallow efficiencies after a cover crop suggest that 80-120 mm of rain may be needed to recover this deficit for cereal cover crops terminated by the appearance of the flag leaf. Early-terminated cover crops have smaller water deficits, recover their water deficit much faster, and may still protect surface moisture to allow better planting opportunities.

Acknowledgements

The support of the trial cooperator and consultants is greatly appreciated for their effort and contributions to the project, along with our project team members in CSIRO (Neil Huth, Brook Anderson), David Freebairn, and the DAF Biometry, Technical and Research Infrastructure staff that supported the heavy management and monitoring loads of these experiments. Thanks also to the Grains Research and Development Corporation, Cotton Research and Development Corporation and the Department of Agriculture and Fisheries for funding the project (DAQ00211).

Trial details

Location:	Croppa Creek
Crop:	Barley cover crop
Soil type:	Grey Vertosol
In-crop rainfall and irrigation:	391 mm (June 2019 to March 2020).

Summer cover crops in short fallow - do they have a place in central NSW?

Colin McMaster, Allan Stevenson and Stuart Strahorn.

NSW Department of Primary Industries, Orange.

GRDC project code: DAQ00211

Keywords

- cover crop, stubble cover, ground cover, short fallow.

Take home messages

- Summer cover crops reduced the winter cash crop (wheat) grain yield by up to 1.5t/ha at Canowindra and 0.6t/ha at Parkes
- Grain yield losses were minimised by spraying out the cover crop early
- The grazing value ($/ha) generated from the cover crop more than compensated for the grain yield reduction based on current commodity prices
- Pros of summer cover crops include increased ground cover, reduced soil erosion from wind and water, cooler and more consistent soil temperatures, improved autumn sowing conditions, valuable summer forage for mixed farming operations, quicker soil water recharge compared with bare ground, reduced herbicide applications over the summer fallow, and improved total soil carbon % and assumed microbial activity
- Cons of summer cover crops include reduced mineral nitrogen (N) and reduced grain yield for the following winter cash crop, increased risk of soil water deficit in low rainfall years (or greater reliance on in-crop rainfall), additional seed costs, patchy establishment of summer cover crop due to rapidly drying soils, high herbicide rate required to terminate cover crop, and increased disease risk (stubble and soil) due to green bridge for the following winter cash crop
- Risks associated with cover crops are reduced by longer fallow period post cover crop for soil moisture recharge and mineralisation of cover residue; incorporating livestock within the system to convert surplus biomass to $/ha; seasons with high rainfall; additional N fertiliser application for winter cash crop
- The optimum ‘crop type selection’ and ‘spray out timing’ will vary depending on individual paddock and enterprise goals.

Background

Dust storms have been a common sight in central NSW in the summer of 2019/2020 due to the combination of drought and low ground cover. Ground cover levels have been on a decline since 2017 with residual stubble decomposing over this time, and limited opportunity to grow fresh biomass over the past 2-3 years. Factors further reducing ground cover levels include growing low biomass pulse crops (e.g. chickpeas), incorporation of lime, grazing stubbles and baling of failed winter crops. Both the magnitude and duration of the current dry period has been unparalleled and is highlighting the value of ground cover.

The benefits of cover crops to protect the soil from wind or water erosion in low stubble scenarios is well understood, however the use of cover crops as a technique to improve water infiltration and storage to improve grain yield for the following winter cash crop is less clear. Recent GRDC funded research (McMaster 2015) has demonstrated that 50% of yield potential can be attributed to summer rainfall and summer fallow management as a result of increased stored water and N. Water and N increase grain yield through grain number (more tillers and more grains per head) and grain size, with a return on investment of controlling summer weeds between $2.20 and $7.20 ha for every dollar invested.

The primary purpose of these experiments was to evaluate if there is a net water gain to the subsequent winter cash crop (wheat) following a summer cover crop, and the associated result on grain yield. The secondary purpose of this project was to evaluate the impact of various spray-out timings (early, mid and late) and crop-types (including single species, mixed species and summer weeds) on the farming system, including grazing value of cover ($), crop nutrition (mineral N and total carbon %), disease pressure (stubble and soil), and soil temperature.

Method

Two sites with zero ground cover were selected in central NSW at Canowindra (high rainfall zone – central east (CE) slopes) and Parkes (medium rainfall zone – central west (CW) plains). Each site consisted of a short and long fallow treatment and the experiment design was a randomised block with 4 replications. Individual plot size was 10m X 10m across all experiments. The following report provides results from the short fallow experiments only, and includes treatment combinations of four cover crops, three spray-out timings and one control (bare ground, weed-free). The summer cover crops were sown using a knife point press wheel plot seeder at 30cm row spacing and the subsequent winter cash crop was sown with a single disc plot seeder (30cm row spacing) due to trash flow requirements. Fertiliser was applied with the seed, at a rate of 50 kg/ha of mono ammonium phosphate (MAP) with the cover crop and 50 kg/ha MAP with the winter crop. The summer cover crops were sown on 26 November (2018) at Canowindra, and 9 December (2018) at Parkes. The subsequent winter crop (Wheat – cv Mustang[⌀]) was sown on 18 May at Canowindra, and 25 May at Parkes.

Short fallow trial (6-month fallow – November 2018 to April 2019)

Treatment details:

- Treatment 1: Cover crop types = cow peas, forage sorghum, mixed species and summer weeds
- Treatment 2: Spray out timings = 50, 80 and 110 days after sowing the cover crop (DAS)
- Treatment 3: Control = bare ground kept weed-free.

The mixed species included cow peas, lab/lab, forage sorghum, millet, tillage radish and sunflower.

Cover crop biomass

Canowindra site

Biomass production ranged from 0.07 to 10.8 t/ha (Table 3) and was influenced by crop type (P<0.001), spray-out timing (P<0.001) and the interaction between both (P<0.001). Highest biomass produced across the site was 10.8t/ha of forage sorghum (sprayed out late), compared with the lowest biomass produced by summer weeds (sprayed out early) with 0.07t/ha.

On average across crop-types, forage sorghum (6.5t/ha) and mixed species (3.4t/ha) produced much higher biomass than the cow pea (1.3t/ha) and summer weed (1t/ha) treatments. Average biomass production further increased as spray-out timing was delayed from early, mid to late with a respective increase of 1.33t/ha, 2.99t/ha and 4.85t/ha. Nitrogen fertility at this site was high (refer to crop nutrients

Table 1. Monthly rainfall and long-term average (LTA) rainfall for Canowindra and Parkes, 2019.

Month	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Canowindra													
Rainfall (mm)	39	34	45	53	1	33	34	13	24	21	20	17	7
LTA (mm)	53	57	50	49	40	44	48	50	48	42	51	49	53
Parkes													
Rainfall (mm)	21	28	23	32	0	29	25	13	10	18	27	11	7
LTA (mm)	54	58	50	46	43	44	50	51	50	46	56	51	54

Table 2. Seed rate, seed cost and field establishment of summer cover crops at Canowindra and Parkes, 2019.									
Treatment		Seed rate	Seed size	Seed cost	Seed cost	Canowindra		Parkes	
		(kg/ha)	Seeds/kg	(per kg)	(per ha)	(Plants m^2)[b]	Est (%)	(Plants m^2)[b]	Est (%)
Forage sorghum		9	32100	$5.20	$46.80	26.8	93%	22.8	79%
Cow pea		16	9500	$3.90	$62.40	12.5	82%	12.6	83%
Mixed species[a]	forage sorghum	2	32100	$5.20	$10.40	4.9	76%	5.2	81%
	millet	5	124000	$2.50	$12.50	19.5	31%	11.3	18%
	cow pea	4	9500	$3.90	$15.60	2.6	68%	3.5	92%
	lab lab	4	4300	$4.00	$16.00	1.5	87%	1.5	87%
	sunflower	1	21052	$20.00	$20.00	1.3	62%	0.6	29%
	tillage radish	1	44642	$9.50	$9.50	5	112%	3.7	83%

[a] = Total seed cost for the mixed species treatment was $84/ha

[b] = Actual plants established per m^2

section) and might explain why biomass production was relatively high at this site. Refer to Table 3 for individual biomass treatment results and Table 5 for feed test results.

Parkes site

Biomass production varied from 0.10 to 2.09 t/ha (Table 4) and was influenced by crop type (P<0.001), spray out timing (P=0.005) and the interaction between both (P=0.05). Biomass results were much less than Canowindra, yet the treatments still ranked similarly with forage sorghum (sprayed out late) producing the highest biomass of 2.09t/ha, and summer weeds (sprayed out early) the lowest at 0.10t/ha.

On average, forage sorghum (1.48t/ha) produced more biomass than mixed species (0.94t/ha), cow pea (0.36t/ha) and summer weed (0.09t/ha) treatments. Biomass increased as spray-out timing was delayed from early (0.33t/ha) to mid (0.95t/ha), but there was no further increase from mid to late (0.87t/ha) spray-out timing. Refer to Table 4 for individual biomass treatment results and Table 6 for feed test results.

Interestingly, the millet seed was much less robust than forage sorghum due to lower plant establishment (Table 2) and crop growth appeared to be visually more affected by the higher temperatures than the forage sorghum. For example, the millet foliage turned limp and floppy whilst the forage sorghum foliage became spikier and more erect (similar to a drought stressed wheat crop). Consequently, millet contributed very little biomass in the mixed species treatment.

Soil temperature at 10cm depth

Canowindra site (11 April at 3pm)

The average soil temperature was 22.2°C and ranged from 18.9°C to 24.3°C. Soil temperature reduced as cover crop biomass increased and was affected by crop type (P<0.001), spray-out timing (P<0.001) and their interaction (P<0.015).

On average, the higher biomass crop types had cooler soil temperatures, with forage sorghum and mixed species being a respective 4.4°C and 3.8°C cooler than the bare ground, cow pea and summer weed treatments. There was no significant difference between the lower biomass crop types of cow peas, summer weeds and bare ground treatments. As spray out timing was delayed, the early and mid-timings were 1.3°C and 2.9°C cooler than the bare ground, respectively. Interestingly, there was no additional cooling effect from the mid and late spray-out timing. Refer to Table 3 for individual treatment results.

Additionally, higher biomass plots were cooler and provided a more consistent soil temperature around the mean when compared to bare ground (data not shown). During the period of 8 March to 20 May, when the bare ground treatment had a range (difference between the daily minimum and maximum temperature) of 10°C or 5°C, the forage sorghum (late spray-out) had a respective range of 6.4°C or 2.5°C.

Cooler soil temperatures would be an indication that evaporation rates were initially reduced under the higher biomass plots. Aside from soil water, higher biomass residues could enable earlier sowing opportunities for winter cereal grazing crops as cooler soil temperatures improve coleoptile length and establishment. Soil temperatures greater than 25°C can reduce crop establishment in winter cereals (Edwards 2006). Conversely, the more consistent soil temperatures of the higher biomass plots could potentially enable summer grain crops such as sorghum to be sown into cooler temperatures than previously practised (Serafin *pers. comm*).

Parkes site (measured 12 April at 3pm)

Parkes was 4.7°C hotter than Canowindra, with an average soil temperature of 26.9°C, ranging from 25.8°C to 27.6°C. Soil temperature was significantly affected by crop type (*P*=0.013), and the interaction between crop type and spray-out timing (*P*=0.052). Spray out timing was not significant (*P*=0.697). Parkes is a hotter region which explains the higher soil temperatures; however, the smaller range of soil temperatures is more of an indication of less biomass produced at this site.

Forage sorghum was 0.8°C cooler than the bare ground treatment. There were no significant differences between the lower biomass plots of bare ground, mixed species, cow peas or summer weed treatments. Refer to Table 4 for individual effects.

Crop nutrients (mineral nitrogen and total carbon %)

Canowindra site

Average mineral N was measured before sowing the winter crop on 1 April. Sampling depth was 1.2 metres and the site average was 272 kg N/ha and ranged from 195 kg N/ha to 343 kg N/ha. Mineral N was influenced by crop type (*P*=0.018) and spray out timing (*P*=0.053), but the interaction between both was not significant (*P*=0.676). Site mineral N was highly variable within treatments, and possibly a legacy effect from the previous canola crop (2018) that was grazed out due to drought.

Highest mineral N was achieved in the bare ground treatment (320.6 kg N/ha), and on average reduced by 79 kg N/ha for the higher biomass crop-types such as forage sorghum and mixed species, and by 46 kg N/ha and 10kgN/ha for the lower biomass crop-types such as cow peas and summer weeds, respectively. Cow peas had little positive effect on soil N levels and this may be due to poor nodulation caused from the high temperatures; lazy nodulation due to high N levels.

Average total carbon percentage was 2% in the 0-10cm soil depth and ranged from 1.75% to 2.25%. Compared with the bare ground treatment (1.76%), total carbon increased by 0.36%, 0.33%, 0.22% and 0.11% in the forage sorghum, mixed species, summer weed and cow pea treatment, respectively. The average total carbon percentage in the 10–30cm was 0.64%, and there were no treatment effects.

Parkes site

Average mineral N was 103.2 kg N/ha and ranged from 61.3 kg N/ha to 152.8 kg N/ha. Mineral N was reduced as the cover crop biomass increased and was affected by crop type (*P*=0.019), but not by spray-out timing (*P*=0.093) or interaction of both (*P*=0.414).

The bare fallow treatment had the highest mineral N with 152.8 kg N/ha, and then reduced on average by 69.5 kg N/ha, 61.1 kg N/ha, 50 kg N/ha and 34.6 kg N/ha for forage sorghum, mixed species, cow pea and summer weed treatments respectively. Refer to Table 4 for individual effects.

The average total carbon percentage was 1.01% in the 0–10cm depth, and 0.48% in the 10–30cm depth. There was not enough biomass produced to alter total carbon at either depth.

Soil water accumulation

Canowindra site

As expected, over the summer period the various cover crops extracted moisture from the soil profile to grow biomass. After cover crop termination there was approximately a 50mm water deficit between the driest and wettest plot (Figure 1). Soil water levels were affected by crop-type (Figure 2a) and spray-out timing (Figure 2b), but no interaction between the two.

The higher biomass crop-types such as forage sorghum and mixed species extracted more moisture than lower biomass crops such as cow pea and summer weeds (Figure 2a). Additionally, spray-out timing also impacted soil water with the mid and late spray-out timing being approximately 30mm dryer than the early spray-out (Figure 2b). Despite the soil water deficit at cover crop termination, the higher biomass plots recharged quicker than the bare ground treatment resulting in no statistical difference in soil moisture from the 16 April to 12 November. The rate of recharge was a surprising result and warrants further investigation to determine if the higher biomass treatment would overtake the bare fallow moisture levels in a normal year.

The legacy effect of the various forms of ground cover will be monitored throughout the 2020 season.

Summer weed results (soil water) are not included due to the uneven nature of summer weed establishment that was not picked up by the soil neutron probe.

Predicta® B results – (stubble and soil pathogens)

Canowindra site

Diseases that were significantly affected by the various cover crops and spray out timings included: Take all; *Pythium clade* F; *Pyrenophora tritici*

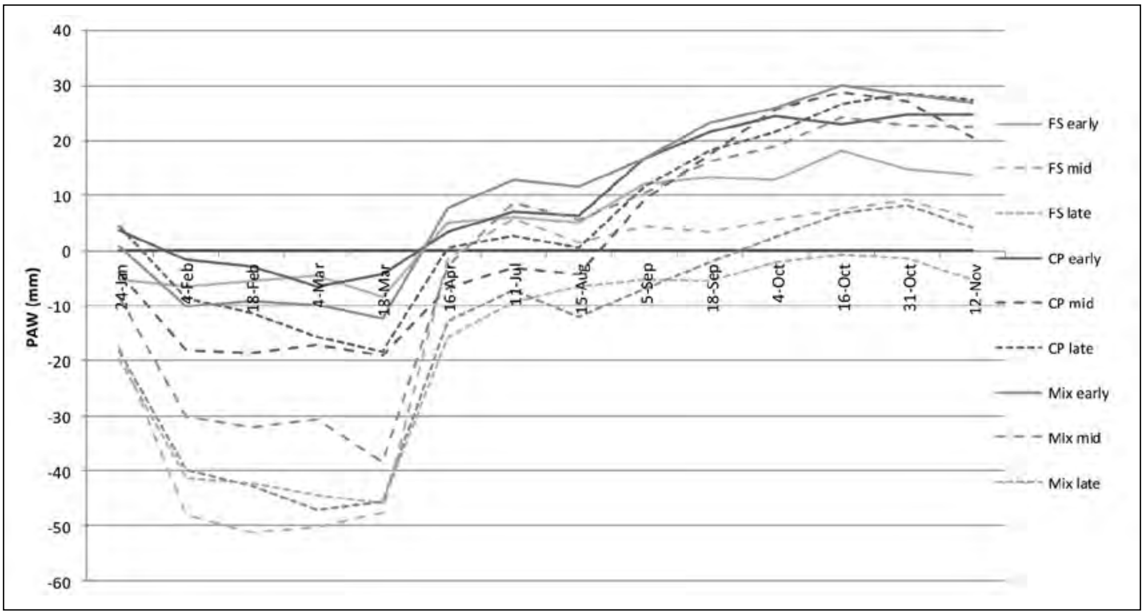


Figure 1. Individual treatment effects on soil water accumulation (+/- mm PAW) compared with the bare ground control at Canowindra NSW.

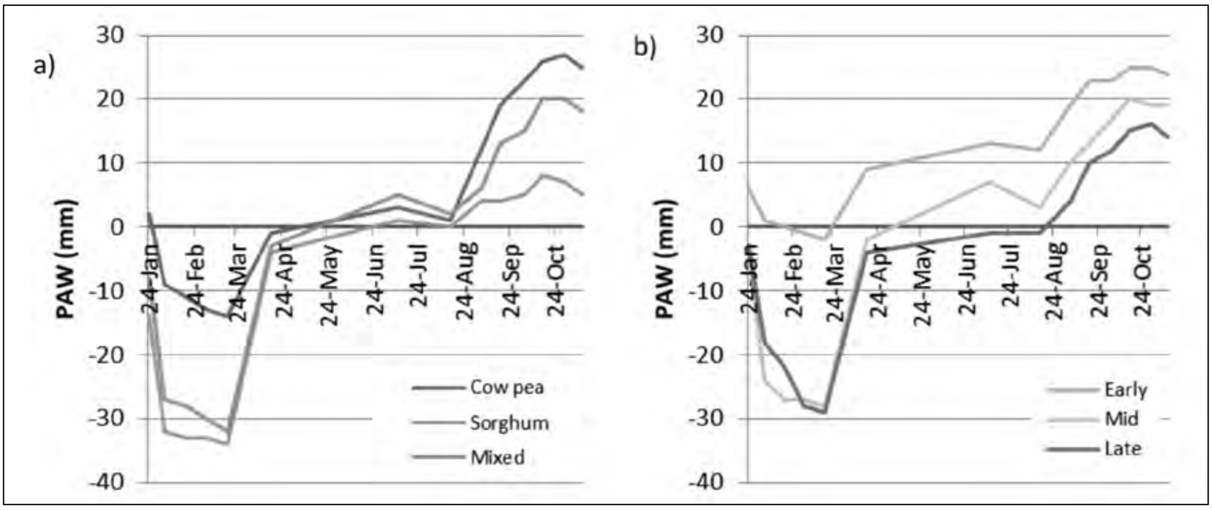


Figure 2. Main effects of cover crop-type (a) and spray-out timing (b) on soil water accumulation compared with the bare ground control at Canowindra NSW.

repentis; Pratylenchus neglectus; Macrophomina phaseolina and *Fusarium* spp. Results will be included in a separate report.

Parkes site

Diseases that were significantly affected by the various cover crops and spray out timings included: Take all; *Pythium clade* F; *Pratylenchus thornei; Macrophomina phaseolina; Didymella pinodes* and *Fusarium* spp.

Grain yield results

Canowindra site

The average grain yield was 1.91t/ha and ranged from 1.13 to 2.93 t/ha. Grain yield was affected by crop-type (P<0.001), spray-out timing (P<0.001) but not the interaction between both (P=0.459).

The highest grain yield (2.93t/ha) was from the bare ground treatment, and on average reduced by 1.4t/ha, 1.2t/ha, 1.2t/ha and 0.6t/ha from the cow pea, forage sorghum, mixed species and summer weed treatments, respectively. Grain yield reduced as spray out timing was delayed with early, mid and late yielding 2.43t/ha, 1.72t/ha and 1.33t/ha, respectively. Interestingly, the cow peas provided little benefit for the following winter cash crop.

Parkes site

The Parkes site was low yielding with an average grain yield of 0.35t/ha, ranging from 0.07 to 0.71 t/ha. Grain yield was affected by crop type ($P<0.001$), spray out timing ($P=0.003$) and the interaction between crop type and spray out timing ($P=0.032$).

The highest grain yield (0.71t/ha) was in the control which was weed-free, bare ground, and on average, grain yield reduced by 0.56t/ha, 0.51t/ha, 0.33t/ha and 0.04t/ha following forage sorghum, mixed species, cow pea and summer weeds, respectively. Compared with the bare ground treatment, grain yield reduced by 0.27t/ha and 0.39t/ha following the early and mid-spray out timing, respectively. There was no further grain yield loss between mid and late spray-out timing. Refer to Table 4 for individual effects.

Table 3. Individual treatment results from short fallow cover crop experiment – Canowindra NSW.

Crop type	Spray-out timing	Ground cover biomass (t/ha)	Soil temperature (°C)	Mineral N (kgN/ha)	Total carbon 0–10cm (%)	Total carbon 10–30cm (%)	Wheat grain yield (t/ha)
Bare	Weed- free	0	24.3	321	1.76	0.637	2.93
Cowpea	Early	0.71	24.2	286	1.75	0.608	2.26
	Mid	1.5	23.6	275	1.87	0.623	1.23
	Late	1.73	23.5	266	2	0.675	1.23
Forage sorghum	Early	2.8	21.7	288	1.93	0.683	2.45
	Mid	5.9	18.9	195	2.17	0.595	1.56
	Late	10.8	19.3	245	2.26	0.738	1.13
Mixed species	Early	1.71	22.2	274	2.01	0.615	2.15
	Mid	4.03	19.4	241	2.14	0.55	1.76
	Late	4.51	20	212	2.12	0.72	1.19
Summer weeds	Early	0.1	24.1	343	2.07	0.608	2.84
	Mid	0.51	23.6	316	1.92	0.69	2.33
	Late	2.32	23.8	276	1.95	0.605	1.75
P value		*<0.001*	*<0.001*	*0.03*	*0.15*	*0.907*	*<0.001*
5% Lsd		*1.1*	*1.1*	*80*	*0.36*	*0.236*	*0.5*

Table 4. Individual treatment results from short fallow cover crop experiment – Parkes NSW.

Crop type	Spray-out timing	Cover Biomass (t/ha)	Soil temperature (°C)	Mineral N (kgN/ha)	Total carbon 0–10cm (%)	Total carbon 10–30cm (%)	Grain yield (t/ha)
Bare	Weed free	0	27.1	153	1.01	0.49	0.71
Cowpea	Early	0.27	27.1	126	1	0.51	0.48
	Mid	0.4	27.3	82	0.99	0.49	0.33
	Late	0.42	27	100	0.95	0.54	0.34
Forage sorghum	Early	0.47	26.5	104	1.02	0.43	0.28
	Mid	1.86	25.8	86	1.12	0.51	0.1
	Late	2.09	26.8	61	1.07	0.57	0.07
Mixed species	Early	0.47	27.2	96	1.01	0.45	0.37
	Mid	1.42	27	84	0.97	0.45	0.15
	Late	0.94	26.1	95	1.08	0.46	0.09
Summer weeds	Early	0.1	27	119	0.97	0.5	0.63
	Mid	0.12	26.9	116	0.1	0.43	0.62
	Late	0.04	27.6	120	1.02	0.46	0.77
P value		*<0.001*	*0.019*	*0.015*	*0.655*	*0.851*	*<0.001*
5% Lsd		*0.754*	*0.9*	*42*	*0.153*	*0.159*	*0.159*

Table 5. Cover crop feed quality results and potential lamb production results – Canowindra.

Crop type	Spray out time	Yield (t DM/ha)	Metabolisable energy (MJ/kg DM)	Crude protein (%)	Liveweight gain (kg/ha) [1]	Value of gain ($/ha)[2]
Cowpea	Early	0.7	10.7	23.3	85	297
	Mid	1.5	10.2	17.6	161	563
	Late	1.7	10.1	17.6	176	617
Forage sorghum	Early	2.8	10.2	14.5	300	1051
	Mid	5.9	10.3	10.2	522	1827
	Late	10.8	11.1	7.9	1062	3716
Mixed species	Early	1.7	11.0	19.9	228	799
	Mid	4.0	10.1	12.7	400	1399
	Late	4.5	10.4	11.3	469	1643

1. Crossbred wether lambs (Border Leicester x Merino or Dorset x Merino), 6 months old, 30 kg live weight utilising 80% of the crop grown.

2. Lamb value of $3.50 per kg.

3. These results are based on feed test results conducted from dry matter samples; sheep were not actually grazed.

Table 6. Cover crop feed quality results and potential lamb production results – Parkes.

Crop type	Spray out time	Yield (t DM/ha)	Metabolisable energy (MJ/kg DM)	Crude protein (%)	Liveweight gain (kg/ha) [1]	Value of gain ($/ha)[2]
Cowpea	Early	0.3	11.1	24.7	37	130
	Mid	0.4	10.0	23.0	40	138
	Late	0.4	10.9	20.3	53	185
Forage sorghum	Early	0.5	10.5	12.6	50	176
	Mid	1.9	11.0	12.8	234	818
	Late	2.1	10.5	9.7	218	761
Mixed species	Early	0.5	10.7	16.2	56	196
	Mid	1.4	10.9	13.9	177	619
	Late	0.9	10.6	11.3	100	352

1. Crossbred wether lambs (Border Leicester x Merino or Dorset x Merino), 6 months old, 30 kg live weight utilising 80% of the crop grown.

2. Lamb value of $3.50 per kg.

3. These results are based on feed test results conducted from dry matter samples; sheep were not actually grazed.

Conclusion

Summer cover crops provide a series of pros and cons for the following winter cash crop. Individual paddock goals, enterprise mix, rainfall and commodity prices will ultimately determine if the pros outweigh the cons. There needs to be a clear understanding of how the cover crop will integrate and benefit the broader farming system.

Soil water recharge following a cover crop is much quicker than bare ground, yet a soil water deficit will occur if no rain falls after cover crop termination. Even in a wet year, there is likely to be a N deficit for the following winter cash crop that would require correcting with additional N fertiliser. Presumably, as total carbon % increases, the reliance on supplementary N could reduce over time with an understanding this will take several years.

Grain only cropping operations with short fallows (6 month) are likely to increase the financial risk profile when growing summer cover crops, as yield was reduced at both experiment sites following a cover crop compared with bare ground. Management techniques that retain stubbles and control summer weeds are still considered best practise, as no additional water is used to grow the biomass. However, the use of cover crops as a 'one off' technique to protect the soil from wind or water erosion in low ground cover scenario's may be warranted but considered a 'one off' rather than regular annual management operation.

Conversely, mixed farming enterprises have good reason to capitalise on the increased biomass of a summer cover crop given the current prices for red meat (Tables 5 and 6). According to these results, the grazing value would more than compensate for the winter crop grain yield penalty. Nutrients such as N would need to be adequate to support such a high output system, however the additional income from the livestock enterprise would compensate for the additional nutritional expenses.

Whilst not absolute, disc seeders are an integral part of the cover cropping system as they improve crop establishment in rapidly drying soils (associated with summer plantings) and provide for the high trash flow requirements of the cover crop system. A patchy cover crop will be no better than a weedy fallow, so crop establishment is an important factor. Consideration needs to be given to seeding depth, particularly for multi-species mixes as the seed size range within the mix will determine the potential seeding depth. For example, millet needs to be sown shallow, but forage sorghum and cow peas can be sown much deeper.

The improved rate of soil water recharge was interesting, and the legacy effects will be monitored throughout the 2020 season to evaluate if the higher biomass treatments overtake the bare fallow.

A separate report will detail results from summer cover crops in LONG fallow paddock scenarios.

Useful resources

http://grdc.com.au/Resources/Factsheets/2015/09/Blackleg-Management-Guide-Fact-Sheet

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Summer cover crops in LONG fallows – central NSW

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Keywords

cover crop, stubble cover, ground cover, long fallow

GRDC code

DAQ00211

Take home messages

- Long fallow duration was 18 months (November 2018 to April 2020), and much of that period was very dry.
- Summer cover crop (Japanese millet) biomass at crop termination increased as spray-out timing was delayed from GS30, GS39 and GS65 at Canowindra with 0.76 t/ha, 2.44 t/ha and 4.24 t/ha, respectively. Parkes biomass was much less with 0.39 t/ha, 0.60 t/ha and 0.77 t/ha, respectively.
- Parkes site failed to produce any substantial biomass/cover from the Millet due to severe moisture and heat stress.
- Greater the cover crop biomass, the greater the soil water deficit at crop termination
- Soil water deficit was temporary, and recharge after the first rainfall event was much quicker in the cover crop treatments compared to the bare ground.
- Despite quicker soil water recharge after the first rainfall event (post cover crop termination), there was no significant difference in soil water at the end of the 18 month fallow between the bare ground and cover crop treatment.
- Nine months post cover crop termination, residual biomass levels had declined by ~ 50% at Canowindra, and ~35% at Parkes.
- Soil temperatures were cooler and more consistent under the higher biomass cover crop plots at Canowindra, but not Parkes (due to lower biomass production)
- Total N % and Total Carbon % in the 0-10cm and 10-30cm were not improved from the cover crop at either sites.
- Grain yield results will not be available till December 2020

Background

Long fallows are typically used in the low rainfall zone in central NSW to shore up water for the following winter cash crop. Additionally, the adoption of summer grain crops within the region has also lead to the adoption of long fallows in the medium rainfall zone of central NSW.

Benefits of Long fallows typically include increased soil water accumulation, nitrogen mineralisation and disease break for the following cash crop. Whilst the con’s include increased risk of wind/water erosion if stubble residues breakdown and leave the soil bare, long fallow disorder and loss of income during the fallow phase.

Long fallow disorder is a reduction or lack of beneficial fungi AMF (Arbuscular mycorrhizal fungi), which naturally occur in the soil, assisting crops to accessing vital nutrients such as phosphorus (P) and zinc (Z). This reduction is caused by the dying out of the fungi due to a lack of host plants over a fallow period (at least 8 to 12months). Long fallow disorder could cause losses in yield of up to 80 percent in maize, chickpeas, linseed and mungbean; 60 percent in sorghum and soybeans; and close to 30 percent in wheat and barley. Therefore a benefit of a summer cover crop is the provision of living root structures to retain and build up AMF levels with in the soil (Somes 2019).

The primary purpose of these experiments is to evaluate if there is a net water gain in a long fallow scenario to the subsequent cash crop following a summer cover crop. The secondary purpose of this experiment is to evaluate the impact of various spray-out timings (early, mid and late) on the farming system including: crop nutrition (mineral N, total N% and total carbon %); disease pressure (stubble and soil); and soil temperature.

Method

Two sites with zero ground cover were selected in central NSW at Canowindra (high rainfall zone – central east (CE) slopes) and Parkes (medium rainfall zone – central west (CW) plains). Experimental design was a randomised block with 4 replications. Individual plot size was 10m X 10m, and treatments include three spray-out timings (early, mid and late) and one control (bare ground, weed-free). Millet (Japanese) was sown at a seeding rate of 10 kg/ha with a knife point press wheel plot seeder at 30cm row spacing. Fertiliser application included 50 kg/ha of mono ammonium phosphate (MAP) that was applied approximately 2cm below the millet seed at sowing. The Millet was sown on 26 November (2018) at Canowindra, and 9 December (2018) at Parkes. Both sites had an additional 11mm of irrigation (via drip lines) post sowing to ensure even cover crop establishment. A subsequent winter cash crop (Canola) was only sown at Canowindra site on 25 April 2020. Parkes was not sown due to failed cover crop.

Treatment details:

- Treatment 1: Spray-out timings = GS 30 (early), GS39 (mid) and GS65 (late)
- Treatment 2: Control = bare ground kept weed-free.

Table 1. Monthly rainfall and long-term average (LTA) rainfall for Canowindra and Parkes, 2019.

Month	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Canowindra site																
Rainfall (mm)	39	34	45	53	1	33	34	13	24	21	20	17	7	41	69	81
LTA (mm)	53	57	50	49	40	44	48	50	48	42	51	49	53	57	50	49
Parkes site																
Rainfall (mm)	21	28	23	*32*	0	29	25	13	10	18	27	11	7	79	79	53
LTA (mm)	54	58	50	46	43	44	50	51	50	46	56	51	54	58	50	46

Table 2. Seed rate (kg/ha), seed size (seeds/kg) and seed cost ($/ha) of millet summer cover crop at Canowindra and Parkes, 2019.

Seed rate (kg/ha)	Seed size (seeds/kg)	Seed cost ($/kg)	Seed cost ($/ha)
10	124,000	$2.50	$25.00

[a] = Average plant establishment across the site

Results and discussion

Cover crop biomass

Canowindra site

Biomass at cover crop termination (Table 3) increased as spray-out timing (P<0.001) was delayed from early, mid to late with a respective increase over the bare treatment of 0.76 t/ha, 2.44 t/ha and 4.24 t/ha. Nine months post cover crop termination the biomass levels further reduced on average by 50%, with the early, mid and late achieving 0.21 t/ha, 1.52 t/ha and 1.99 t/ha, respectively.

Parkes site

Biomass at cover crop termination (Table 4) was much less than Canowindra, with only small increases in biomass as spray-out timing (P<0.001) was delayed from early, mid to late with a respective increase over the bare treatment of 0.39 t/ha, 0.60 t/ha and 0.77 t/ha. Nine months post cover crop termination the biomass levels reduced on average by 35%, with the early, mid and late achieving 0.06 t/ha, 0.44 t/ha and 0.51 t/ha, respectively

Soil temperature at 10cm depth

Canowindra site (11 April 2019 at 3pm)

The average soil temperature (Table 3) was 22.45°C, and ranged from 20.25°C to 24.15°C. As spray-out timing (P<0.001) was delayed, the early, mid and late were 0.45°C, 2.45°C and 3.9°C cooler than the bare ground treatment, respectively.

Additionally, higher biomass plots were cooler and provided a more consistent soil temperature around the mean when compared to bare ground. During the period of 8 March to 20 May 2019, when the bare ground had a range (difference between the daily minimum and maximum temperature) of 10°C or 5°C, the late spray out had a respective range of only 7.4°C or 3.5°C degrees.

Cooler soil temperatures would be an indication that evaporation rates were initially reduced under the higher biomass plots. Aside from soil water, higher biomass residues could enable earlier sowing opportunities for winter cereal grazing crops as cooler soil temperatures improve coleoptile length and establishment. Soil temperatures greater than 25°C can reduce crop establishment in winter cereals (Edwards 2006). Conversely, the more consistent soil temperatures of the higher biomass plots could potentially enable summer grain crops such as sorghum to be sown into cooler temperatures than previously practised (Serafin *pers. comm*).

Parkes site (measured 12 April 2019 at 3pm)

The average soil temperature (Table 4) was 26.8°C, and ranged from 26.5°C to 24.15°C. There was no significant effect of spray-out timing (P=0.218) on soil temperature.

Crop nutrients (mineral nitrogen and total carbon %)

Canowindra site

Mineral N was measured to a depth of 1.2m on the 1 April 2019 to evaluate changes in nitrogen availability approximately 2 months post cover crop termination. Site average was 282 kgN/ha, and ranged from 184 kgN/ha to 344 kgN/ha.

Treatments with the highest mineral N was bare ground (344 kgN/ha) and early spray-out (379 kgN/ha), and then reduced to 221 kgN/ha and 184 kgN/ha with the mid and late spray-out, respectively. Site mineral N was highly variable within treatments, and possibly a legacy effect from the previous canola crop (2018) that was grazed out due to drought.

The average Total N % for the site was 0.19% in the 0-10cm depth, and 0.09% in the 10-30cm depth. Total N was not affected by any treatment at either depth.

The average total carbon % for the site was 2.02% in the 0-10cm depth, and 0.65% in the 10-30cm depth. Total carbon % was not affected by any treatment at either depth.

Parkes site

Average mineral N was 104 kg N/ha and ranged from 86 kgN/ha to 123 kgN/ha. Bare ground had the highest mineral N of 123 kgN/ha, and then reduced by 10 kgN/ha, 30 kgN/ha and 37 kgN/ha from the early, mid and late spray-out timing, respectively.

The average Total N % for the site was 0.10% in the 0-10cm depth, and 0.06% in the 10-30cm depth. Total N was not affected by any treatment.

The average Total carbon % for the site was 1.0% in the 0-10cm depth, and 0.33 % in the 10-30cm depth. Total carbon % was not affected by any treatment.

Soil water accumulation

Canowindra site

After cover crop termination there was approximately a 50mm water deficit between the driest and wettest plot (Figure 1). Soil water levels declined as spray out timing was delayed.

Figure 1 highlights that the greater biomass plots (ie later spray-out timings) extracted water to grow the biomass, and consequently left the soil profile dryer than the bare ground control. Despite the soil water deficit at cover crop termination, the higher biomass plots recharged quicker than the bare ground treatment resulting in no statistical difference in soil moisture from the 16 April 2019 to March 2020. The rate of recharge was a surprising result and warrants further investigation to determine if the higher biomass treatment would overtake the bare fallow moisture levels in a more typical year.

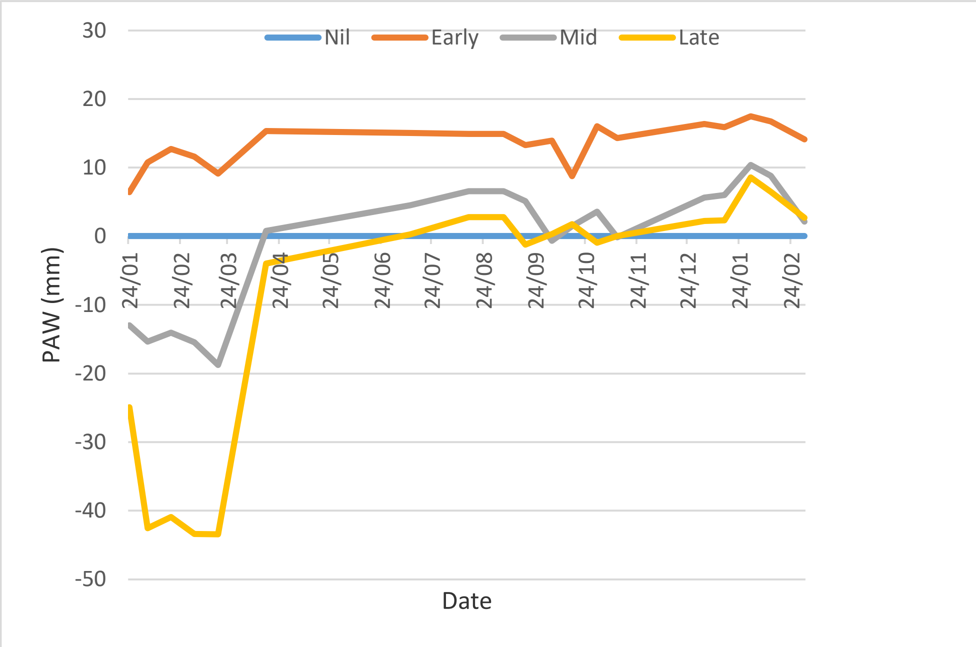

Figure 1. Impact of spray-out timing on soil water accumulation (+/- mm PAW) compared with the bare ground control at Canowindra NSW

Parkes site

Gravimetric soil water results indicate a 40mm soil water deficit between the driest and wettest plot approximately 2 months post cover crop termination. Soil water levels declined as spray-out timing was delayed. Important to note that the Parkes cover crop essentially wilted away and provided very little ground cover over across any treatment throughout the fallow duration.

Predicta® B results – (stubble and soil pathogens)

Canowindra site

Diseases that were significantly affected by the presence of the millet cover crop included: Take all; *Pythium clade* F; *Pyrenophora tritici repentis*; *Pratylenchus neglectus*; *Macrophomina phaseolina* and *Fusarium* spp (Table 3).

Parkes site

Diseases that were significantly affected by the millet cover crop included: Take all; *Pythium clade* F; *Pratylenchus thornei*; *Macrophomina phaseolina*; *Didymella pinodes* and *Fusarium* spp (Table 4).

Table 3: Results from Canowindra Long fallow - cover crop experiment 2019/20

Measurement	Spray-out treatment				P value	5% L.s.d
	Bare	Early	Mid	Late		
Millet plant establishment (m^2)	0.0	81.2	72.1	78.1	<0.001	20.0
Biomass (t/ha) @ Crop termination (CT)	0.0	0.8	2.4	4.2	<0.001	0.4
Biomass (t/ha) @ 9 month post CT	0.0	0.2	1.5	2.0	b	b
Soil temperature (°C) - 11/4/19 @ 3pm	24.2	23.7	21.7	20.3	<0.001	0.8
Total PAW (mm)[a] - 1/4/19 (0-120cm)	191.2	191.5	173.0	151.4	0.008	25.7
PAW mm (0-10cm)	*11*	*13*	*15*	*16*	*<0.001*	*1.7*
PAW mm (10-30cm)	*17*	*24*	*20*	*22*	*0.348*	*7.3*
PAW mm (30-60cm)	*52*	*61*	*49*	*42*	*<0.001*	*7.1*
PAW mm (60-90cm)	*62*	*58*	*48*	*38*	*<0.001*	*10.5*
PAW mm (90-120cm)	*49*	*36*	*42*	*34*	*0.128*	*13.8*
Cash crop grain yield – Canola (cv Bonito)	*b*	*b*	*b*	*b*	*b*	*B*
Crop nutrition						
Mineral N (kgN/ha) - 1/4/19 (120cm depth)	344	379	221	184	<0.001	75
Min N (0-10cm)	*111*	*112*	*55*	*36*	*<0.001*	*25.3*
Min N (10-30cm)	*87*	*88*	*74*	*61*	*0.331*	*35.2*
Min N (30-60cm)	*97*	*114*	*57*	*54*	*0.001*	*30.5*
Min N (60-90cm)	*31*	*45*	*22*	*20*	*0.001*	*11.6*
Min N (90-120cm)	*18*	*21*	*15*	*14*	*0.079*	*6.0*
Total Nitrogen % (0-10cm) - 1/4/2019	0.18	0.19	0.19	0.18	0.220	0.02
Total Nitrogen % (10-30cm) -1/4/2019	0.08	0.09	0.08	0.09	0.603	0.02
Total Carbon % (0-10cm) - 1/4/2019	1.90	2.09	2.07	2.03	0.239	0.22
Total Carbon % (10-30cm) - 1/4/2019	0.59	0.70	0.59	0.62	0.618	0.18
Predicta B results (measured April 2019)						
Cereal cyst nematode	-	-	-	-	-	-
Stem nematode	-	-	-	-	-	-
Take-all (wheat + oat strains)	0.00	2.03	2.54	2.51	<0.001	0.10
Take-all (oat only)	-	-	-	-	-	-
R. solani AG8	-	-	-	-	-	-
Crown rot	0.43	1.77	2.27	2.25	<0.001	0.66
Pyrenophora tritici-repentis	0.51	0.75	0.67	0.85	0.516	0.49
Bipolaris	0.33	1.00	1.02	0.94	0.233	0.71
Pythium clade f	0.70	1.34	1.11	1.24	0.087	0.47
Eutiarosporella	0.00	0.28	0.48	0.15	0.04	0.35
Eyespot	-	-	-	-	-	-
Pratylenchus neglectus	0.51	1.09	2.38	2.38	<0.001	0.83
Pratylenchus thornei	-	-	-	-	-	-
Pratylenchus penetrans	-	-	-	-	-	-
Pratylenchus quasitereoides	-	-	-	-	-	-
Phytophthora medicaginis	-	-	-	-	-	-
Didymella pinodes/Phoma pinodella	0.00	0.00	0.00	0.08	0.606	0.17
Phoma koolunga	-	-	-	-	-	-
Macrophomina phaseolina	1.09	1.29	3.77	4.09	<0.001	0.31
Phoma rabiei	-	-	-	-	0.692	
S. sclerotiorum	0.43	0.26	0.46	0.54	0.974	1.28

a = PAW measured via conducting gravimetric method across 5 soil cores per plot

b = Statistics will be included in final report after cash crop harvest

Table 4: Results from Parkes Long fallow – cover crop experiment 2019/20

Results	Spray-out treatment				P value	5% L.s.d
	Bare	Early	Mid	Late		
Millet plant establishment (m^2)	0.0	49	52	55	<0.001	4.5
Biomass (t/ha) @ Crop termination (CT)	0.0	0.4	0.6	0.8	<0.001	0.1
Biomass (t/ha) @ 9 month post CT	0.0	0.1	0.4	0.5	[b]	[b]
Soil temperature (°C) – 11/4/2019 @ 3pm	27.2	27.1	26.5	26.5	0.218	0.4
Total PAW (mm)[a] – 1/4/2019 (0-120cm)	214	200	189	174	0.029	12.5
PAW mm (0-10cm)	11	10	6	5	<0.001	1.2
PAW mm (10-30cm)	56	47	43	36	0.001	4.1
PAW mm (30-60cm)	64	64	60	55	0.14	4.6
PAW mm (60-90cm)	0	53	48	50	0.496	48.4
PAW mm (90-120cm)	31	31	30	29	0.828	2.5
Nutrition results						
Mineral N (kgN/ha) – 1/4/2019 (120cm depth)	123	113	93	86	<0.001	7.1
Min N (0-10cm)	*54*	*59*	*56*	*43*	*0.029*	*5.8*
Min N (10-30cm)	*30*	*21*	*12*	*13*	*<0.001*	*2.7*
Min N (30-60cm)	*20*	*18*	*11*	*13*	*<0.001*	*1.7*
Min N (60-90cm)	*8*	*6*	*7*	*7*	*0.471*	*1.0*
Min N (90-120cm)	*11*	*8*	*8*	*11*	*0.262*	*2.2*
Total Nitrogen % (0-10cm) – 1/4/2019	0.09	0.10	0.10	0.10	0.223	0.006
Total Nitrogen % (10-30cm) - 1/4/2019	0.06	0.06	0.06	0.06	0.867	0.006
Total Carbon % (0-10cm) – 1/4/2019	0.92	0.98	1.00	0.96	0.391	0.043
Total Carbon % (10-30cm) – 1/4/2019	0.42	0.05	0.40	0.44	0.047	0.047
Predicta B results a						
Cereal cyst nematode	-	-	-	-	-	-
Stem nematode	0.42	2.26	2.41	2.3	<0.001	0.115
Take-all (wheat + oat strains)	-	-	-	-	-	-
Take-all (oat only)	-	-	-	-	-	-
R. solani AG8	-	-	-	-	-	-
Crown rot	1.39	2.98	2.99	2.57	0.006	0.401
Pyrenophora tritici-repentis	0.90	0.93	0.78	0.85	0.794	0.163
Bipolaris	0.20	0.00	0.38	0.13	0.237	0.195
Pythium clade f	1.43	1.55	1.56	1.64	0.527	0.14
Eutiarosporella	0.00	0.00	0.63	0.00	0.431	0.521
Eyespot	-	-	-	-	-	-
Pratylenchus neglectus	-	-	-	-	-	-
Pratylenchus thornei	0.41	1.10	1.11	0.84	0.112	0.284
Pratylenchus penetrans	-	-	-	-	-	-
Pratylenchus quasitereoides	-	-	-	-	-	-
Phytophthora medicaginis	-	-	-	-	-	-
Didymella pinodes/Phoma pinodella	1.69	1.72	2.11	2.31	0.356	0.403
Phoma oolunga	-	-	-	-	-	-
Macrophomina phaseolina	1.43	2.51	2.28	2.73	0.234	0.61
Phoma rabiei	-	-	-	-	-	-
S. sclerotiorum	0.00	0.00	0.00	0.59	0.274	

a = PAW measured via conducting gravimetric method across 5 soil cores per plot

b = Statistics will be included in final report after cash crop harvest

Conclusion

Grain yield from the cash crop will be ultimate measure to evaluate if the millet cover crop was beneficial for the following cash crop, and any conclusions should be put on hold until grain yield results are available.

These results support other findings that soil water recharge post a cover crop is much quicker than bare ground, and the likelihood of having a soil water deficit at the completion of the long fallow period is extremely low.

The short term reduction in mineral Nitrogen to grow the cover crop will be temporary, and much of that nitrogen will be in a plant available form by the time the following cash crop is sown.

Predicta B results highlight that cover crops may increase the risk of some plant disease, but the extended fallow length is likely to make this a low risk.

This report will be updated and refined once the cash crop (canola) is harvested.

Useful resources

http://grdc.com.au/Resources/Factsheets/2015/09/Blackleg-Management-Guide-Fact-Sheet

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Cover crops in grain and cotton farming systems (DAQ00211)

Yanco Spray Out Timing Experiment 2019/20

Author: Hayden Petty - Cotton Agronomist NSW Department of Primary Industries

Key findings

- Cotton yields were not improved by cover cropping in this experiment
- High stubble loads from spraying out the cover crop after the cereals reached Z39 negatively affected established cotton plant numbers and consequently lint yield
- Cover crops terminated at Z39 saw no yield penalty but stored more soil water than the fallow treatment

Introduction

The aim of growing a cover crop during the winter fallow between summer crops is ultimately to improve soil structure. Cover crops can increase organic matter in the soil, providing increased; aeration, aggregate stability, soil water holding capacity, nutrient cycling and erosion control. The aim of this experiment was to improve the infiltration and water holding capacity of red brown earth irrigated by furrow. Prior experimentation on this soil type showed the type of cover crop grown has minimal influence on crop yields, however, the amount of biomass produced has an effect.

Establishing a desirable plant stand of cotton hinges on soil temperature, moisture and its physical parameters. To ensure a field is suitable to plant cotton, there is great emphasis placed on having a uniform seed bed with capacity to hold water once irrigated. If cover cropping is to have a place in the cotton system, land preparation must be conducted prior to the cover crop being planted. It is essential the field undergoes a no till system to retain the cover crop to influence the subsequent cotton crop. Termination of the cover crop should then occur with enough time to establish cotton. The research question now posed is how much biomass needs to be produced to have a positive influence on the above soil parameters that will contribute to an increase in lint yield. In other words, when can a grower terminate the cover crop?

Site Details

Location	Yanco Agricultural Institute
Soil Type	Red Brown Earth
Previous Crop	Cotton
Bed Configuration	1.83 m
Sowing	Cover crops: Stubble King disc seeder, 200 mm row spacing Cotton: John Deere 1705 MaxEmerge2, 0.91 m row spacing
Soil pH_{CaCl}	6.8 (0-10 cm)
Mineral N at sowing	114 kg N/ha (0-90 cm)
Fertiliser Applied	Cover crops: 100 kg/ha mono-ammonium phosphate (MAP) at sowing Cotton: 260 kg/ha nitrogen as N26 water run in crop and 100 kg/ha nitrogen as urea broadcast
Weed Control	Cover crop termination: glyphosate (570 g/L) at 2 L/ha, carfentrazone-ethyl (400 g/L) at 60 mL/ha and paraquat (360 g/L) at 2 L/ha (double knock) Cotton Pre-emergent: pendimethalin (440 g/L) at 2 L/ha, terbutryn (500 g/L) at 2 L/ha Cotton Post-emergent: glyphosate (690 g/kg) at 1.5 kg/ha, clethodim (240 g/L) at 500 mL/ha
Disease and Pest Management	Seed treatment: Vibrance® Complete & Cruiser® At sowing: Thimet (200 g/kg) at 5 kg/ha In-crop: dimethoate (400 g/L) at 500 mL/ha (early season)
Variety	Cover crop: Eurabbie oats (28%), Compass[A] barley (47%), Morava[A] vetch (19%) and Buster tillage radish (6%) Cotton: Sicot 746B3F

Treatments

Treatment	Description	Termination Date
Control	Winter fallow	N/A
Early Spray out	Cover crop terminated at cereal growth stage Z30	7 August 2019
Mid Spray out	Cover crop terminated at cereal growth stage Z39	3 September 2019
Late Spray out	Cover crop terminated at cereal growth stage Z55	30 September 2019

All plots subsequently planted down to cotton.

Results & Discussion

Cover crop establishment

The cover crop mixture (as listed above) was sown at 80 kg/ha and achieved 200 plants/m^2. Plant proportion favoured cereals (barley and oats) of up to 70% whilst the vetch averaged 14% of the mix and radish 11%. The crop was established on rainfall and was not irrigated through the season.

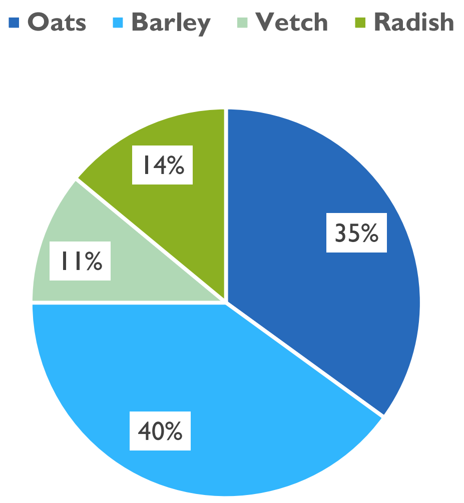

Figure 1. Proportion of cover crop species established

Cover crop biomass

The early spray out treatment terminated at cereal growth stage Z30 returned 1.53 t/ha of dry matter consisting of green leafy material at almost complete ground cover and an NDVI reading of 0.8. There was 3.57 t of dry matter produced from the Z39 termination which returned an NDVI reading of 0.72 due to the large proportion of cereals undergoing stem elongation exposing the soil. The timing of the last spray out returned an NDVI reading of 0.51 as the crop was suffering from drought stress and undergoing premature senescence. It produced 5.46 t of dry matter per ha and was significantly lignified at the time of termination.

Table 1. Cover crop biomass produced at each of the spray out timings

Treatment	Biomass (t/ha)
Early spray out	1.53
Mid spray out	3.57
Late spray out	5.46

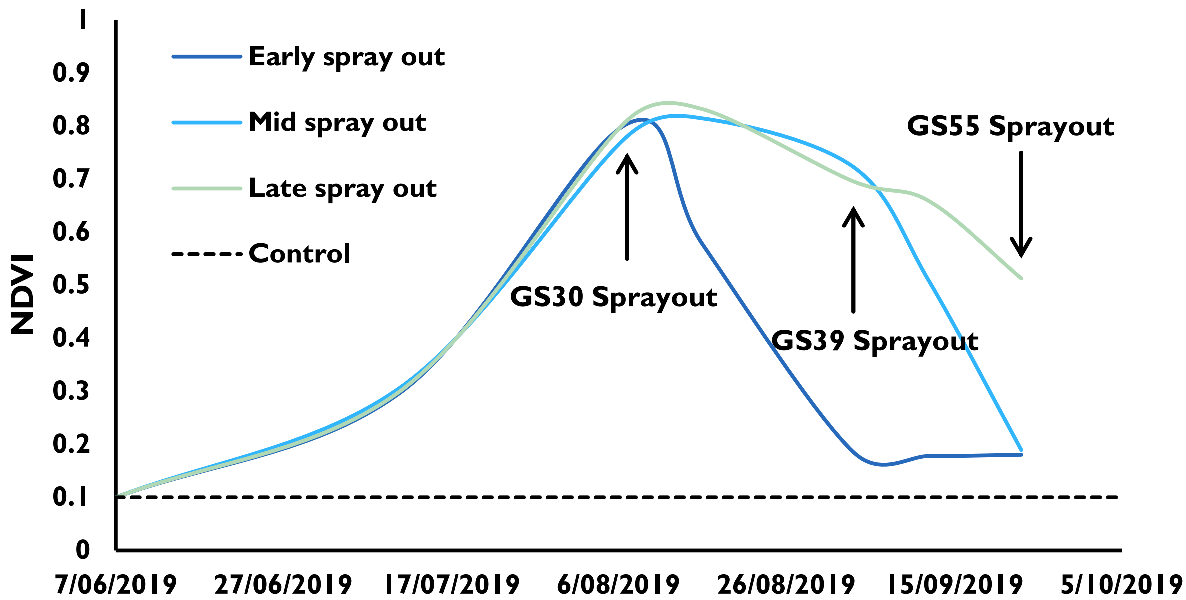

Figure 2. NDVI readings taken with a handheld GreenSeeker to obtain an indication of the ground cover produced by the cover crop treatments.

Cover crop soil water

Neutron moisture meter readings were taken from each plot intermittently throughout the experiment in both the cover crops and the cotton. From this, volumetric soil moisture was estimated and based on the calibration of the crop lower limit and drained upper limit the plant available water capacity was also calculated. Presented in Table 2 is the plant available water (PAW) for each treatment and depth. Soil water just after sowing and at the time of the early spray out treatment saw no significant differences between treatments, indicating that the cover crops had not used a significant amount of water at this time. When the second treatment was applied, the control and early spray out plots were equal. However, the mid and late spray out plots had used more water from the top 35 cm of the soil profile. Furthermore, the late spray out treatment had used the most water to grow the cover crop using 31.15 and 17.98 mm of PAW more than the early and mid spray out treatments respectively.

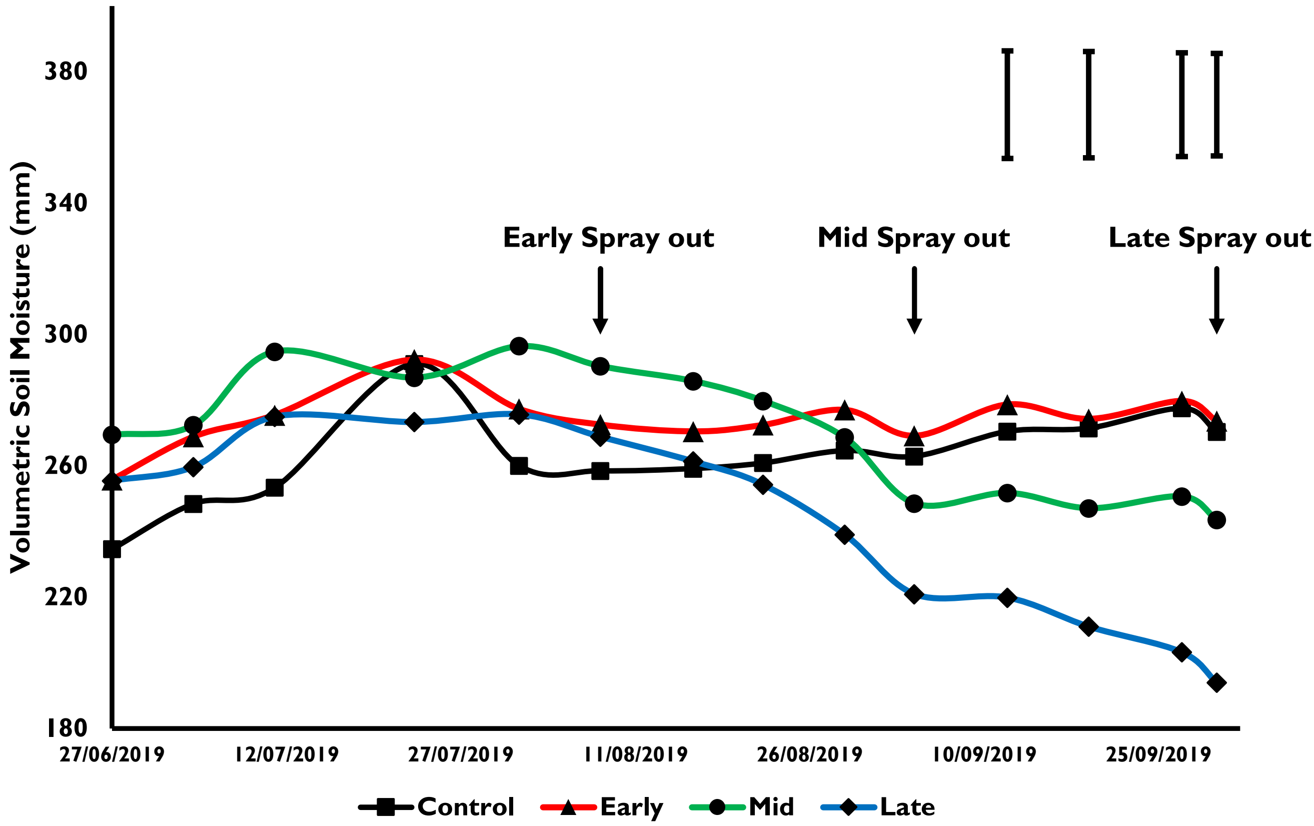

Figure 3. Volumetric soil moisture of the total soil profile from 0 – 100 cm for the time period that cover crops were growing. Vertical LSD bars represent a P-value < 0.05. Arrows indicate the timing of when each spray out treatment was terminated.

Table 2. Plant available water in mm across depth and spray out treatments for the period that cover crops were growing. LSD (P-value < 0.05) presented on the interaction between spray out treatment x depth and separately for total.

Date	Depth	Control	Early Spray out	Mid Spray out	Late Spray out	LSD
Post-sowing 27/06/2019	0-25	37.77	38.01	38.63	38.45	ns
	25-35	12.30	12.56	12.58	12.71	
	35-45	7.35	8.60	8.34	8.72	
	45-55	4.34	6.62	6.56	6.79	
	55-65	4.09	5.66	6.24	6.29	
	65-80	9.04	10.53	12.79	11.13	
	80-100	17.65	16.78	19.98	17.15	
	Total	93.23	99.87	105.19	100.07	ns
Early Spray out 8/08/2019	0-25	38.96	37.46	37.43	36.34	ns
	25-35	13.05	12.97	13.15	12.90	
	35-45	8.72	9.11	9.49	9.34	
	45-55	5.77	7.50	8.01	8.17	
	55-65	5.08	6.78	7.63	7.32	
	65-80	10.48	12.52	14.59	12.40	
	80-100	18.82	18.23	21.40	18.09	
	Total	101.7	105.5	111.7	103.6	ns
Mid Spray out 4/09/2019	0-25	38.55	37.54	29.37	27.98	2.882
	25-35	13.06	12.70	9.78	9.29	
	35-45	8.37	8.83	6.97	6.72	
	45-55	5.55	7.13	6.28	5.80	
	55-65	5.36	6.67	7.10	6.18	
	65-80	10.96	12.48	14.38	11.49	
	80-100	19.63	18.42	21.26	18.23	
	Total	103.33 b	104.47 b	95.12 ab	85.01 a	12.224
Late Spray out 30/09/2019	0-25	37.36	37.30	26.80	23.80	2.964
	25-35	13.05	12.74	9.15	7.74	
	35-45	8.41	8.83	6.88	5.47	
	45-55	6.13	7.42	6.11	4.38	
	55-65	5.96	6.91	7.10	5.01	
	65-80	11.95	13.10	14.75	10.43	
	80-100	20.19	19.10	22.26	18.20	
	Total	105.42 bc	105.93 c	92.76 b	74.78 a	11.676

^^ ns denotes not significant at P-value < 0.05

Soil temperature

Following termination of the cover crop treatments the soil temperature was recorded from 10 cm depth. Taken at 08:00 am on 8 October 2019 all plots averaged 19.1 °C. There were no significant differences detected at the alpha level of 0.05 between treatments. Exceeding the safe planting threshold temperature of 14 °C for cotton and having forecasted average temperatures on a rising plane it was decided to plant on 9 October 2019. The bay was then irrigated on 10 October 2019 to germinate the seed. The irrigation resulted in an average soil temperature of 17.9 °C (ns), dropping by 1.1 °C. This small insignificant drop in temperature is a function of the red brown earth lacking clay content and having the ability to warm quickly.

Water run times

At first irrigation, the time it took for water to reach the end of each furrow was recorded. The control having no cover present in the furrows took just 67.3 minutes for the water to break through to the tail drain. The early spray out timing broke through in 89.6 minutes which was not significantly different from the control. The mid and late spray out timings significantly slowed down the water run time taking 148.1 and 163.6 minutes respectively, however, were not significantly different from each other.

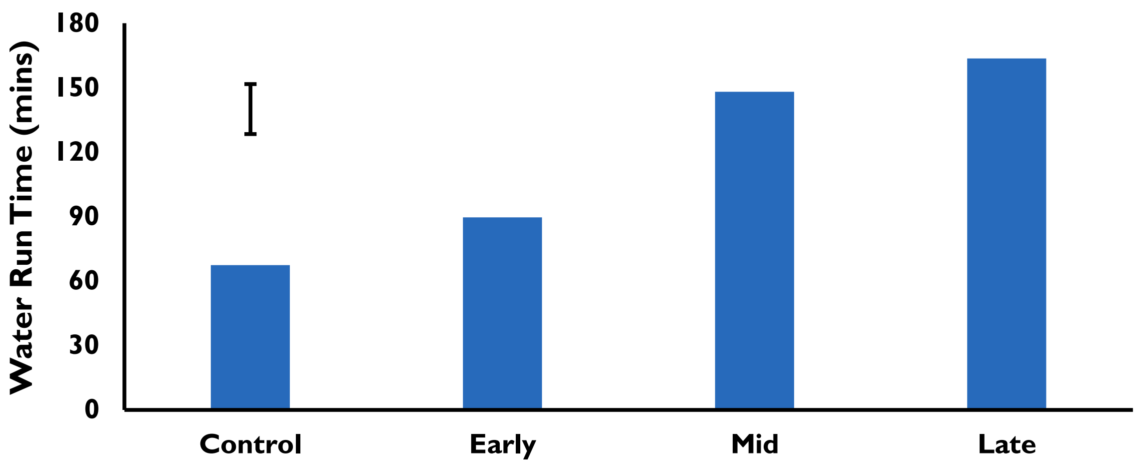

Figure 4. Water run times per treatment measured at first irrigation. LSD (P<0.05) = 23.28 minutes.

Cotton emergence

From the germination date of 10 October 2019, it took 6 days for the first cotyledons to emerge on 16 October. The control having no cover load present established the most plants/m^2 averaging 12.83. The early spray out timing resulted in 11.45 plants but was not significantly different from the control. The mid and late spray out timings established 10.34 and 8.08 plants/m^2 respectively which differed significantly from the control. The decrease in plant numbers with increasing cover loads is largely due to seed placement affected by the stubble and moisture content of the soil. From Table 2, the reduction of soil water by the larger cover loads resulted in a very dry seed bed and as such seed placement was variable causing dry down and poor germination.

Table 3. Average established plant numbers measured across each of the cover crop treatments applied.

Treatment	Average Plants/m^2
Control	12.83 a
Early spray out	11.45 ab
Mid spray out	10.34 b
Late spray out	8.08 c
LSD (P<0.05)	*2.21*

Cotton biomass

Each plot was assessed for squaring date and a biomass sample taken. Across all treatments the date of first square averaged 17 December 2019 (ns). The biomass at this time was heaviest for the control, achieving 687.7 kg DM/ha. The reduction in biomass recorded for the early spray out timing was not significantly different from the control. The mid and late treatments had accumulated 427.4 and 358 kg DM/ha respectively and differed significantly from the control but not from each other.

Date of first flower was recorded as 17 January 2020. The differences identified at first square were largely a result of the established plant numbers and were still evident at flowering. Having almost 1200 kg DM/ha difference between the control and the late spray out treatment.

By defoliation there were no significant biomass differences between treatments and the biomass averaged 15024 kg DM/ha. Cotton is a very good crop at compensating growth and maximising the available space and water by producing vegetative branches. First pass defoliation was applied on 15 April 2020 and the crop required three defoliations to drop leaf and open bolls.

Table 4. First square and first flower biomass taken across each treatment.

Treatment	Biomass First Square (kg DM/ha)	Biomass First Flower (kg DM/ha)
Control	687.7	4600
Early	544.7	4111
Mid	427.4	3843
Late	358	3410
LSD (P<0.05)	*147.52*	*711.8*

Phenology

The crop type looked visually different between treatments as the mid and late spray out treatments required the plant to compensate and produce more vegetative branches. The number of nodes produced by the crop did not vary between treatments and averaged in total 23 nodes. At the start of flowering the crop retained 7.1 nodes above the white flower. On average the crop declined one node above the white flower until it reached physiological maturity (cut out) on 4 February 2020. It did not require the use of growth regulants to balance crop growth during the flowering period as this is a characteristic of the soil type.

Boll counts

Boll counts were taken prior to defoliation to determine the drivers of yield. As the crop compensated to overcome the differences in plant number there were no treatment differences identified in biomass after flowering. This same trend can be seen in the boll count numbers where the plants in the late spray out timing had more bolls compared to the control. However, the boll counts per meter were not significant and the average across all treatments was 155.1 bolls/m.

Table 5. Boll counts taken across all treatments measured as bolls/m and number of bolls/plant.

Treatment	Bolls/m	Bolls/plant
Control	143.3	10.76
Early	148.6	14.44
Mid	158.4	16.81
Late	170.2	19.19
LSD (P<0.05)	*41.73*	*7.452*
F pr.	*0.448*	*0.129*

Cotton soil water

Once the cotton was planted and flushed up, the soil water deviations seen at the end of the cover crops was eliminated. There were no significant differences between treatments for PAW up until flowering when the crop starting using large amounts of water. Both the mid and late spray out treatments measured more water in the profile compared to the control and early spray out. This can be explained by the reduced plant stand in both treatments as there were not enough plants to extract the available moisture present in the profile. It could also be a function of the cover crop residues improving water infiltration under irrigation however, these inferences cannot be assumed in this experiment.

Towards the end of the season the control and early spray out treatments started to extract moisture from depth more than the mid and late treatments (table 6). The higher plant stands in these treatments likely resulted in the crop depleting soil moisture sooner than the mid and late treatments forcing root growth to explore the soil profile in search of moisture.

Change in plant available water over time (figure 6) shows the additions and depletions of soil water from sowing of the cover crop to defoliation of the cotton. The extraction of soil from the spray out treatments is clearly depicted here and reflects the total soil moisture data presented above (figure 3). Once the cotton crop was irrigated to germinate the planted seed, all treatments returned to an equal level of soil moisture. Once the crop started extracting larger amounts of water it was evident that a treatment effect was at play. As mentioned above, this treatment effect could be a function of improved infiltration or poor plant stand.

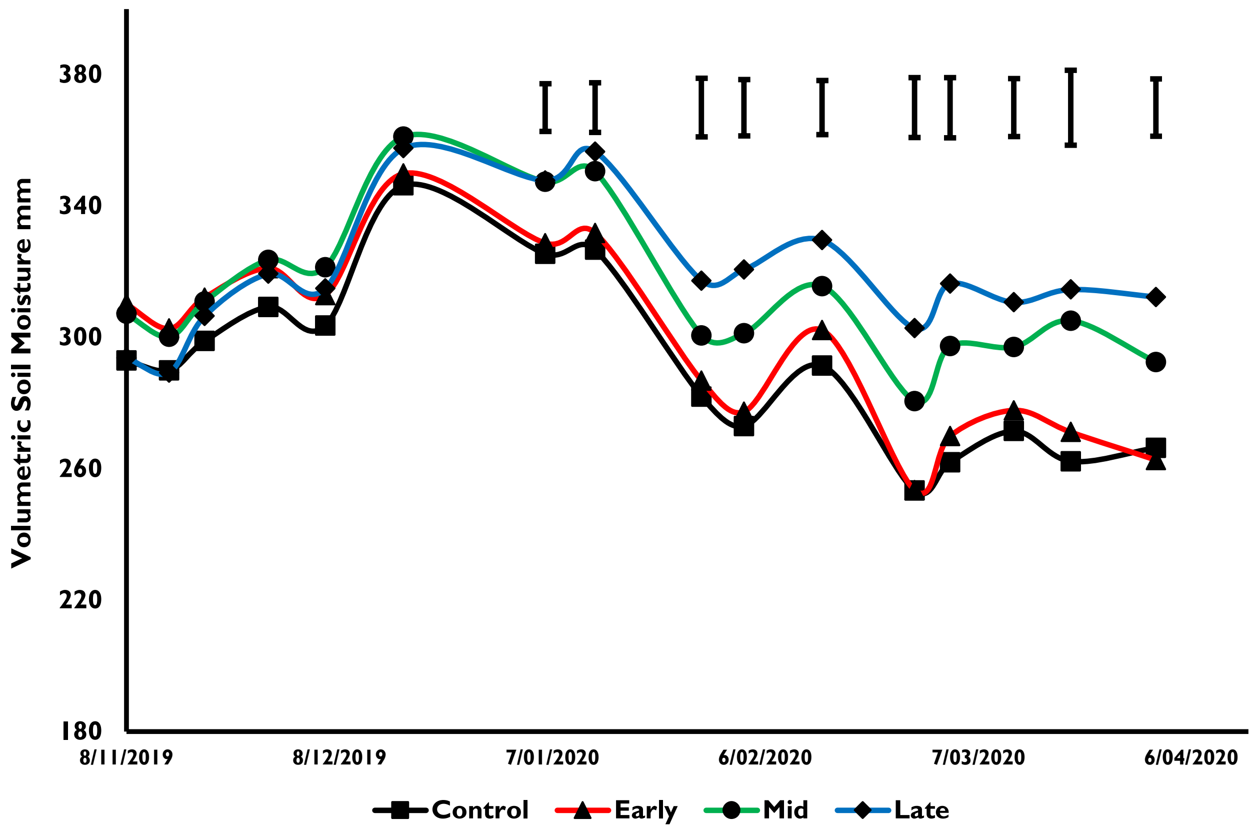

Figure 5. Volumetric soil moisture of the total soil profile from 0 – 100 cm for the time period that the cotton crop was growing. Vertical LSD bars represent a P-value < 0.05.

Table 6. Plant available water in mm across depth and spray out treatments for the period that the cotton crop was growing. LSD (P-value < 0.05) presented on the interaction between spray out treatment x depth and separately for total.

Date	Depth cm	Control	Early Spray out	Mid Spray out	Late Spray out	LSD
Early Season Growth 8/11/2019	0-25	39.2	38.59	39.53	39.93	1.268
	25-35	12.66	13.06	13.12	13.58	
	35-45	9.26	9.83	9.82	9.98	
	45-55	8.22	9.43	9.19	9.2	
	55-65	8.29	9.41	9.25	8.32	
	65-80	15.06	16.7	16.38	14.07	
	80-100	19.69	21.25	20.13	18.31	
	Total	112.7	118.4	117.6	113	ns
First Square 17/12/2019	0-25	41.2	39.6	41.41	41.27	ns
	25-35	14.35	14.18	14.69	14.78	
	35-45	10.91	11.14	11.4	11.54	
	45-55	10.92	11.18	11.25	11.48	
	55-65	10.71	11.08	11.28	11.19	
	65-80	19.16	19.77	20.56	20.02	
	80-100	24.46	25.41	26.16	25.23	
	Total	131.6	132.4	136.8	135.5	ns
First Flower 13/01/2020	0-25	36.04	36.93	38.65	39.75	ns
	25-35	12.04	12.68	13.39	14.34	
	35-45	9.88	10.17	10.76	11.38	
	45-55	10.37	10.4	11.08	11.44	
	55-65	10.33	10.7	11.16	11.57	
	65-80	19.25	19.23	20.47	20.47	
	80-100	25.42	25.71	26.19	25.95	
	Total	123.4 a	125.4 a	132.4 b	134.7 b	5.52
Defoliation 1/04/2020	0-25	37.28	37.45	38.66	40.47	ns
	25-35	10.44	11.34	11.92	13.02	
	35-45	6.77	8.27	8.08	9.48	
	45-55	5.73	6.81	7.13	8.8	
	55-65	7.4	7.03	7.85	8.87	
	65-80	14.39	12.66	15.84	16.81	
	80-100	21.18	20.18	22.33	22.32	
	Total	103.7 a	102.3 a	113 b	120 b	6.442

^^ ns denotes not significant at P-value < 0.05

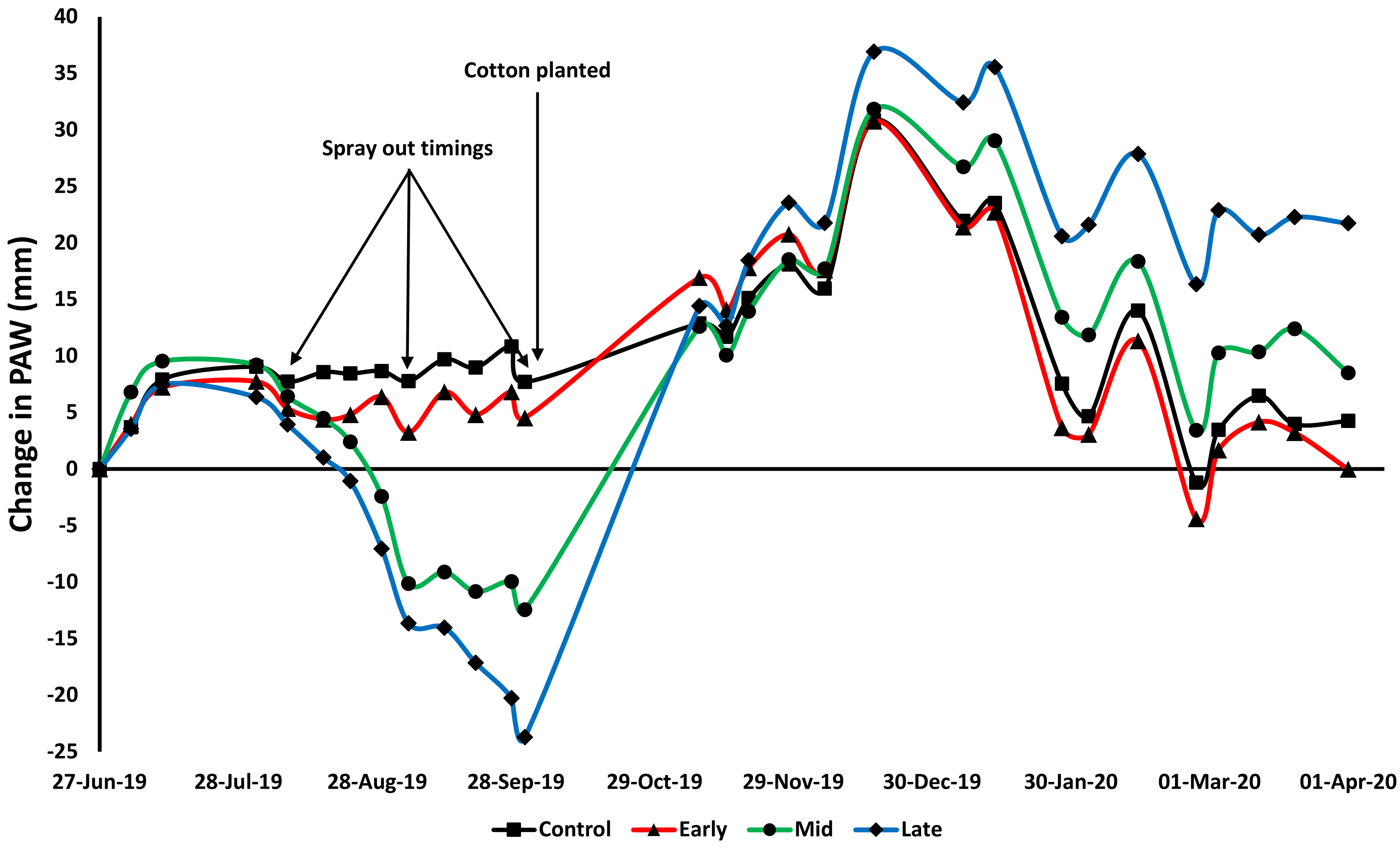

Figure 6. Change in plant available water during the cover crop growth period and during the cotton season.

Soil Nitrogen

No significant difference in soil nitrogen was identified between cover crop spray out treatments. On average there was 112 kg N/ha from 0 – 90 cm when the cover crops were sown. After all cover crops had been terminated, soil was analysed for nitrogen again prior to cotton being planted. At this time there was 16 kg N/ha to 90 cm. The cotton crop was supplied with 360 kg N/ha via water run and broadcast methods and on average the soil retained 57 kg N/ha to 90 cm after crop destruction.

Yields

Machine picked lint yields were above the district average of 11 bales/ha and given the difficult season the crop performed well. Lint yields harvested across all treatments saw a 1.76 bale/ha decrease from the control (highest yielding) to the late spray out (lowest yielding). All other treatments did not vary significantly from the control of 13.79 bales/ha.

This negative yield response to the increased amount of biomass by a late spray out is likely a result of reduced establishment. Plant numbers per meter dropped 4.75 by spraying out late compared to the control. Similarly, the mid spray out treatment yielded statistically the same as the control and yet the number of plants established per meter in this treatment dropped by 2.49 from the control. It can be assumed that the plant compensatory growth under these circumstances can compensate for a loss of 2.5 plants/m but fails to achieve the same yield potential with only 8.1 plants/m.

Table 7. Lint yields picked from each of the treatments expressed as 227 kg bales per hectare. Parenthesis indicate percentage of control.

Treatment	Bales/ha
Control	13.79 (100) a
Early	13.56 (98) a
Mid	13.49 (98) a
Late	12.03 (87) b
LSD (P<0.05)	*1.242*
F pr.	*0.028*

Cost Analysis

Cover crops are a sacrificial crop designed to improve soil health and structure. In a cotton system input costs are high and in a good season the crop can return high yields and a decent profit. Sowing a cover crop prior to cotton is another input cost that needs to be considered. Given that this experiment shows no yield gain from cover crops in the first season it will be hard for a grower to consider this farming practice based on economics alone. The cover crop mixture sown in this experiment was elaborate and expensive costing in excess of $80 /ha in seed alone. In total, with chemical to terminate the cover crop and the machinery used to sow and spray (assuming full ownership of the machinery and not including labour) the practice of planting a cover crop was $195.58 /ha on top of the input costs associated with growing cotton.

However, the benefits of cover cropping are rarely seen in the first season as the effect of crop rotations often takes years to produce a result. With carbon sequestration now a common practice to offset industrial emissions of CO_2, cover cropping may become a farming system to help growers become carbon neutral.

Table 8. Cost analysis of sowing a cover crop

Product	Amount ($/ha)
Chemical	24.16
Spray Rig	6.10
Barley seed	12.80
Oat seed	7.68
Vetch Seed	13.55
Tillage Radish Seed	47.06
Fertiliser (DAP)	75.00
Seeder	9.23
Total	**$195.58**

Summary

There were no benefits of cover cropping reflected in cotton yields after just one season. It is safe to assume that the improvement of soil structure and health takes longer than 12 months to have a significant influence on crop yields. The best performing treatment was the mid spray out treatment where the cover crop was terminated at Z39 and produced 3.57 t of dry matter. The yields in this treatment were not significantly different from the control. It slowed the movement of water through the furrow and resulted in more PAW towards the end of the cotton season. Given the availability of water and assuming no other limiting factors, if the number of established plants per meter could be compensated for with a higher sowing rate, then the yields under this system could potentially be improved above the control.

The cost associated with sowing a cover crop should be approached from an investment angle and not as a direct input cost of the cash crop in that season. It should be noted that a cover crop does not require the complexity of the mix used in this experiment. The most cost-effective cover crop is one that can be sown in a timely manner with seed stored on farm.

More research needs to be conducted on the organic carbon sequestered by cover cropping and the economic benefit of improving soil structure over time needs to be explored.

Acknowledgments

The project ‘Cover crops in grain and cotton farming systems’ (DAQ00211) is a collaboration between the NSW Department of Primary Industries, the Cotton Research and Development Corporation, the Grains Research and Development Corporation and the Queensland Department of Agriculture and Fisheries.

Thank you to Gabby Napier, Sam Hopper, John Dando and Alan Boulton for technical support. To the team of researchers and consultants working in the cover crop space, I thank you for your time and advice during the life of this project.

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Cover crops in grain and cotton farming systems (DAQ00211)

Yanco Cover Crop Rotation Experiment 2017/19

Author: Hayden Petty

Key findings

- Increasing the amount of biomass present in the cotton farming system through cover cropping and rotation types has shown to increase yield
- Species of cover crop is less relevant than the amount of biomass it can produce
- More soil moisture was available in the profile where an irrigated summer crop (sorghum or cotton) was previously grown when compared to a long fallow

Introduction

Cotton growing soils of Australia are predominantly grey self-mulching vertisols with a large plant available water holding capacity (WHC). With cotton yields and recent prices favouring expansion into the southern cotton growing areas of NSW, there has been an increase in the amount of land developed to grow cotton. A considerable amount of this newly developed land consists of red brown earths (RBE) which poses issues surrounding poor infiltration and less water holding capacity.

Cover cropping is often used in winter cropping rotations as a method of improving water stored in the profile over summer, as well as having other benefits such as increasing soil organic matter, providing disease breaks, improved nutrient cycling and weed control. In cotton systems, soil is more often disturbed by tillage, it tends to be sodic and under constant irrigation it has the propensity to become poorly structured. This coupled with soils that inherently have low water holding capacity and infiltration properties, such as red brown earths, are potentially restricting the yield of cotton.

To improve cotton yields grown on red brown earths irrigated through furrow irrigation, an experiment was designed using cover crops and crop rotations to investigate increasing organic matter and improving soil structure.

Site Details

Location	Yanco Agricultural Institute
Soil Type	Red Brown Earth
Previous Crop	Soybeans
Bed Configuration	1.83 m
Sowing	Cover crops: Stubble King disc seeder, 200 mm row spacing Cotton: Janke tyne cone seeder, 0.91 m row spacing
Soil pH_{CaCl}	6.8 (0-10 cm)
Mineral N at sowing	83 kg/ha N to (70 cm depth)
Fertiliser Applied	Cover crops: 100 kg/ha mono-ammonium phosphate (MAP) at sowing Cotton: 200 kg N/ha at sowing
Weed Control	Cover crop termination: glyphosate (450 g/L) at 2.5 L/ha, carfentrazone-ethyl (400 g/L) at 40 mL/ha and paraquat (135 g/L) + diquat (115 g/L) at 2.5 L/ha (double knock) Cotton Pre-emergent: pendimethalin (440 g/L) at 2 L/ha, terbutryn (500 g/L) at 2 L/ha Cotton Post-emergent: glyphosate (690 g/kg) at 1.5 kg/ha
Variety	Cover crops: Eurrabbie oats, Compass[A] barley, Morava[A] vetch and Buster tillage radish Sorghum: MR-Buster Cotton: Sicot 746B3F

Treatments

The experiment consisted of four main treatments: control, long fallow, sorghum (winter/sorghum) and continuous cropping (full winter/summer). The sub-plot treatments consisted of three cover crop species: oat/vetch mix, radish and barley.

Table 1. An outline of treatments imposed to identify the cover crop/rotation interaction on infiltration and plant available water capacity of soils.

Rotation	Winter 2017	Summer 2017/18	Winter 2018	Summer 2018/19
Long Fallow (LF)	Cover crop	Fallow	Fallow	Cotton
Winter/Sorghum (W/S)	Cover crop	Sorghum	Fallow	Cotton
Full Winter/Summer (FR)	Cover crop	Cotton	Cover crop	Cotton
Control	Fallow	Cotton	Fallow	Cotton

Results

To conclude the rotation experiment, all plots were planted to cotton in the 2018/19 summer to examine the combined effects of the preceding cover crops. After the experimental plots were re-planted on 5 November 2018, 90% establishment occurred 10 days after planting on 15 November with an average of 14 plants per m^2 (ns).

The date of first flower occurred on 16 January 2019 across all plots. This coincided with a period of extreme heat causing significant fruit shedding and a rapid decline in the number of nodes above the white flower. Node production at this time also ceased, halting at 15 nodes for a week. The crop grew to 20 nodes in total, a small crop that struggled to reach canopy closure as a result of being replanted and being grown on RBE soil with poor infiltration and WHC.

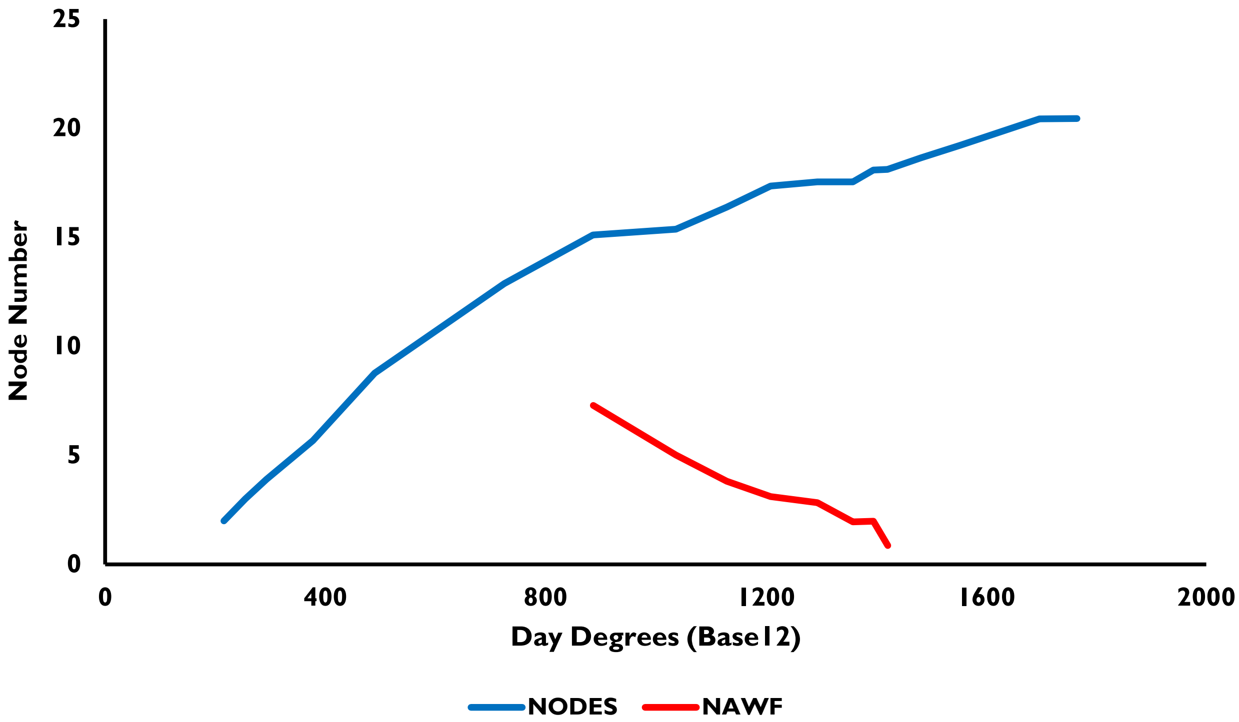

Figure 1. Nodes and NAWF plotted against day degrees expressed at a base of 12°C.

Biomass cuts were taken both at first flower and defoliation. Analysis of this data returned no significant differences between the treatments. Biomass at flowering averaged 3246 kg/ha of dry matter. At defoliation the crop averaged across all treatments 12838 kg/ha of dry matter.

Yields across the experiment were below the regional average of 10 bales/ha for southern NSW. However, the yields picked from the plots are representative for the trial and any differences that arise allow for inferences to be made between treatments. The long fallow treatments yielded poorly across all species of cover crop averaging 5.7 bales/ha (Figure 2). By adding sorghum to the farming system in the summer prior to cotton improved yields above the long fallow treatment by more than 1 bale/ha. The species of winter cover crop preceding the sorghum had no effect on yields of the following cotton crop. The full cotton rotation including winter cover in each winter saw yield improvements above the long fallow treatment but was on par with the sorghum fallow treatment. The control of back to back cotton with fallows over each winter was not significant from any treatment except the full cotton rotation including barley as winter cover. The yield difference between these two treatments was 1.03 bales/ha. Between the highest yielding treatment (Full rotation barley) and the lowest (long fallow radish) was 1.9 bales/ha.

Increasing yield by 1 bale/ha at current prices increases gross income by approximately $500 per ha for cotton lint alone. These yield differences are likely attributed to the soil constraints of red brown earths and is possible that such vast differences would not be achievable on more productive grey self-mulching clays however, this research needs to be conducted in the south.

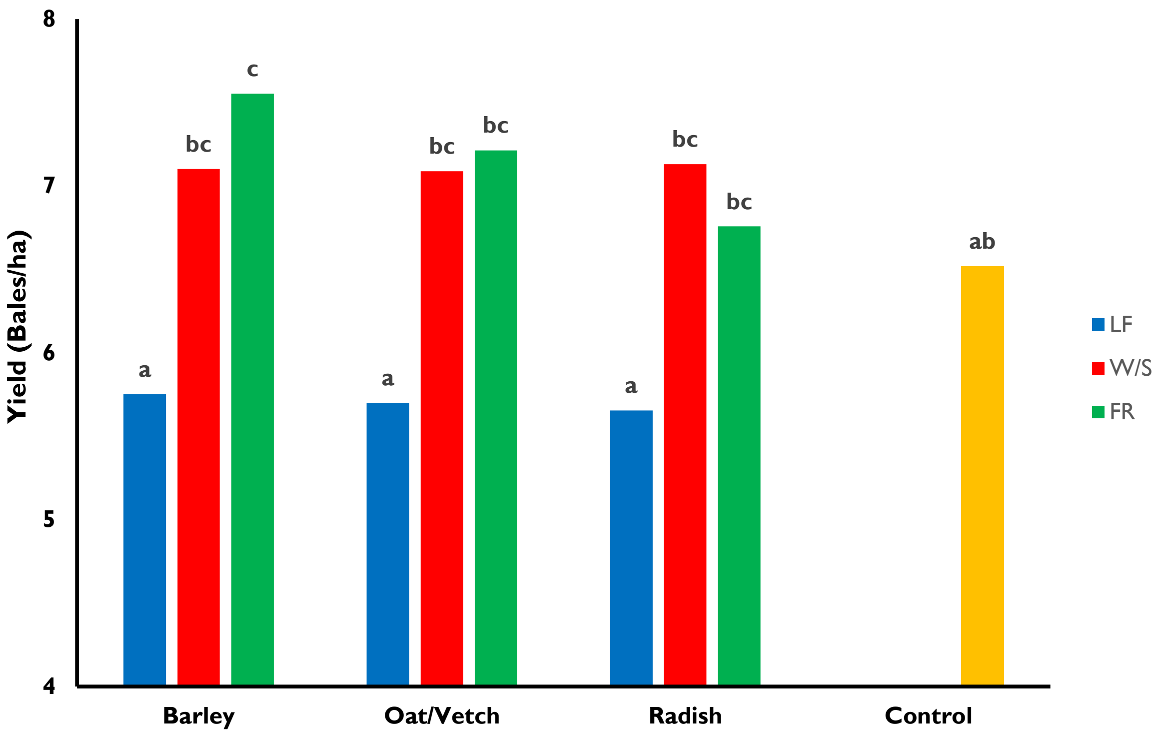

Figure 2. Cotton yield (bales/ha) for each of the 10 treatments. LF = long fallow, W/S = winter cover crop and sorghum in previous summer and FR = back to back cotton with cover each winter. LSD of 0.991 bales/ha (P<0.05).

Biomass vs yield

Such differences in yield between treatments with no considerable differences in crop growth and development throughout the season suggests water/soil dynamics may have had some influence. By plotting yield data against total accumulated biomass from the cover crop treatments preceding the final cotton crop suggests that increasing biomass increases yields.

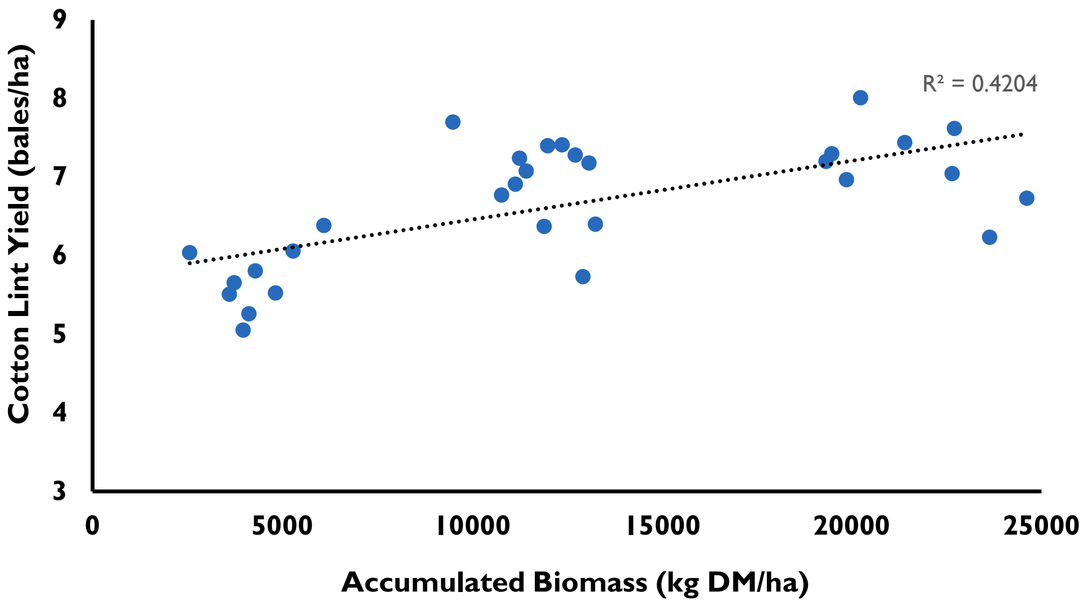

Figure 3. cotton lint yields plotted against total accumulated biomass measured during the 2-year rotation.

Soil Water

Soil water was measured using neutron moisture monitors to a depth of 100 cm across all treatments in the experiment. Presented in figure 4, is the total plant available water to 100 cm depth. Initial readings from the final cotton season indicates that the long fallow (LF) treatment had more soil moisture in the profile than the other treatments. The treatment with the most plant available water at planting was the long fallow radish containing 109.21 mm of water. The driest treatment was winter/sorghum and barley as the initial cover crop with just 86.19 mm of moisture.

As the crop developed and started extracting more water, the relationship seen early in the season flipped around. The long fallow treatments consistently had less soil moisture than the other treatments (blue lines). The soil water status of the LF treatment through the season also attributed less yield as seen in figure 2. During the flowering and boll fill period the full rotation oat/vetch mix had significantly more water than other treatments.

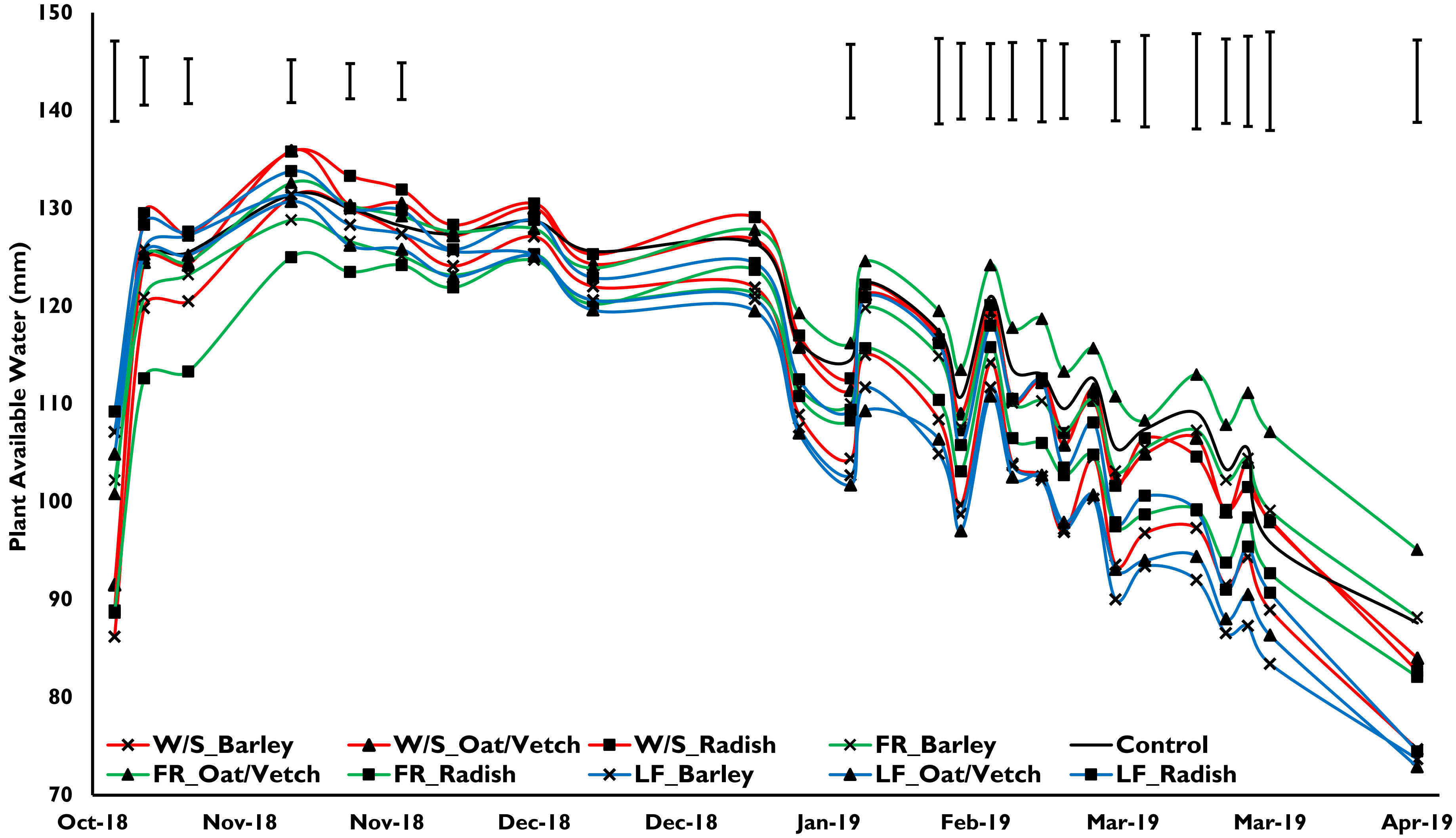

Figure 4. Plant available water over time for each of the cover crop treatments.

Summary

Cotton lint yields were improved above the long fallow treatments by the addition of cover crops into the system. The farming system that grew the most biomass over time (cover crop and cash crop combined) subsequently yielded the highest in the final year of the rotation. Increased stored soil water was present in the profile under the treatments where a summer irrigated crop was grown prior to the final cotton crop. The species type of cover crop showed no benefit to yield but was rather a function of the biomass it could produce.

Acknowledgments

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Quantifying the effectiveness of cover crops as a means of increased water infiltration and reduced evaporation in the northern region

Modelling Component

(GRDC project DAQ00211)

Neil Huth[1] and Brook Anderson[1]

[1]CSIRO Agriculture and Food, P.O. Box 102 (203 Tor St), Toowoomba, Qld, 4350

1 Methodology

1.1 Short-term simulation of Coorangy cover crop experiment.

Simulation analyses were undertaken using the APSIM (Agricultural Production Systems Simulator) (Holzworth *et al.* 2014) model which has been tested and applied extensively within this geographical region (Holzworth et al, 2018). APSIM was specified to reproduce the management of the trial. The model was initialized at cover crop termination for each treatment and the control. Soil properties were taken from the Coorangy experimental site; measured prior to the experiment. Climate data was taken from the local meteorological station situated at the site. The model was initialized using soil water, soil nitrogen and residual stubble measured for each treatment, with soil layer depths in the model corresponding to sampling depths. As stubble was not measured for carbon and nitrogen content throughout the trial, values were estimated based on stubble type and quantity and supplied to the model. The model was further tuned to this dataset by adjusting the runoff response to allow simulated water infiltration to align with observed data.

1.2 Analysis for decision-making using long-term modelling.

Following the calibration outlined above, a long-term modelling analysis was undertaken using the parameterisation for soils and cover crop residues from the APSIM model developed for the Coorangy experiment. Long term weather data (1900-2020) were obtained for the nearby town of Toobeah (28.4175° S, 149.8710° E) using the SILO weather database (Jeffrey *et al.* 2001, https://www.longpaddock.qld.gov.au/silo/). Simulations were prepared to simulate fallow conditions for bare soil and for fallows after cover crops providing up to 3 t/ha of surface stubble. Simulations of fallow conditions were undertaken for November-April (following Spring cover crops) and May-April (following Autumn cover crops) with initial plant available water (PAW) of 60mm or 120 mm. Data from the Coorangy and Nareen experimental sites showed that the net change in soil water storage at the end of the cover crop relative to uncropped fallow land was closely related to the mass of stubble grown (20.3 mm per t/ha of stubble, R2=0.90). This value was used to initialise soil water for each stubble level relative to the bare soil fallow.

2 Results and Discussion

2.1 Short-term simulation of Coorangy cover crop experiment

Results from simulations demonstrate the ability of the APSIM model to capture soil water dynamics observed at the site. Figure 1 shows the predicted soil moisture content in the 0-120cm profile compared with the observed data. The model captures observed soil water dynamics well, except in the millet late treatment (R^2 = 0.41, RMSE = 25.1 mm). Poor agreement of modelled and observed data in the millet late treatment is possibly the result of error in NMM readings due to soil cracks around the access tube at termination, or the effect increased runoff from adjacent plots resulting in increased infiltration during the fallow. Model predictions showed strong agreement with observed data for the millet early, mid and control treatments,, capturing observed dynamics very well over the fallow period (R^2 = 0.88, RMSE = 3.94mm).

In addition to soil moisture, the model was assessed for its ability to simulate stubble breakdown from cover crop termination to planting of the subsequent winter crop. Figure 2 shows predicted residue weight after cover crop termination compared to observed data. The model effectively captures stubble breakdown over the fallow period in the millet early and mid treatments, with slight over prediction of stubble breakdown in the millet late treatment. Over estimation of stubble breakdown in the late spray out treatment is possibly the result of overestimating the nitrogen content of the stubble, whereby increased nitrogen availability would facilitate faster breakdown of stubble (Simpfendorfer et al. 2004).

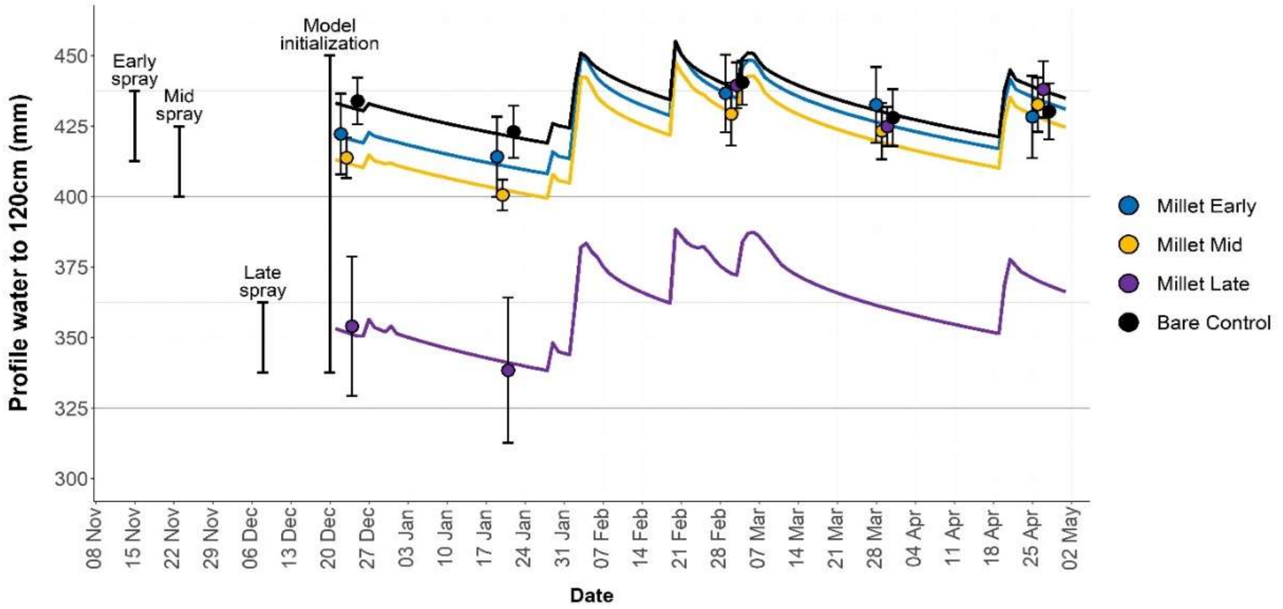

Figure 1. *APSIM simulated profile water (to 120cm) for early, mid and late millet spray out and control treatments (solid lines), compared with observed data (points) for Coorangy. Observed data is plotted as treatment means with error bars representing standard error. Simulated data is plotted from model initialization (19/12/2017) to planting of subsequent winter crop (1/5/2018). Cover crop termination dates include early spray (15/11/2017), mid spray (23/11/2019) and late spray (08/12/2017).*

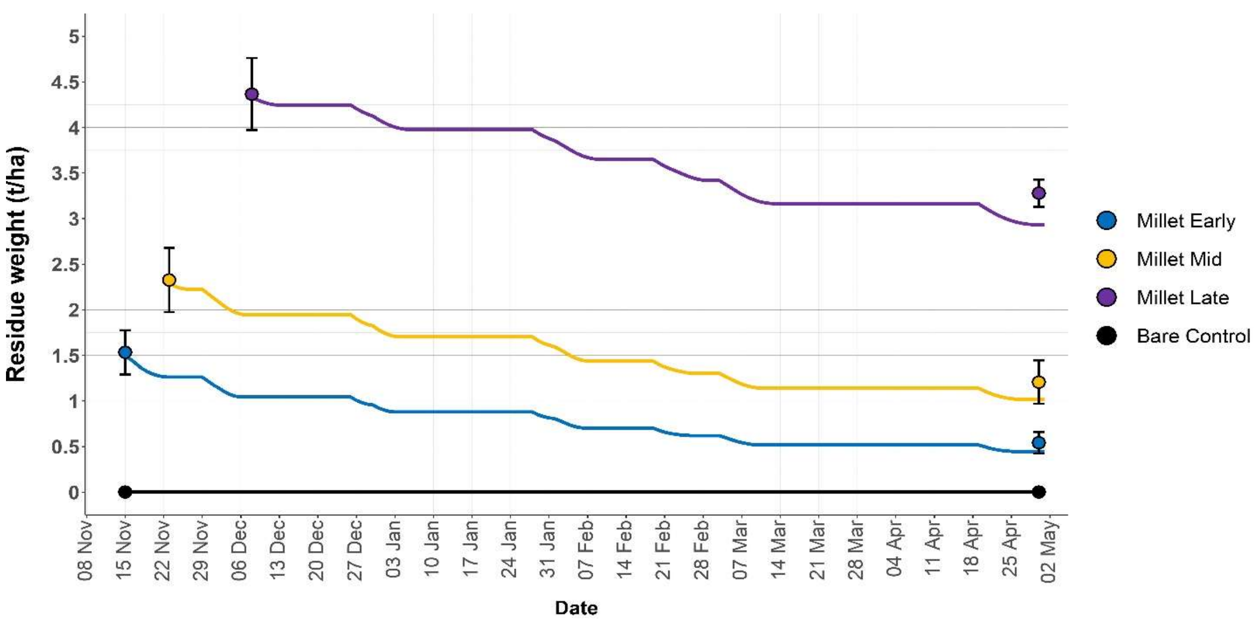

Figure 2. *Simulated residue breakdown for early, mid and late millet spray out and control treatments (solid lines), compared to observed data (points) for Coorangy. Observed data is plotted as treatment means with error bars representing standard error. Simulated data is plotted from cover crop termination to planting of subsequent winter crop (1/5/2018). Cover crop termination dates include early (15/11/2017), mid spray (23/11/2019) and late spray (08/12/2017).*

Results from modelling soil water and stubble breakdown over the fallow period at Coorangy has shown that the APSIM model can effectively capture the variables of greatest interest in growing cover crops. By including an array of climate and starting conditions, as well as different cover crop sowing dates and lengths, we can use the model to better understand the effectiveness of cover crops within a crop rotation and how to most effectively use cover crops to benefit soil health and subsequent crop production.

2.2 Analysis for decision-making using long-term modelling.

The simulations indicate benefits from spring cover cropping for soil water storage in many years when initial PAW is low (Figure a). In dry years, the benefits of cover crops in improved water retention are not sufficient to overcome the water required to grow the cover crop. The is occurs in approximately 10% of years for small cover crops (1 t/ha) or 50% of years for larger cover crops (3 t/ha). In wet years, there is sufficient in-fallow rainfall to fill the soil to its capacity and so there is little benefit of cover crops in approximately 5% of years. However, improved soil water storage from small cover crops can lead to improved soil water for winter planting for a wide range of rainfall conditions between these extremes (Rainfall percentiles 25-95%). Note that the increased water use by larger cover crops reduces this range of net benefit to a smaller set of years (Rainfall percentiles 50-95%).

Cover crops reduce erosion risk during fallows by reducing runoff volumes and sediment concentration in runoff water (Figure b). Even small stubble levels (1 t/ha) are predicted to eliminate sediment losses in up to 50% of years. While cover crops may have little benefit for water storage in very wet years (Figure a), higher levels of stubble are predicted to be effective in preserving soils during these years of high erosion risk (Figure b).

These results suggest that costs associated with cover cropping could perhaps be saved if the seasonal outlook is for significantly below average rainfall (e.g. El Niño) when benefits on soil water storage are unlikely and erosion losses are inherently low. If the seasonal outlook is for significantly above-average rainfall (e.g. La Niña) cover cropping could be undertaken with low risk of impacting moisture storage for following crops, but with effective cover for managing risk from a wide range of stubble levels. For years between these extremes (In-fallow rainfall 200-500mm), there is some opportunity for modest increases in soil water storage (average 17mm).

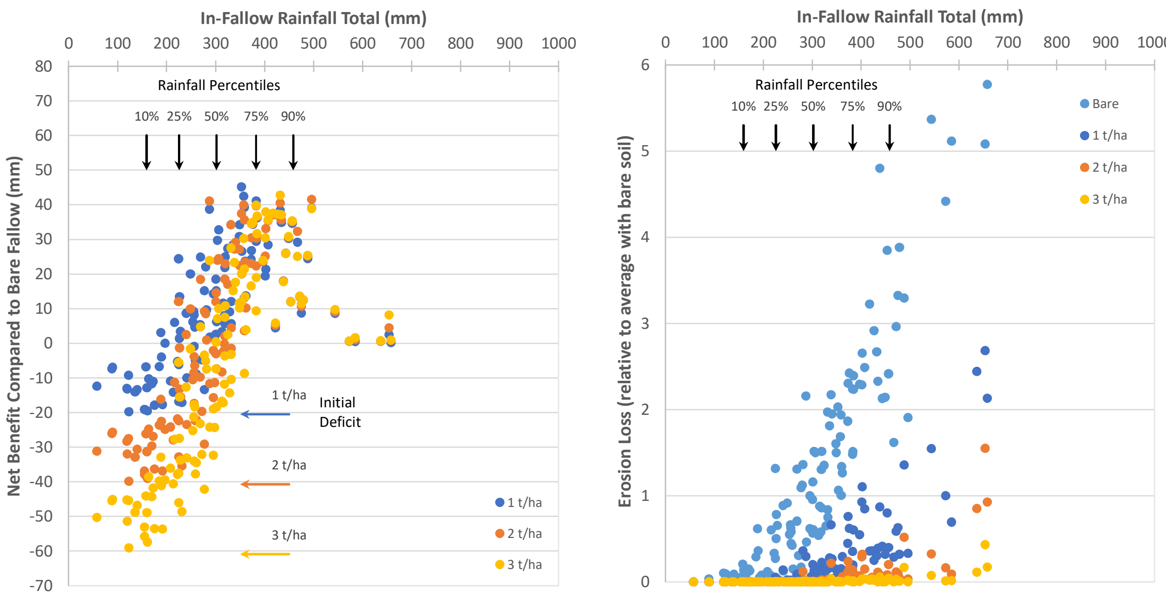

Figure 3a) Net benefit of Spring cover crops of varying stubble mass on stored soil moisture for the following winter compared to bare soil fallow with 60mm starting PAW, and b) Relative reduction in erosion losses due to cover crops during the fallow. Bare soil erosion rates are shown for comparison. Rainfall percentiles for the fallow period are shown. The initial soil water deficit for the fallow period due to cover crop water use is indicated for each scenario.

The benefits of cover cropping diminish if stored water is already high in the Spring (Figure 4a). Benefits from increased soil water storage are similar for drier years but are reduced for wet seasons with little benefit from the wettest 50% of years. In these seasons, the remaining soil water storage capacity can be refilled by in-fallow rainfall in most years if PAW is high. However, the value of stubble for protecting soils from erosion losses remains and is likely of increased benefit under these conditions.

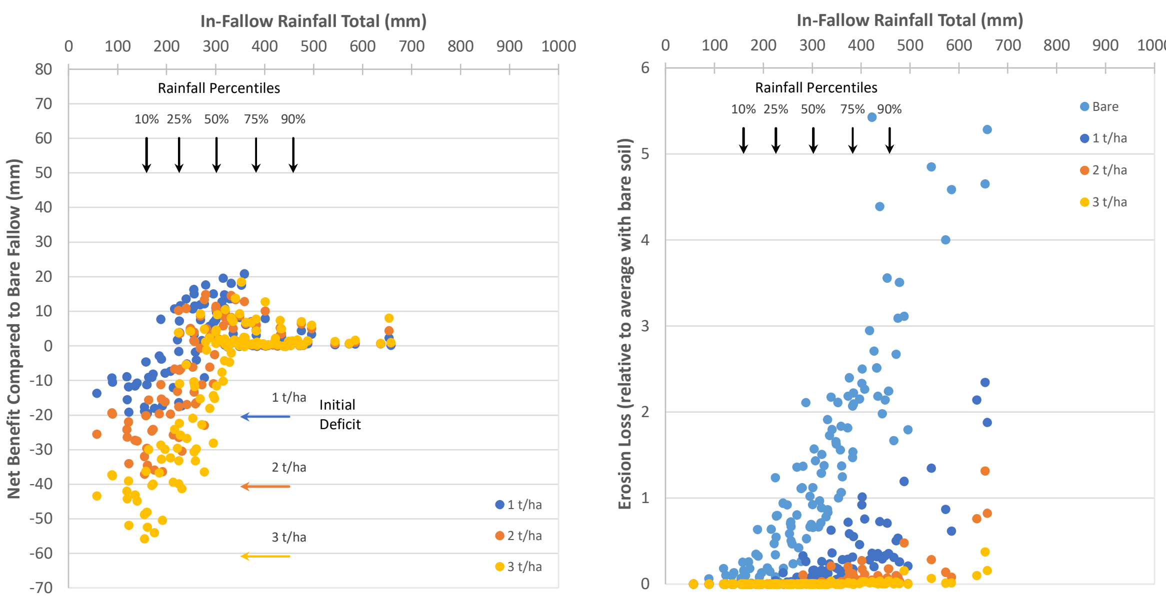

Figure 4a) Net benefit of Spring cover crops of varying stubble mass on stored soil moisture for the following winter compared to bare soil fallow with 120mm starting PAW, and b) Relative reduction in erosion losses due to cover crops during the fallow. Bare soil erosion rates are shown for comparison. Rainfall percentiles for the fallow period are shown. The initial soil water deficit for the fallow period due to cover crop water use is indicated for each scenario.

Finally, similar results are found for longer fallow periods following Autumn-grown cover crops. However, the longer duration of the fallow provides for increased rainfall to be captured and therefore the initial loss of water in growing the cover crop is returned via increased water storage in most years for small cover crops. However, the increased duration also means that there is a greater probability of adequate rainfall to fill the soil profile in wet years (>10% of years). Again, between these two extremes (In-Fallow Rainfall 300-700mm) there remains some opportunity for modest increases in soil water storage (average 15 mm). As expected, the extended fallow period brings higher risks from erosion. Stubble cover is again valuable in preserving soils, however, whereas 3 t/ha of stubble was effective in eliminating losses in nearly all (c. 95%) years for the shorter fallow period, losses are predicted to occur in 25% of years. Decisions for planting Autumn cover crops may need less consideration of potential losses in dry years but greater focus on value of risk mitigation in wet years.

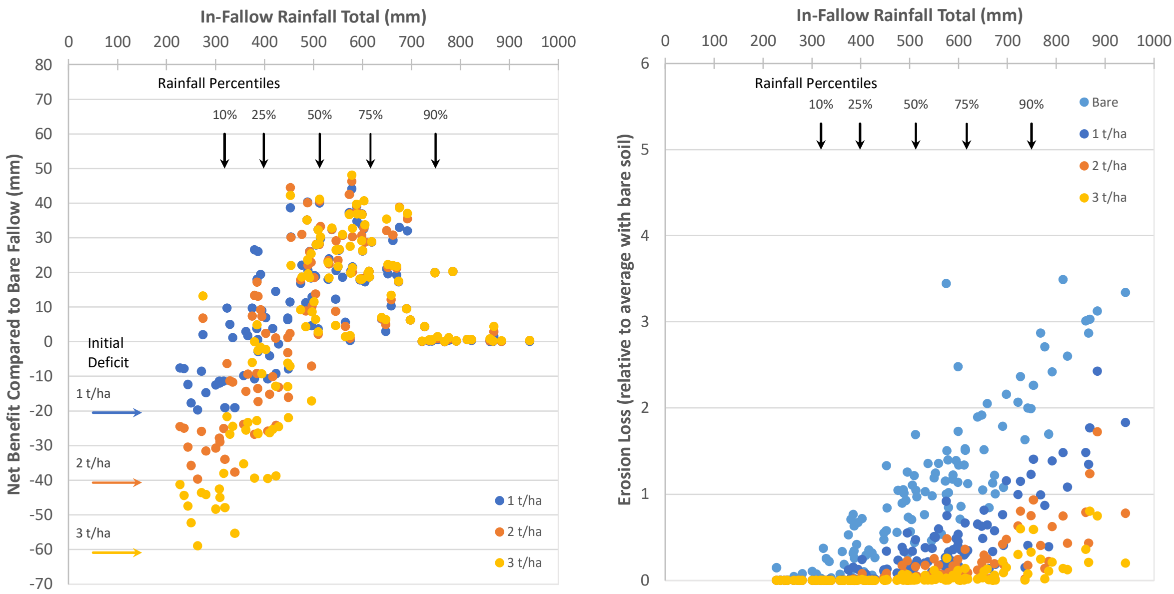

Figure 5a) Net benefit of Autumn cover crops of varying stubble mass on stored soil moisture for the following winter compared to bare soil fallow with 60mm starting PAW, and b) Relative reduction in erosion losses due to cover crops during the fallow. Bare soil erosion rates are shown for comparison. Rainfall percentiles for the fallow period are shown. The initial soil water deficit for the fallow period due to cover crop water use is indicated for each scenario.

3 Conclusions

For many years cover crops have been recognised for their role in protecting soil from runoff and erosion, suppressing weeds and increasing water infiltration in an agricultural system (Dabney *et al.* 2001). Managing a cover crop to provide the greatest benefit while minimizing costs is a tricky game. In the context of seasonal variability in soil and climate conditions, cover cropping does not always lead to a net benefit. By utilizing computer models, we can gain valuable insight the conditions required for a successful cover crop. Through modelling the Coorangy cover crop experiment, and validating simulated results with observed data, we have shown that the APSIM model can effectively capture soil and stubble dynamics observed during the experiment. Implementing this model into a long-term simulation, using an array of starting soil conditions and 120 years of climate data, we identified several criteria under which cover crops provided net benefit to the agricultural system. According to the model, when conditions are not extremely wet or dry, cover crops provide net benefits in both long- and short-term fallow systems. During these years, cover crops provide erosion control and facilitate increased water infiltration, with average net water storage benefits of 17mm and 15mm for short- and long-fallow periods respectively. During dryer years, cover crops offered little benefit, as erosion risk is inherently low, and the water lost through producing a cover crop is not replenished by rainfall. During wetter years, cover crops, while offering little benefit to water storage, provided valuable benefit to erosion control, with evidence indicating substantial reductions in sediment loss compared to bare fallow. This modelling indicates that assessment of cover cropping options should be informed by seasonal climate forecasts and estimates of PAW.

Interpretation of results from modelling the Coorangy experiment provide considerable insight into the conditions required for growing a successful cover crop. Given the potential risk associated with planting cover crops, especially considering the current variability in seasonal conditions, modelling experiments such as this offer valuable insight to the decision-making process.

4 References

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Cover crop analysis – a simple static model

David Freebairn June 2020

The basic proposition for including a cover crop as part of a fallow is that the water consumed growing a cover crop is less than the gain in water associated with greater soil cover after the cover crop is terminated. Fig. 1 shows that fallow efficiency (% of rainfall stored in soil) can vary depending on the season and soil cover. Numerous tillage studies and data from this study support the proposition that “the opportunity” is real (Fig. 2)

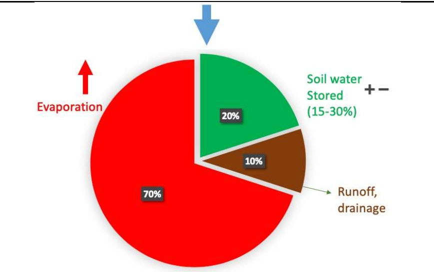


Fig. 1 Typical summer fallow water balance

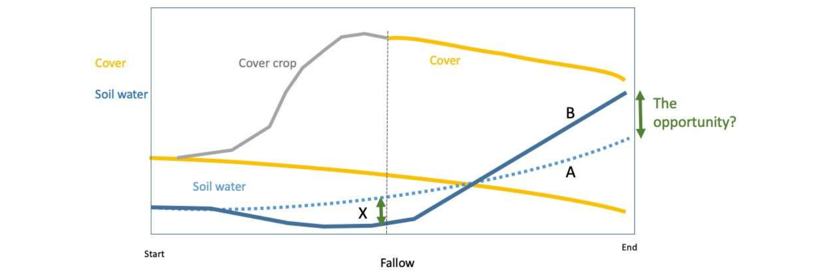
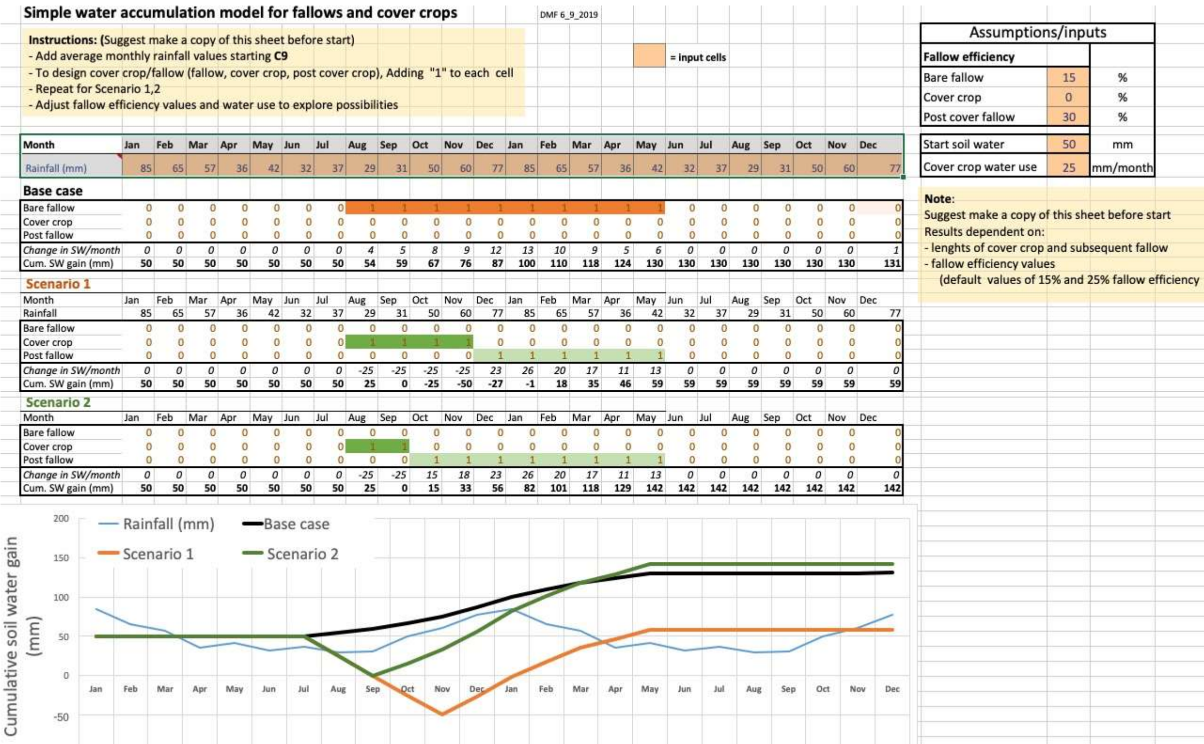


Fig. 2 Schematic showing theoretical dynamics in soil cover and soil water for a low cover fallow (A) and a cover crop-fallow (B)

A static spreadsheet analysis was constructed that allows for comparisons between various fallows including: start and end dates; duration of cover crop. Key inputs include: monthly rainfall for the location; fallow efficiency values for a reference condition and post cover crop; and water use by the cover crop (Figure 3)



Simple water accumulation model for fallows and cover crops DMF 6_9_2019

Instructions: (Suggest make a copy of this sheet before start)
- Add average monthly rainfall values starting **C9**
- To design cover crop/fallow (fallow, cover crop, post cover crop), Adding "1" to each cell
- Repeat for Scenario 1,2
- Adjust fallow efficiency values and water use to explore possibilities

= input cells

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall (mm)	85	65	57	36	42	32	37	29	31	50	60	77	85	65	57	36	42	32	37	29	31	50	60	77
Base case																								
Bare fallow	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
Cover crop	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Post fallow	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Change in SW/month	0	0	0	0	0	0	0	4	5	8	9	12	13	10	9	5	6	0	0	0	0	0	0	1
Cum. SW gain (mm)	50	50	50	50	50	50	50	54	59	67	76	87	100	110	118	124	130	130	130	130	130	130	130	131

Scenario 1

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall	85	65	57	36	42	32	37	29	31	50	60	77	85	65	57	36	42	32	37	29	31	50	60	77
Bare fallow	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cover crop	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Post fallow	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0
Change in SW/month	0	0	0	0	0	0	0	-25	-25	-25	-25	23	26	20	17	11	13	0	0	0	0	0	0	0
Cum. SW gain (mm)	50	50	50	50	50	50	50	25	0	-25	-50	-27	-1	18	35	46	59	59	59	59	59	59	59	59

Scenario 2

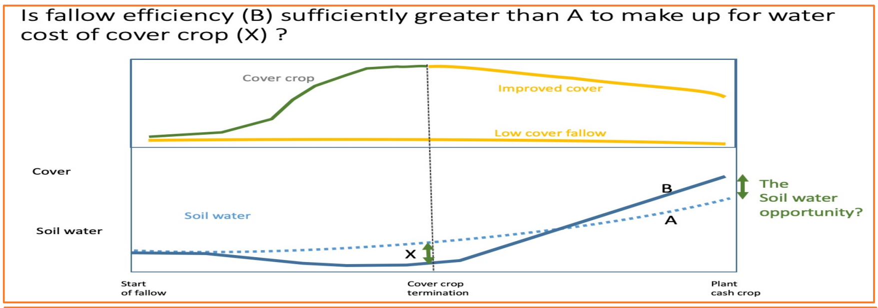
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bare fallow	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cover crop	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Post fallow	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
Change in SW/month	0	0	0	0	0	0	0	-25	-25	15	18	23	26	20	17	11	13	0	0	0	0	0	0	0
Cum. SW gain (mm)	50	50	50	50	50	50	50	25	0	15	33	56	82	101	118	129	142	142	142	142	142	142	142	142

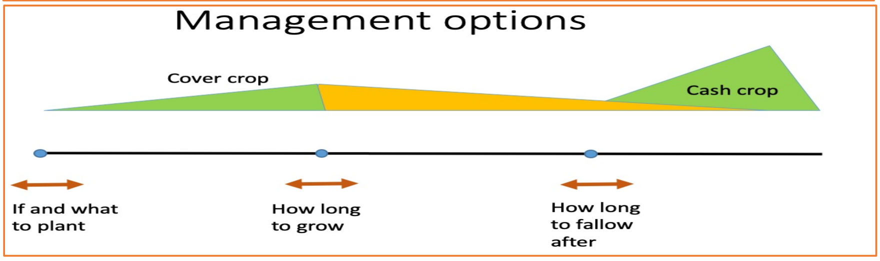
Assumptions/inputs		
Fallow efficiency		
Bare fallow	15	%
Cover crop	0	%
Post cover fallow	30	%
Start soil water	50	mm
Cover crop water use	25	mm/month

Note:
Suggest make a copy of this sheet before start
Results dependent on:
- lenghts of cover crop and subsequent fallow
- fallow efficiency values
  (default values of 15% and 25% fallow efficiency

Figure 3 Spreadsheet screen showing inputs and outputs for a base case and two scenarios.

Inputs are derived from current and previous studies. While this analysis is simple and static, it allows for quick comparisons based on empirical evidence from a range of studies. For example, the difference in fallow efficiency between bare soil and no-till is commonly 10-15% similar to the hypothetical analysis above. At least initially, this style of analysis allows the project team to explore possibilities using their own data and is an efficnet process for exploring some initial “what ifs?”





This spreadsheet allows for a simple comparison of soil water dynamcis for three scenarios based on:

- average monthly rainfall

- specified fallow efficiency (% rainfall stored) for each fallow type

- monthly water use during the cover crop

Suggest put your local maonthly rainfall in, and play with some scenarios and modify fallow efficiency values

Static water model for comparing fallow and cover crops

DMF 28_9_2019

Instructions: (Suggest make a copy of this sheet before start)
- Add average monthly rainfall values starting **C9** (some data in "Rain data" tab)
- Design cover crop/fallow sequence by adding "1" to each cell
- Adjust fallow efficiency values and water use to explore possibilities

0,1 = input cells

Assumptions/inputs		
Fallow efficiency		
Bare fallow	15	%
Cover crop	0	%
Post cover fallow	30	%
Start soil water	50	mm
Cover crop water use	25	mm/month

Site: **Goondiwindi rainfall**

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Rainfall (mm)	85	65	57	36	42	32	37	29	31	50	60	77	85	65	57	36	42	32	37	29	31	50	60	77

Base case

Bare fallow	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
Cover crop	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Post fallow	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Change in SW/month	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*4*	*5*	*8*	*9*	*12*	*13*	*10*	*9*	*5*	*6*	*0*	*0*	*0*	*0*	*0*	*0*	*1*
Cum. SW gain (mm)	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**54**	**59**	**67**	**76**	**87**	**100**	**110**	**118**	**124**	**130**	**130**	**130**	**130**	**130**	**130**	**130**	**131**

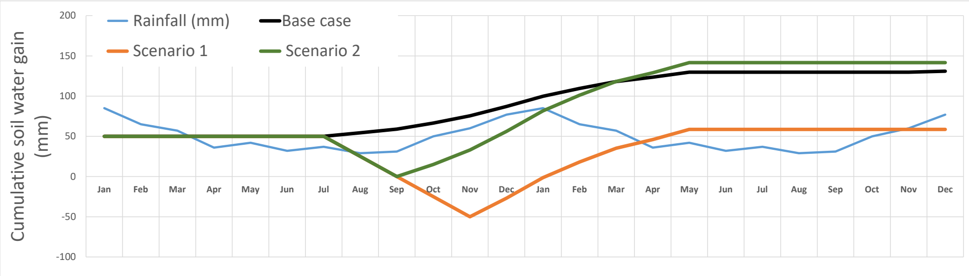
Scenario 1

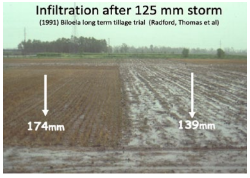
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall	85	65	57	36	42	32	37	29	31	50	60	77	85	65	57	36	42	32	37	29	31	50	60	77
Bare fallow	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cover crop	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Post fallow	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0
Change in SW/month	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*-25*	*-25*	*-25*	*-25*	*23*	*26*	*20*	*17*	*11*	*13*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Cum. SW gain (mm)	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**25**	**0**	**-25**	**-50**	**-27**	**-1**	**18**	**35**	**46**	**59**	**59**	**59**	**59**	**59**	**59**	**59**	**59**

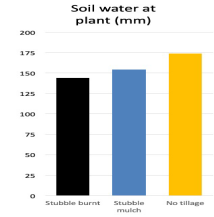
Scenario 2

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bare fallow	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cover crop	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Post fallow	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
Change in SW/month	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*-25*	*-25*	*15*	*18*	*23*	*26*	*20*	*17*	*11*	*13*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Cum. SW gain (mm)	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**25**	**0**	**15**	**33**	**56**	**82**	**101**	**118**	**129**	**142**	**142**	**142**	**142**	**142**	**142**	**142**	**142**

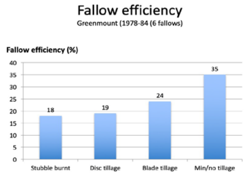
Note:
Suggest make a copy of this sheet before start
Results dependent on:
- lenght of cover crop and subsequent fallow
- fallow efficiency values
  (default values of 15% and 25% fallow efficiency







Felton, Marcellos and Martin 1995 3 NSW sites over 2 years



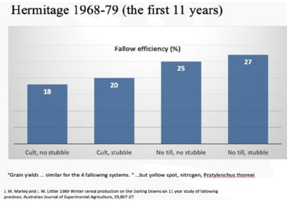
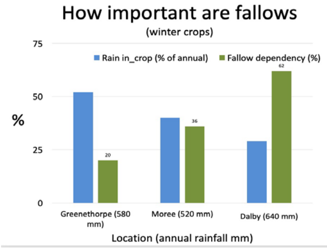
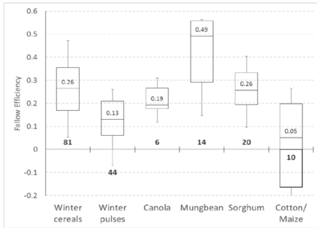


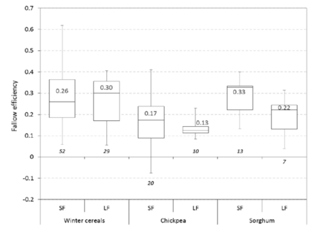
Table 1 Influence of tillage and soil cover on runoff and water storage on a grey brigalow clay (Greenwood 1978-83).

Tillage management (fallow cover)	Bare fallow (<5%)	Disc tillage (25%)	Blade tillage (45%)	Min/no till (>65%)
Fallow efficiency (%)	21	25	26	32
Range of FE	9-29	8-38	17-36	12-32
Reduced runoff (mm)	-	24	32	15
Extra soil water (mm)	-	13	16	36





James Hagan
Sorghum Solid Plant
Mungs double cropped with previous cereal stubble (High FE largely cereal stubble + very short fallow period related)
Cotton + Maize essentially Bare
Most confidence in W Cereal, W Pulse and Sorg
All data taken from Farming systems sites (Emerald to Trangie regional variations)



SF vs LF differences due to
A) stubble breakdown
B) Seasonable conditions following crop
ie wheat cereal short fallow covers summer period with high evap demand
long fallow then includes the winter period (improving overall FE%)
Sorghum is inverse of this, SF covers winter period, whilst LF adds in a summer which reduces overall FE%

Once again Emerald to Trangie – regional variations

Monthly average rainfall

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Goondiwindi	85	65	57	36	42	32	37	29	31	50	60	77
Parkes	52	49	53	39	43	48	53	48	46	50	61	59
Canowindra	54	51	45	37	40	49	55	49	47	50	57	59
Yanco	29	35	36	27	36	40	40	38	37	36	35	35
Narrabri	76	63	45	36	45	40	44	1	37	47	63	73

Yanco

2017	10	13	19	23	25	2	24	33	1	28	21	91
2018	24	1	4	[illegible]	[illegible]	29	6	9	12	7	58	22
2019	11	28	15	33	34	37	29	13				
Avgs	29.0	34.6	35.7	27.4	35.8	40.1	40.2	38.4	36.6	35.9	34.8	34.5

Parkes

2018	35	20	6	6	21	28	2	18	17	35	111	28
2019	41	10	47	0	26	32	14	14				
Avgs	51.8	49.5	53.2	39.1	42.9	48.3	53.5	47.7	45.9	50.0	60.7	59.4

Narrabri

2016	118	17	18	22	39	104	60	103	123	60	18	27
2017	106	12	193	13	25	42	11	20	4	63	60	38
2018	39	19	48	[illegible]	[illegible]	8	8	31	9	82	58	56
2019	10	3	81	0	30	1	14	1				
Avgs	76.4	63.4	45.4	35.7	44.8	40.4	44.5	31.5	37.1	46.6	63.0	72.7

Canowindra

2017	42	0	153	27	25	3	13	46	16	56	47	125
2018	20	38	1	14	40	35	8	38	24	53	99	51
2019	73	47	68	1	43	41	23	29				
Avgs	54.0	51.3	45.1	37.5	40.5	48.7	54.7	49.4	46.7	50.2	56.6	59.2

Statistics for the Australian Grains Industry
Biometry Report Series

Statistical Report
Quantifying the effectiveness of cover crops as a means of increased water infiltration and reduced evaporation in the northern region
GRDC project DAQ00211

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September 3, 2020

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Executive Summary

This SAGI-North biometrical report contains the statistical analyses performed on multiple field trials conducted in the 2017/18 and 2018/19 seasons across the GRDC defined Northern Region (NSW and QLD) related to the GRDC project 'Quantifying the effectiveness of cover crops as a means of increased water infiltration and reduced evaporation in the northern region (DAQ00211)'. Advances in agronomy have resulted in better use of available soil water to improve individual crop performance. However, effective capture and storage of rainfall remains a major challenge for grain and cotton growers in the Northern Region, where dryland crops typically transpire only 20-40% of rainfall.

The cover crop project focuses on the capture and storage of rainfall by exploring whether cover crops can increase the *net* water accumulation (PAW) in dryland systems, with low ground cover ($< 30\%$) in the Northern Region. Specifically, the project attempts to ascertain

- What is the net water cost to grow cover crops?
- What is the net water gain to subsequent grain crops (fallow and early growth periods)?
- What is the impact on the yield of the grain crops?

In terms of the change in volumetric soil moisture, there were mixed results in terms of net water gain when using cover crops as opposed to a fallow period (i.e. the control). All of the trials showed no significant improvement in plant available water (PAW) by the time it came to plant the grain crop, with the exception being the Parkes short fallow trial. Another key research question was to determine if the grain crop planted following the cover crop would result in more grain yield than a fallow period (i.e. the control). The analyses provided mixed results, with cover crops resulting in significantly more yield for some trials (e.g. Coorangy), whilst at other trials the control had a significantly higher grain yield than the cover crop treatments (e.g. Canowindra).

Overall, the analyses in this report indicates that cover crops have the potential to improve PAW in certain conditions. The next step would be to determine under which circumstances do cover crops result in an improvement in PAW. It is also evident that improvements in PAW do not necessarily coincide with improvements in grain yield, and thus further research is required to investigate additional possible benefits of cover cropping beyond PAW.

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1 Introduction

This SAGI-North biometrical report contains the statistical analyses performed on multiple field trials conducted in the 2017/18 and 2018/19 seasons across the GRDC defined Northern Region (NSW and QLD) related to the GRDC project 'Quantifying the effectiveness of cover crops as a means of increased water infiltration and reduced evaporation in the northern region (DAQ00211)'. The next couple of paragraphs provide a brief summary of the background information regarding the project aims.

Advances in agronomy have resulted in better use of available soil water to improve individual crop performance. However, effective capture and storage of rainfall remains a major challenge for grain and cotton growers in the Northern Region, where dryland crops typically transpire only 20-40% of rainfall.

Research from former GRDC projects suggests that cover crops and increased stubble loads can reduce evaporation and increase infiltration to provide net gains in plant available water (PAW) over traditional fallow periods. Consequently, cover crops may be a key component of improved farming systems; providing increased productivity, enhanced profitability and better sustainability.

The cover crop project focuses on the capture and storage of rainfall by exploring whether cover crops can increase the *net* water accumulation (PAW) in dryland systems, with low ground cover ($< 30\%$) in the Northern Region. Specifically, the project attempts to ascertain

- What is the net water cost to grow cover crops?
- What is the net water gain to subsequent grain crops (fallow and early growth periods)?
- What is the impact on the yield of the grain crops?

2 Description of the research study

2.1 Trial structure and experimental design

A series of eight field trials were conducted across the Australian northern region (i.e. across New South Wales and Queensland) in the 2017/18 and 2018/2019 seasons. Before the grain crop is planted across the entire trial, cover crops are grown and then terminated. Differences in i) the type of cover crop, ii) spray out timing and iii) management form the treatments. Each trial had a different treatment structure which is summarised below:

- Coorangy 2017/18 (southern Queensland)
  - Grain crop: Wheat
  - Treatment structure: 9 treatments x 5 replicate blocks
  - Each treatment consisted of a different combination cover crop (1 treatment is the control), spray-out timing and management practice
  - Experimental design: Randomised block design
- Yelarbon 2017/18 (southern Queensland)
  - Grain crop: Cotton
  - Treatment structure: 10 treatments x 5 replicate blocks
  - Each treatment consisted of a different cover crop (1 treatment is the control) x spray-out timing combination
  - Experimental design: Randomised block design
- Canowindra and Parkes - Short Fallow 2018/19 (central NSW)
  - Grain crop: Wheat
  - Treatment structure: 13 treatments x 4 replicate blocks
  - Treatments consist of 4 cover crops x 3 spray-out timings + a control

  - Experimental design: Randomised block design
- Yanco 2017/18 or 2018/19 (southern NSW)
  - Grain crop: Cotton
  - Treatment structure: 10 treatments consisting of difference farming systems
  - Experimental design: Split plot design
- Undabri 2018/19 (southern Queensland)
  - Grain crop: Wheat and Cotton
  - Treatment structure: 12 treatments (including a control) consisting of different combinations of cover crop, spray out timing and management practice
  - Experimental design: Randomised block design
- Murra Cul Cul 2018/19 (southern Queensland)
  - Grain crop: Wheat
  - Treatment structure: 10 treatments (including a control) consisting of different combinations of cover crop, spray out timing and management practice
  - Experimental design: Randomised block design
- Nareen 2018/19 (southern Queensland)
  - Grain crop: Wheat
  - Treatment structure: 12 treatments (including a control) consisting of different combinations of cover crop, spray out timing and management practice
  - Experimental design: Randomised block design

2.2 Measurements

For each of the trials, the following response variables were analysed where measured:

- Volumetric soil moisture difference (mm) via the neutron probes
- Volumetric soil moisture difference (mm) via soil samples

2.2 Measurements

- Ground cover %
- Grain yield of the subsequent grain crop (where recorded).

Since the treatments (i.e. combinations of cover crops and spray out timing) applied within trials were quite different, it is infeasible to attempt to compare treatments across trials. Hence each trial was analysed separately.

2.2.1 Volumetric soil moisture difference (mm) via the neutron probes

Neutron probe (NMM) readings were made at each depth (0-30cm, 30-60cm, 60-90cm, 90-120cm and 120-150cm) and at regular time intervals which can then be used to approximate PAW.

Simple linear regressions were used to calibrate the neutron probe readings to estimate volumetric soil moisture at each depth using the initial neutron probe readings and gravimetric soil moisture readings from the soil samples just after planting of the cover crop. These were then used to estimate the difference in volumetric soil moisture from just after sowing the cover crop to just prior to planting of the grain crop. The difference in volumetric soil moisture is equivalent to the difference in PAW since the crop lower limit is cancelled out when calculating the difference in volumetric soil moisture.

At some trials, soil samples and bagging were also completed just prior to the planting of the grain crop as another approximation to volumetric soil moisture/PAW.

As the key research question revolves around net water gain to the subsequent grain crop, the analysis of the NMM readings and soil samples presented in this report focus on the readings made just prior to sowing the subsequent grain crop. Moreover, since the key interest is to determine how much water has increased/decreased in each plot, the response variable that was used in the analysis was the difference in the NMM readings from just prior to planting of the grain crop to just prior to or after planting the cover crop.

An analysis of the difference in total volumetric soil moisture (i.e. total PAW, the sum of the differences at all depths) is also provided at the request of agricultural researchers, although this analysis should be taken with a grain of salt due to bias from:

1. The conversion to total PAW could be disproportionate (and thus have unequal weighting) for each depth, resulting in an inaccurate comparison of treatment levels.
2. There could be some minor overlap between the NMM readings at each depth as the intervals summed together are at 30cm increments. However, the neutron probes are known to detect neutrons up to 20cm away in each directions (i.e. a total of 40cm away from the neutron probe location).

2.2 Measurements

2.2.2 Ground cover

Ground cover was also calculated for each trial at regular time intervals during the growth of the cover crops.

2.2.3 Grain yield

Grain yield of the subsequent grain crop (yield, cotton) was also measured such that the grain crop was planted across the entire trial and grain yield was measured within each individual plot to compare differences due to the planting of different cover crops with a fallow period (i.e. control) prior to planting of the grain crop.

2.3 Statistical methods

All analyses were performed in a linear mixed model framework using residual maximum likelihood (REML) (Patterson & Thompson, 1971) via the `ASReml-R` package (Butler *et al.*, 2017) in the `R` software environment (R Core Team, 2019). All treatments are fitted as fixed effects and hence predictions from the model are empirical best linear unbiased estimates (eBLUEs). Design terms were fitted as random in all trials. Transformations of the response variable were imposed in some analyses to meet the assumption of homogeneity of variance. Spatial field trends were adjusted for using the methods of Gilmour *et al.* (1997), although spatial adjustments were only required in a couple of instances as most of the trials had a reasonably small number of plots.

A number of variance structures were considered to capture the covariance/correlation across times (ground cover and biomass analyses) or depths (neutron probe or soil moisture analyses). These include, in increasingly complexity:

1. Identity matrix (`id`)
2. Heterogeneous residual variance (`idh`)
3. Heterogeneous correlation (`corh`)
4. Autoregressive heterogeneous correlation (`ar1h`, depths only)
5. Ante-dependence of order k (`ante,k`)
6. Unstructured (`us`)

For more information on these variance structures, see the corresponding chapter in the `ASReml-R` package manual (Butler *et al.*, 2017). Within each analysis, the most parsimonious variance structure was selected using the residual maximum likelihood ratio test (REMLRT).

Significance testing of treatment factors was performed using Wald tests with an approximate F-statistic (Kenward & Roger, 1997). Fishers least significant difference (LSD) testing was performed to compare treatment levels within a factor. Outlier checks were performed and advice provided from agronomists regarding if each outlier remains in the final analysis. Significance testing was completed at the 5% level for grain yield, ground cover and biomass. For volumetric water measurements which are expected to be more noisy, LSD values are provided at both the 5 and 10% levels.

3 Results

3.1 Coorangy 2017/18

3.1.1 Analysis - NMM Reading (24/04/18)

This analysis focused on the difference between the neutron probe readings just after planting the cover crops (27/10/2017) on each plot and the neutron probe readings (NMM) just prior to planting of wheat on all plots (24/04/2018). There was no significant difference between the cover crop treatments at all depths as there was a large amount of noise between the five replicates which could not be adjusted for by the replicate block or other spatial trends for each treatment. Predictions at each depth are shown in Figure 3.1 and 3.2 which have been converted to change in volumetric soil moisture (mm) after calibrating the NMM readings with the soil sample measurements.

3.1.2 Analysis - Ground cover

The analysis of ground cover % was performed across six different dates. A logit transformation was used in the analysis of ground cover to meet the assumption of homogeneity of variance. An ante-dependence variance-covariance structure of order 1 was determined to be the most parsimonious variance structure to capture correlations across time. There was a significant interaction effect between time and cover crop with the control having the lowest ground cover at all times and late millet having the most ground cover from December 2017 onwards. The back-transformed predictions can be seen in Figure 3.3.

3.1.3 Analysis - Grain yield

In the analysis of grain yield, there was a significant overall treatment effect. LSD testing determined that the control had significantly lower grain yield than all other cover crop treatments. Late millet had a significantly larger grain yield than all other treatments except for the cover crop sorghum with a mid spray out timing. Predictions for all the cover crop treatments can be seen in Figure 3.4.

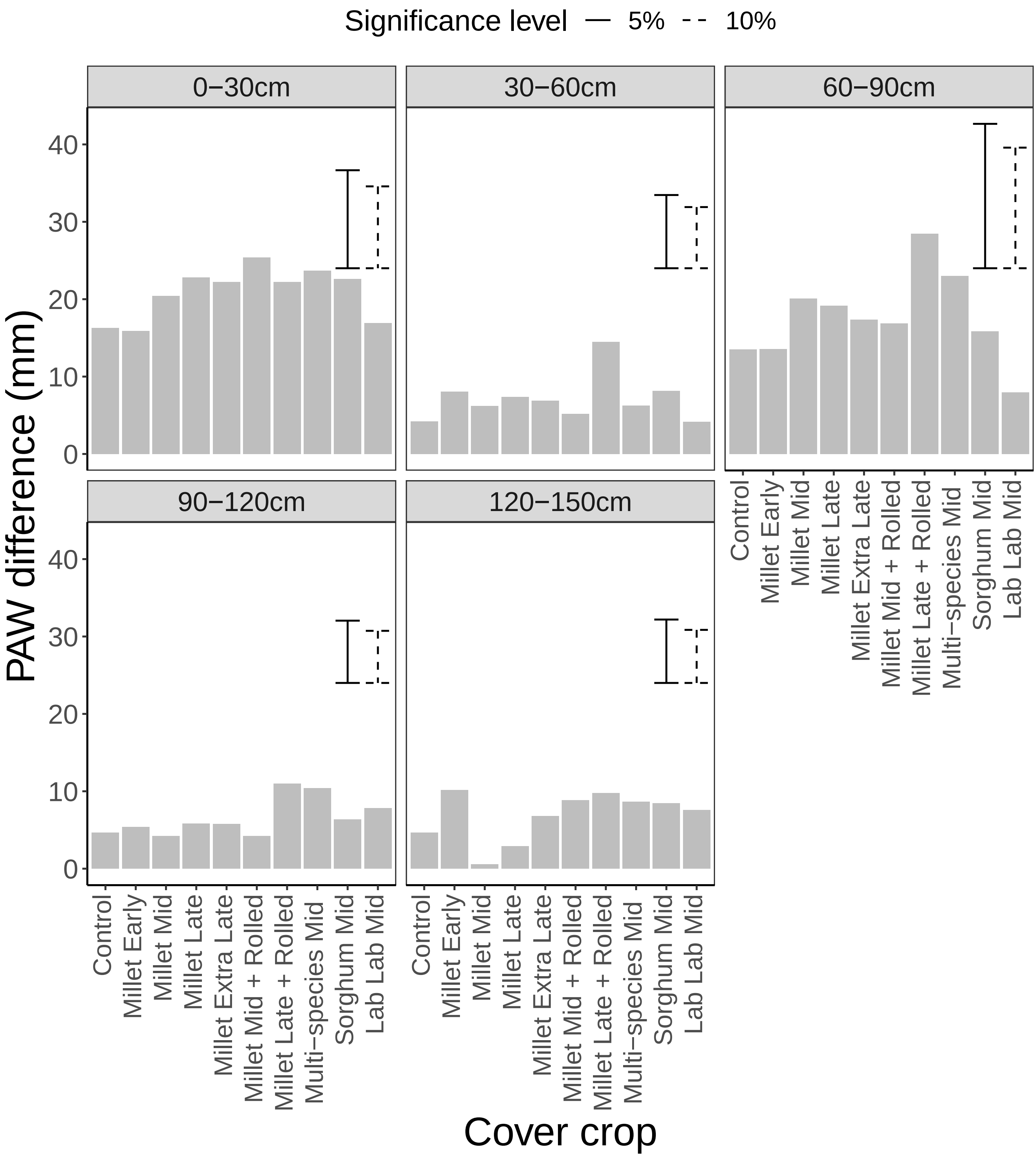

Figure 3.1: Predictions of the difference in soil water at Coorangy from just after planting of the cover crops to just prior to planting of wheat (27/10/2017 - 24/04/2018). The vertical error bars denote the LSD values for each depth at the 5% and 10% significance levels. There was no significant treatment effect at all depths ($P > 0.05$).

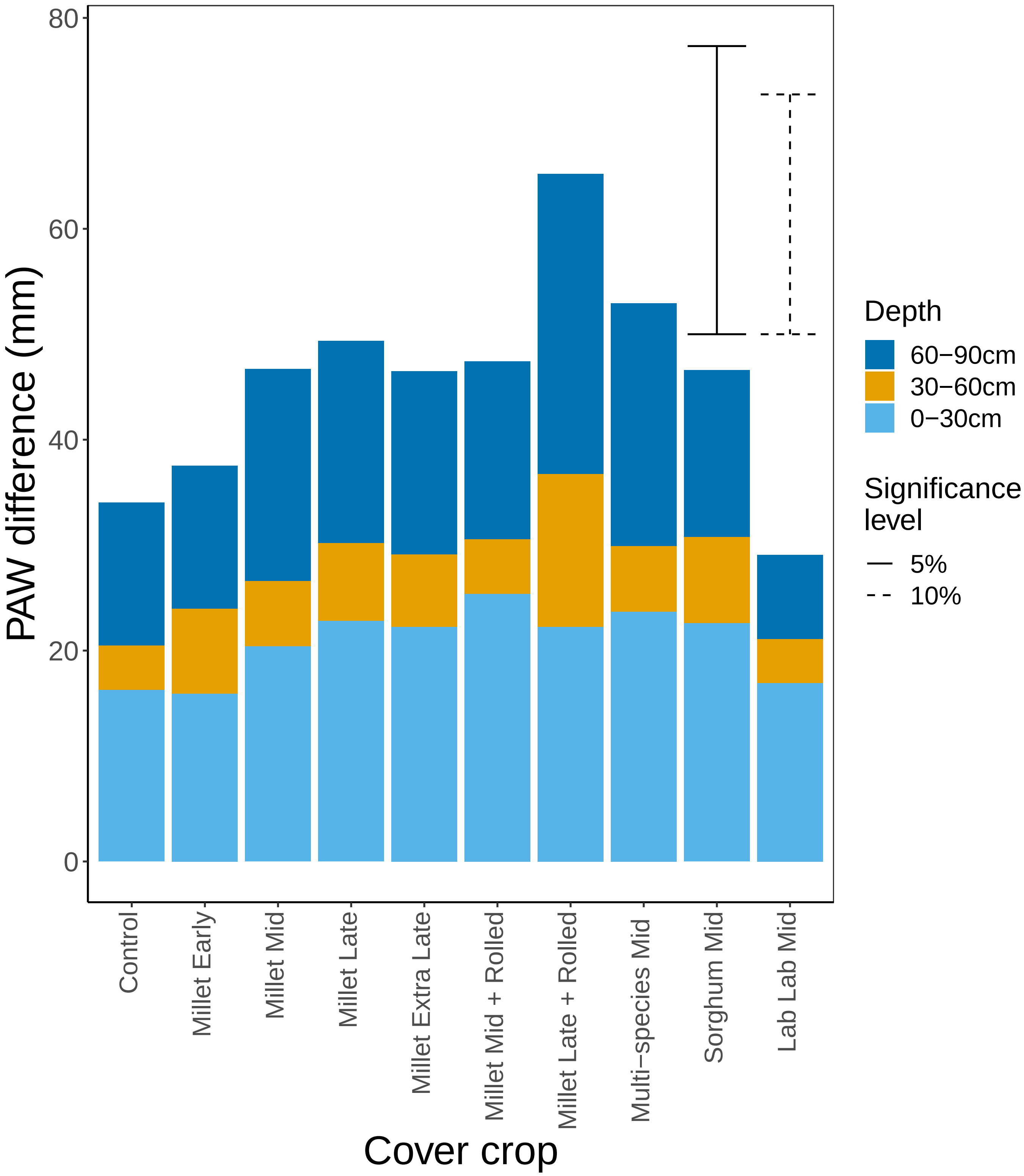

Figure 3.2: Stacked bar chart of the predictions of the difference in soil water (0-90cm depth) from just after planting of the cover crop to just prior to planting of wheat at Coorangy (27/10/2017 - 24/04/2018). There was no significant treatment effect ($P = 0.178$). The LSD value is 27.3 and 22.7 at the 5% and 10% significant levels respectively.

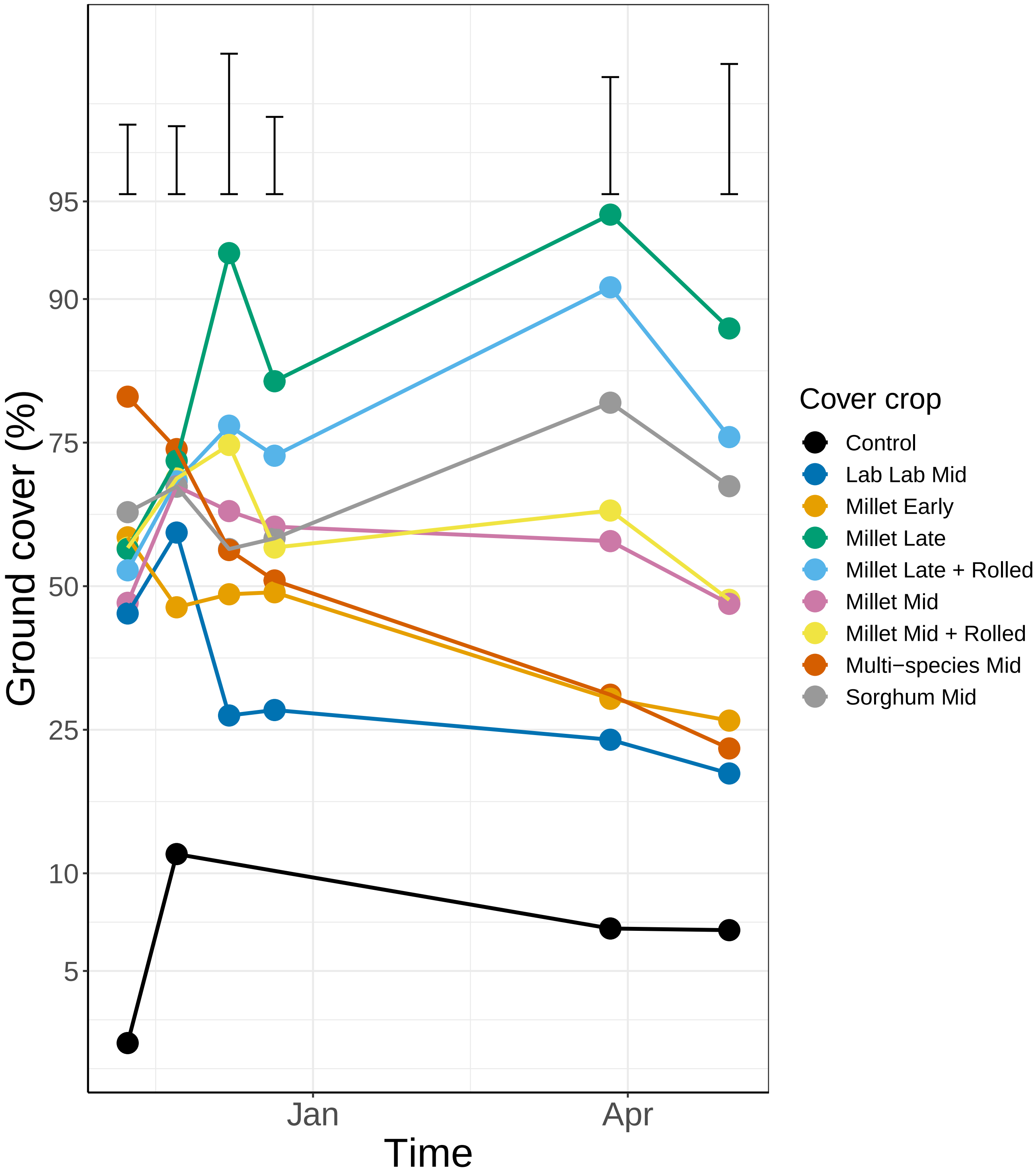

Figure 3.3: Back-transformed predictions of ground cover at Coorangy for each treatment at a range of dates from November 2017 to April 2018. There was a significant interaction between time and cover crop ($P < 0.1$). The vertical error bars denote the LSD value for each date that measurements were recorded.

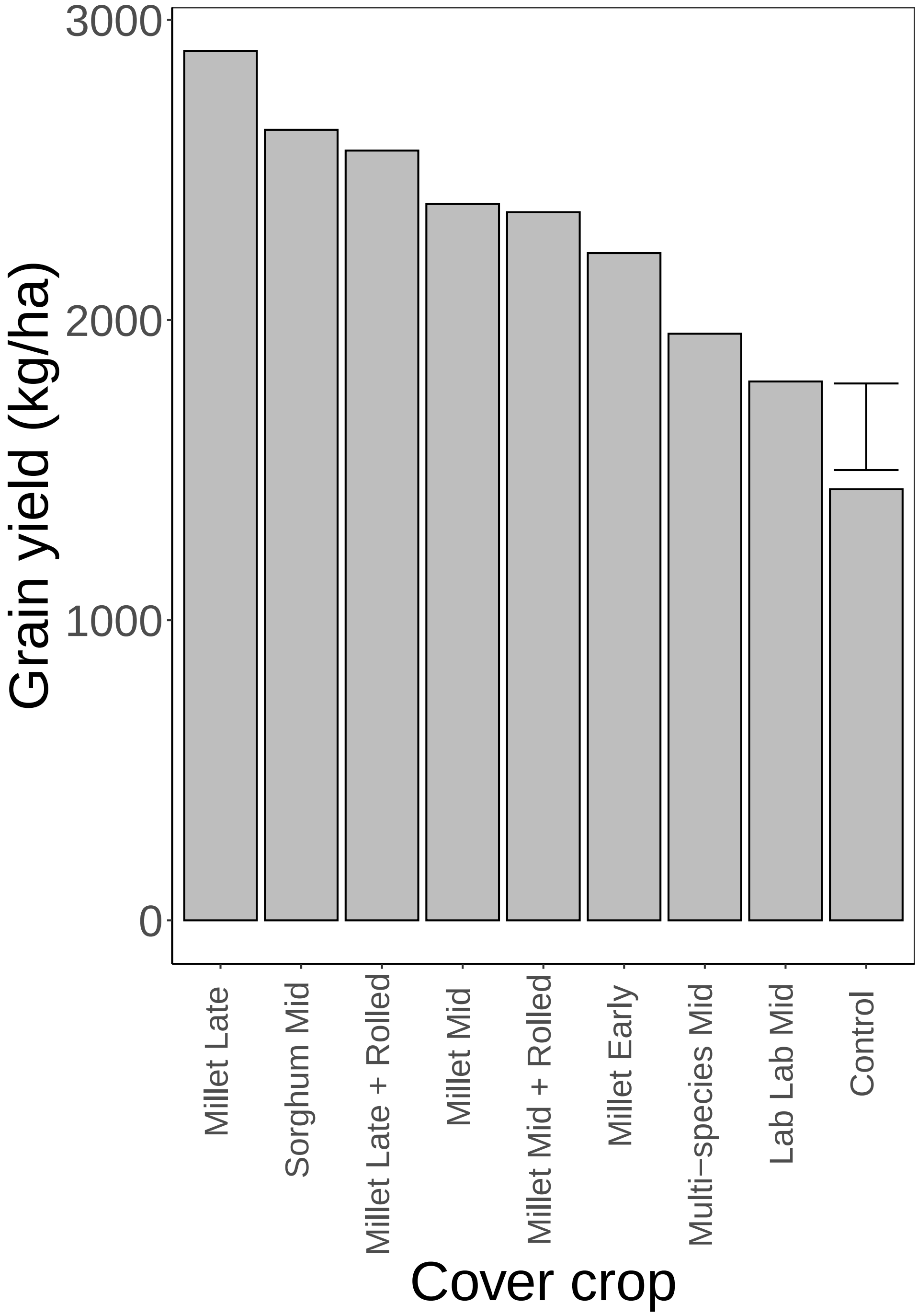

Figure 3.4: Wheat yield predictions for each treatment at Coorangy. The vertical error bar denotes the LSD value (LSD = 289kg/ha).

3.2 Yelarbon 2017/18

In this trial, there was a hole in an irrigation line causing flooding in plots 7-10, 17-19, 27-30, 36-40, 46-50 and plot 20 to be dug up. In an attempt to reduce the confounding between treatment effects and a flooding effect, a `flooded` indicator was included as a co-variate (flooded or not flooded) whenever statistically significant to account for treatment differences caused by the flooding.

3.2.1 Analysis - NMM Reading (15/11/2017)

This analysis focused on the difference between the neutron probe (NMM) readings just after planting of the cover crop (23/07/2017) and the NMM readings just prior to planting of cotton on all plots (15/11/2017). There was a significant difference between the cover crop treatments at all depths except for 0-30cm, with the cereal harvest having a significantly lower volumetric soil moisture than all other treatments. The early spray out was the only treatment to have a higher total volumetric soil moisture than the control. However, there was no significant difference to the control at all depths. Predictions at each depth can be seen in Figure 3.5 and across all depths in Figure 3.6.

3.2.2 Analysis - Ground cover

No transformation was required for the analysis of ground cover at Yelarbon. A heterogeneous `ar1` variance structure was included to capture correlations between the treatments across time. There was a significant interaction effect between the cover crop treatment and time. Predictions from the model can be seen in Figure 3.7.

3.2.3 Analysis - Biomass (cover crop)

In addition to ground cover, an analysis was also performed to investigate how biomass of the winter cereals varied across time. A heterogeneous `ar1` variance structure was included to capture correlations between the treatments in biomass across time. There was a significant cover crop by time interaction effect. The predictions can be seen in Figure 3.8.

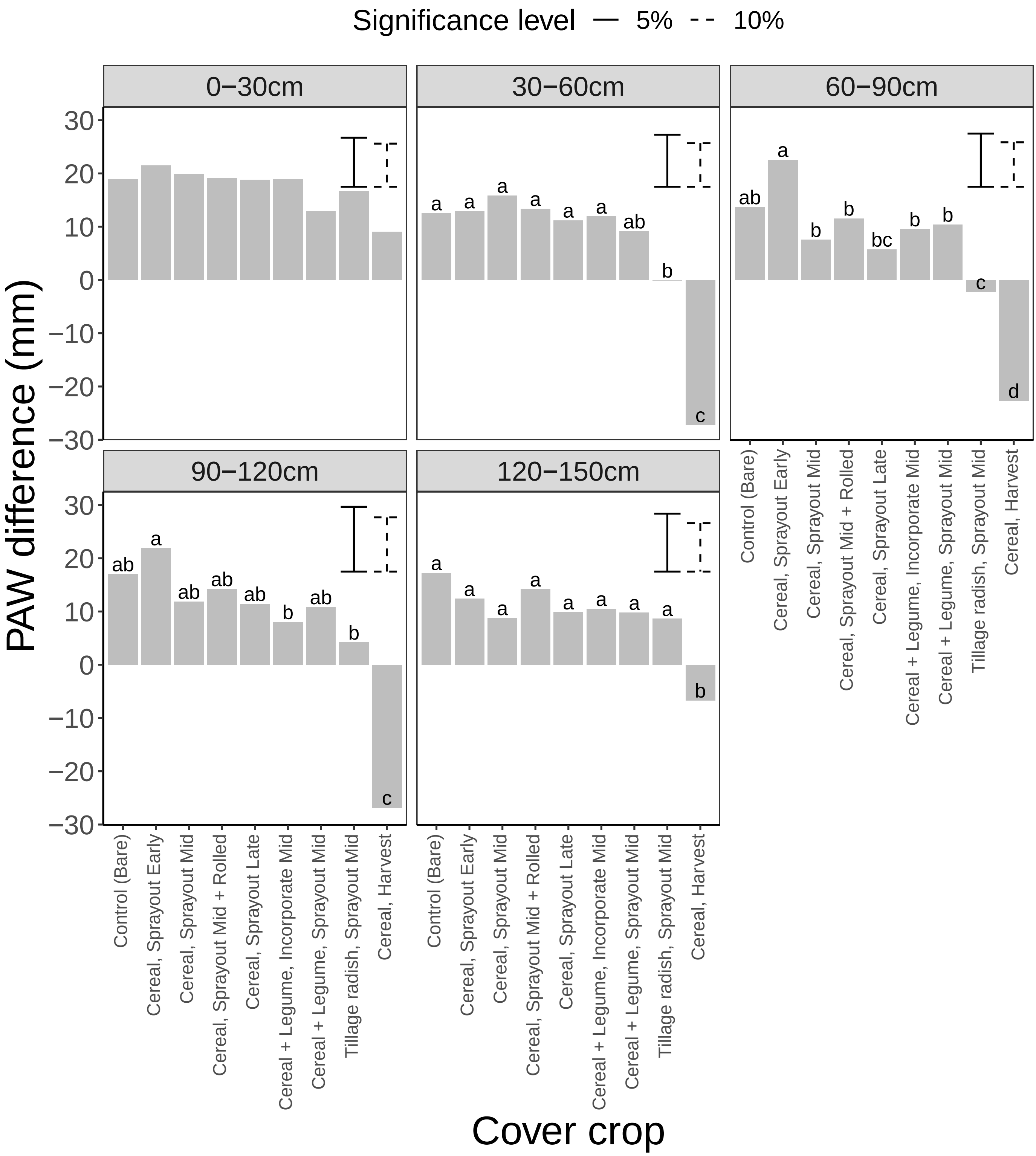

Figure 3.5: Predictions of the difference in volumtetric soil mositure at Yelarbon from just after planting of the cover crop and just prior to planting of the cover crops (23/07/17 - 15/11/2017) as estimated based on the neutron probe readings. The vertical bar denotes the LSD value at each depth at the 5% and 10% significance levels. The LSD lettering is at the 5% significance level

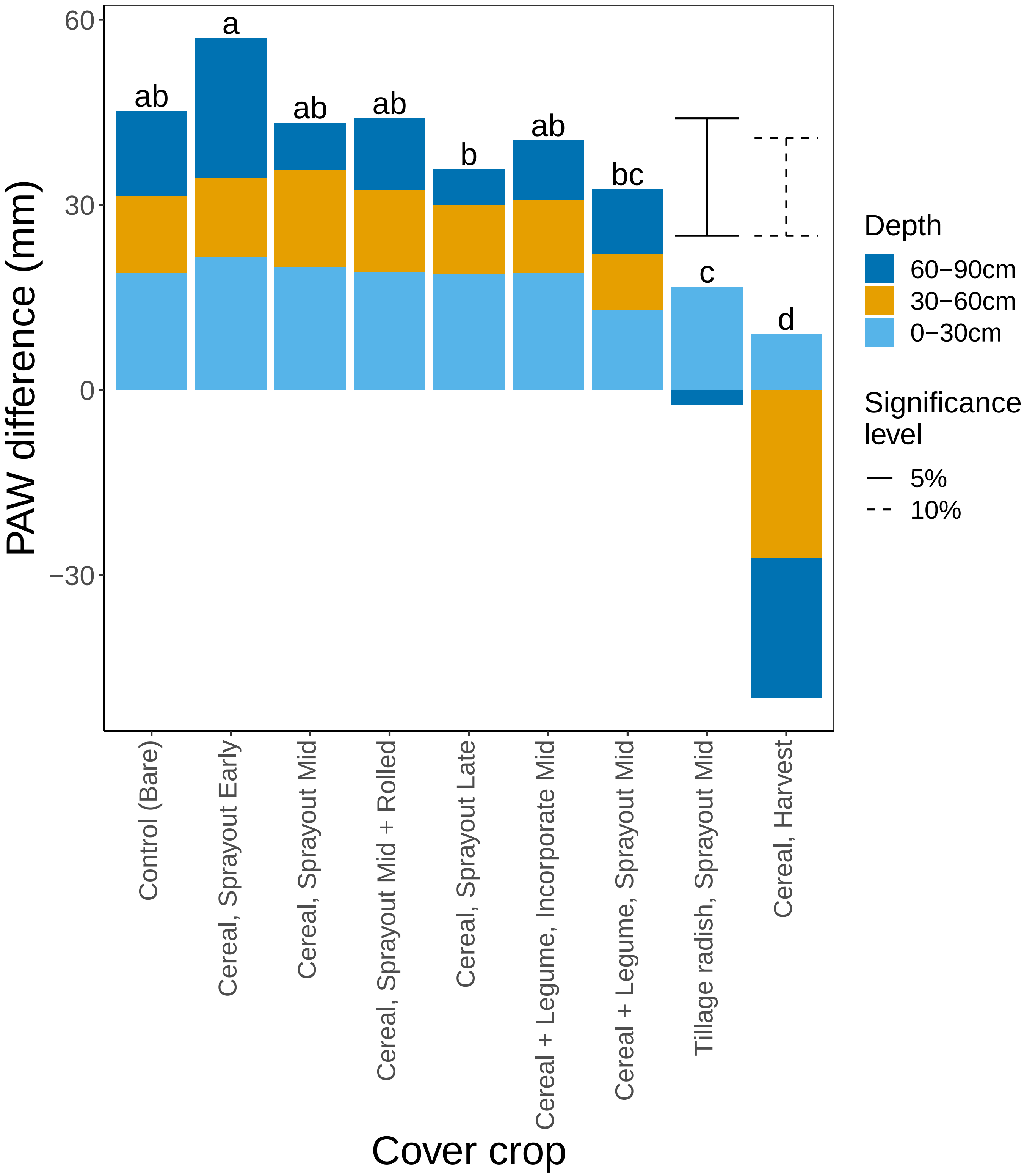

Figure 3.6: Stacked bar chart containing the predictions of the difference in volumtetric soil mositure (0-90cm depth) from just prior to planting of the cover crops to just prior to planting of cotton (23/07/17 - 15/11/2017) as estimated based on the neutron probe readings at Yelarbon ($P < 0.001$). THe LSD value is 19.0 and 15.9mm at the 5% and 10% significance level respectively. The LSD lettering is at the 5% significance level.

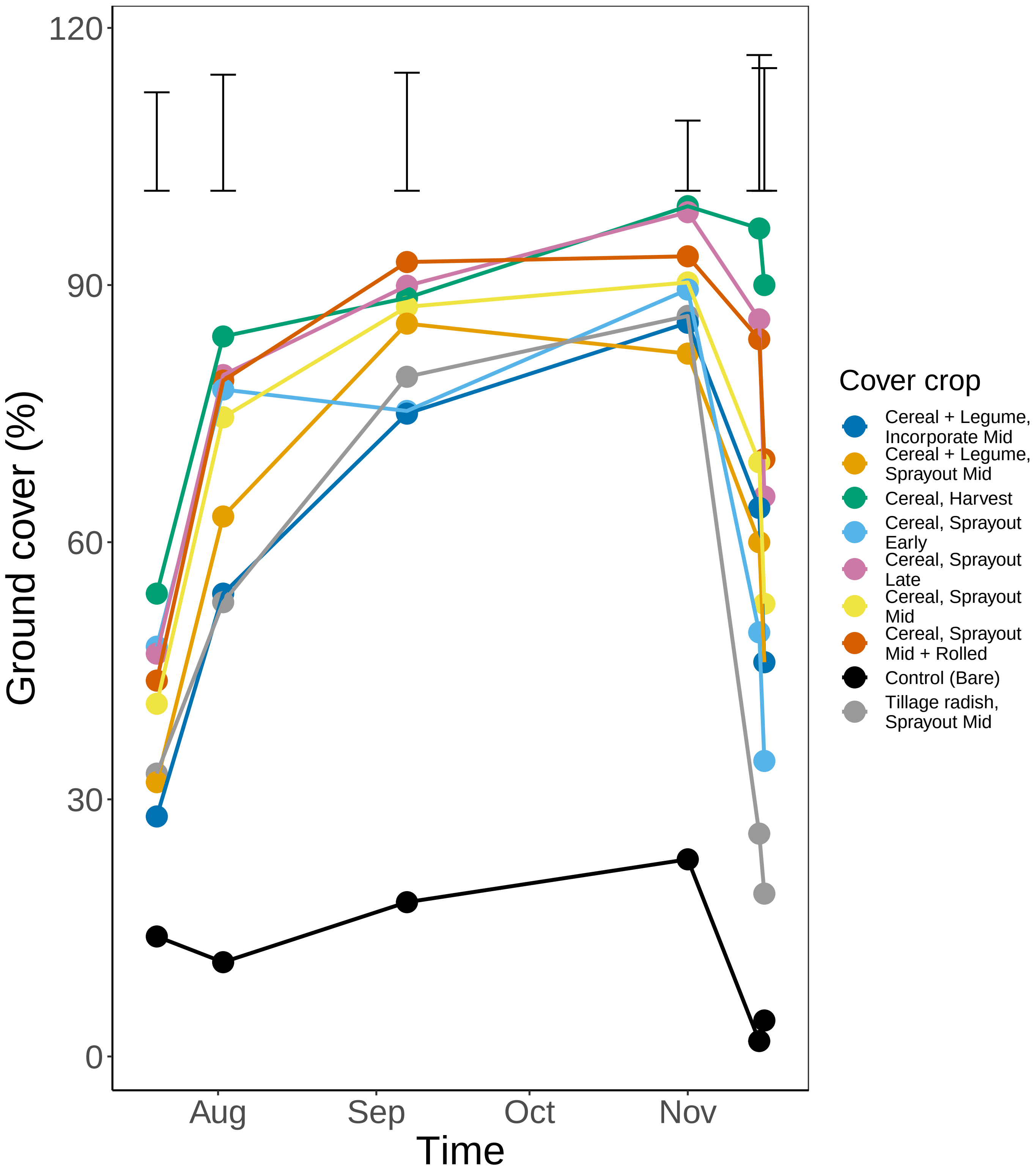

Figure 3.7: Predictions of ground cover at Yelarbon for each cover crop across time from July 2017 to November 2017. There was a significant time by cover crop treatment interaction effect. The vertical error bars represents the LSD value at each time point that ground cover was recorded.

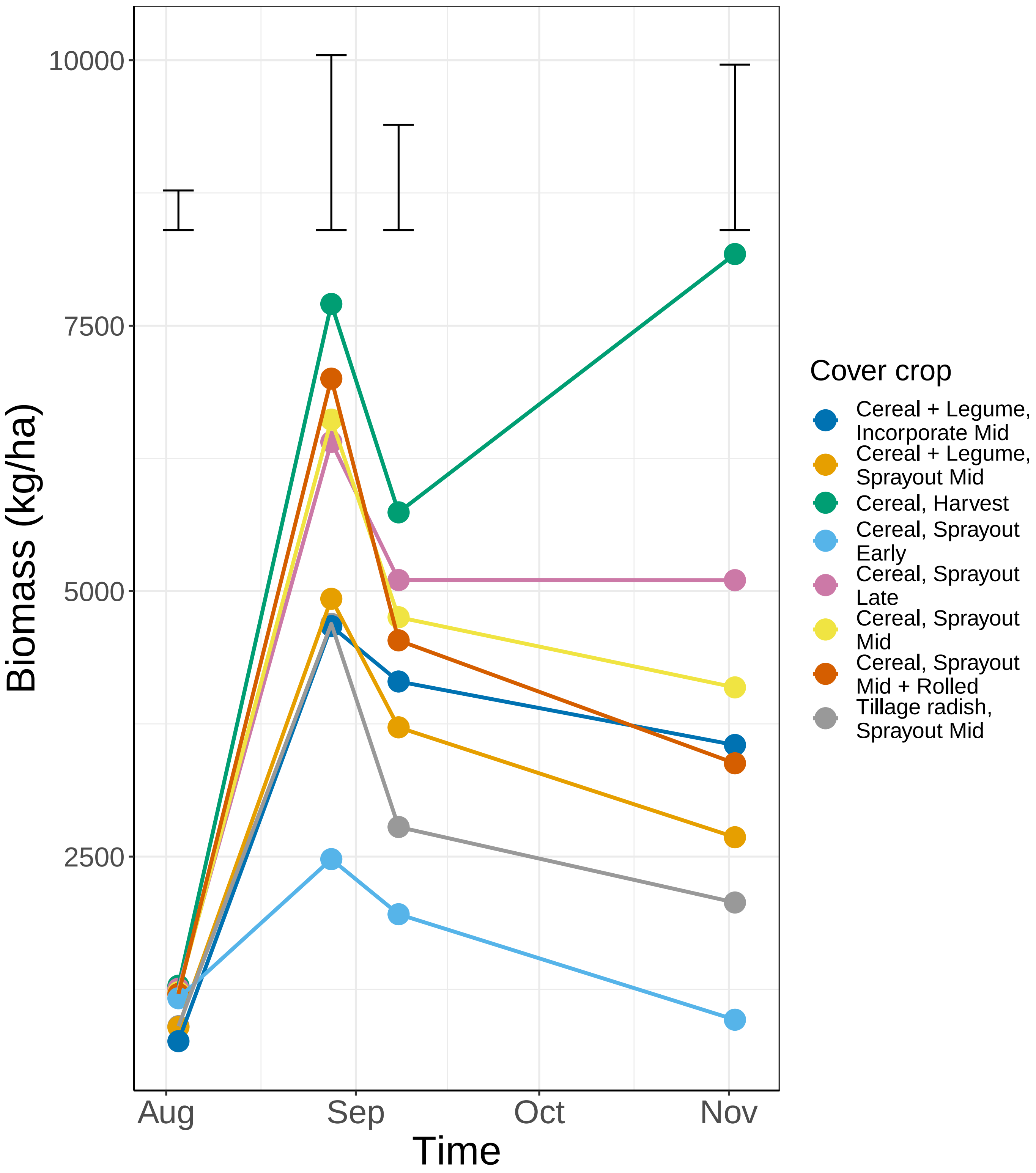

Figure 3.8: Cover crop biomass predictions at Yelarbon for each cover crop across time from August 2017 to November 2017. There was a significant time by cover crop treatment interaction effect. The vertical error bars represents the LSD value at each time point that biomass was recorded.

3.3 Canowindra short fallow - 2018/19

3.3.1 Analysis - Grain yield

In the analysis of wheat yield for all 13 treatments, there was a significant treatment effect ($P < 0.001$) with the weed free fallow (i.e. the control) having a significantly higher grain yield than all other treatments except for the summer weed and feedex sorghum cover crops with an early spray out timing. When partitioning out the control, there was no significant interaction effect between cover crop and spray out timing. There was a significant cover crop main effect ($P < 0.001$) and a significant spray out timing main effect ($P < 0.001$) with the earlier spray out timings resulting in significantly higher grain yield than the later. Yield predictions for the cover crop and spray out timing main effect can be seen in Figures 3.9 and 3.10 respectively.

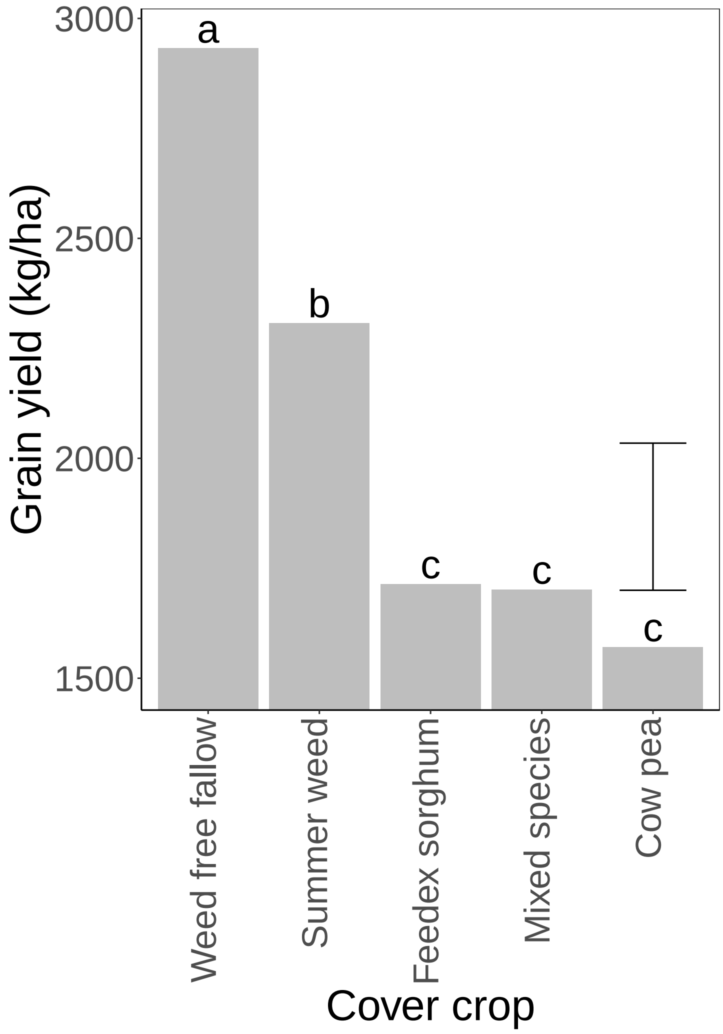

Figure 3.9: Yield predictions of the wheat grain crop for the cover crop main effect at the Canowindra short fallow trial. The vertical error bar denotes the LSD value (LSD = 334kg/ha).

3.3 Canowindra short fallow - 2018/19

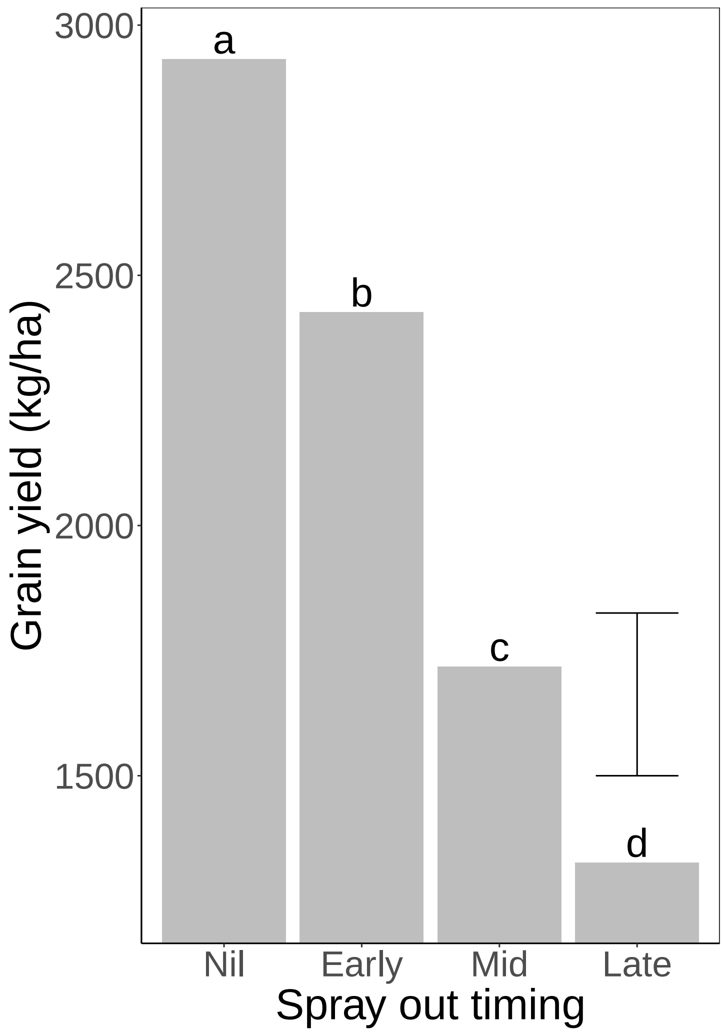

Figure 3.10: Yield predictions of the wheat grain crop for the spray out timing main effect at the Canowindra short fallow trial. The vertical error bar denotes the LSD value (LSD = 325kg/ha).

3.4 Parkes short fallow - 2018/19

3.4.1 Analysis - NMM Reading (15/04/2019)

The Parkes short fallow trial consisted of three spray out timings (early, mid, late) by four cover crops plus a control, for a total of 13 treatments. The analysis took the difference in the NMM readings from the time of planting of the cover crop (23/12/2018) until just prior to sowing of wheat (15/04/2019). To capture covariance/correlation across depths, a heterogeneous ar1 model was fit as the most parsimonious variance structure. There was also a random row effect included at depth 120-150cm to capture extraneous field trend in the row direction.

The analysis of the 13 treatments resulted in a significant treatment effect at all depths except for depth 30-60cm which was approaching significance ($P = 0.040, 0.053, < 0.001, < 0.001, < 0.001$ at depths 0-30, 30-60, 60-90, 90-120 and 120-150cm respectively). Predictions for the difference in NMM readings can be seen in Figure 3.11.

An additional analysis was done to explore the interaction effect between spray out timing and cover crop by partitioning out the weed free fallow (i.e. the control). In this analysis, there was no significant cover crop x spray out timing interaction effect except at depth 120-150cm ($P < 0.001$). There was also no significant spray out timing main effect except at depth 90-120cm ($P = 0.027$). There was a significant cover crop main effect at all depths ($P = 0.004, 0.004, < 0.001, < 0.001, 0.001$ at depths 0-30, 30-60, 60-90, 90-120 and 120-150cm respectively). The predictions for the cover crop main effect can be seen in Figure 3.12.

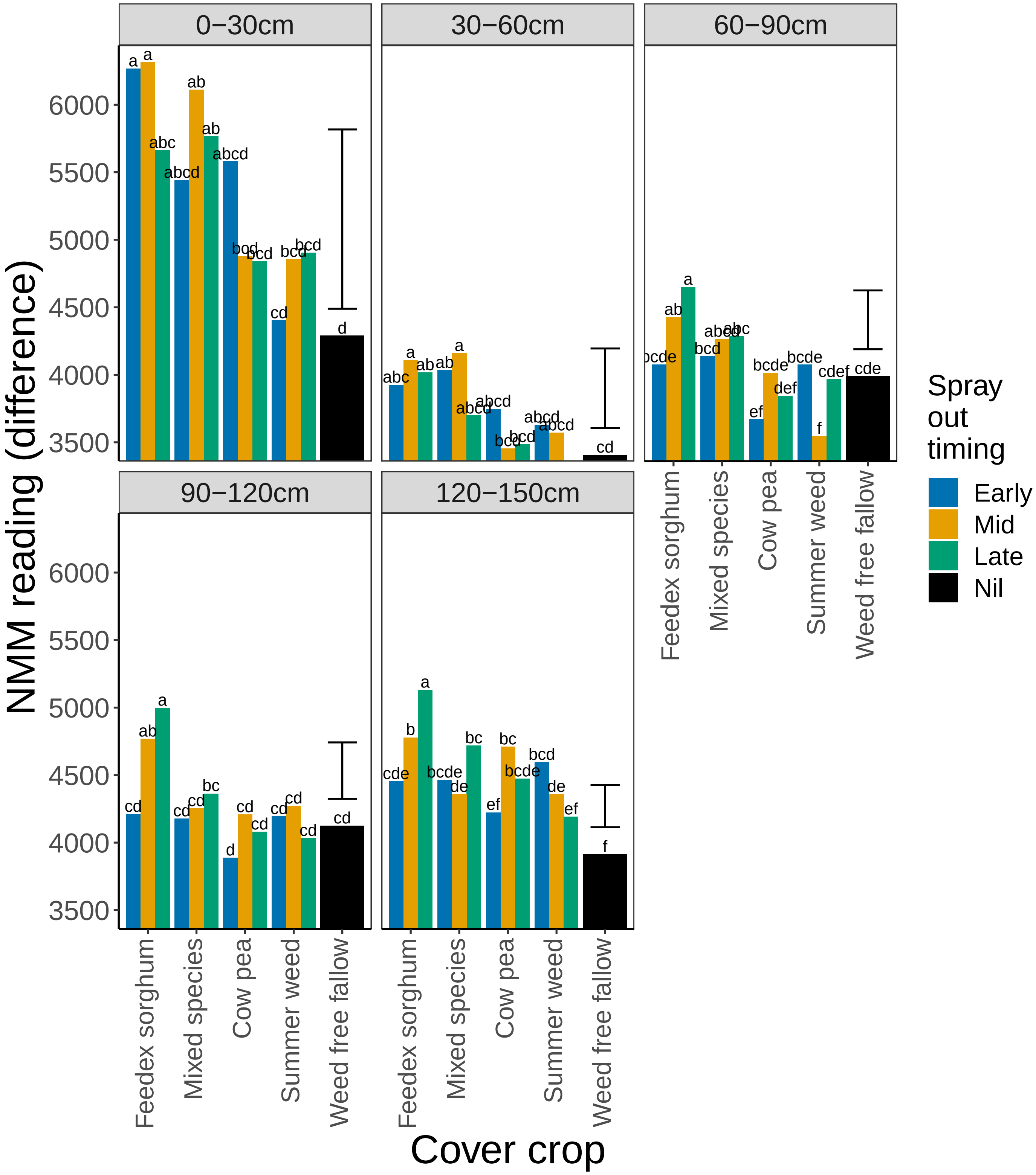

Figure 3.11: Predictions of the change in NMM readings readings at the Parkes short fallow trial (23/12/2018 - 15/04/2019) for the cover crop x spray out timing interaction effect at each depth separately. The vertical error bars denote the LSD value for each depth.

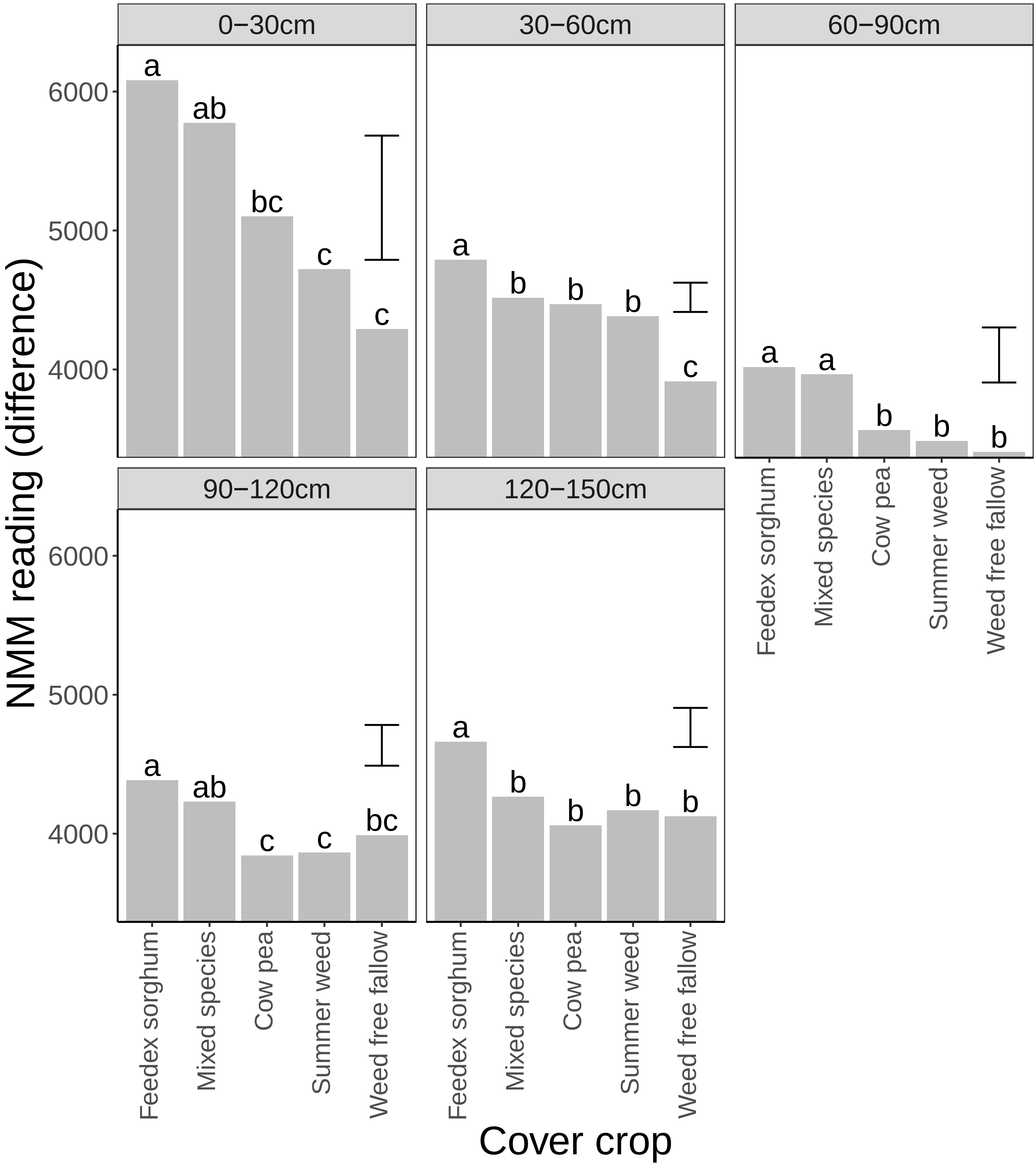

Figure 3.12: Predictions of the change in NMM readings at the Parkes short fallow trial (23/12/2018 - 15/04/2019) for the cover crop main effect at each depth separately. The vertical error bars denote the LSD value for each depth.

3.5 Yanco - 2018/19

The trial at Yanco is different to all of the other trials in the project since the treatments are comprised of different farming systems (i.e. rotations) as opposed to different cover crops. The research question at this trial is to determine whether the different rotations can reduce water evaporation and increase infiltration.

The trial consisted of 10 different farming system treatments such that a different crop was planted in i) winter 2017 ii) summer 2017/18 and iii) winter 2018. In summer 2018/19, cotton was planted in all plots and the volumetric soil moisture within each plot was compared using neutron probes to approximate VSM.

The statistical analysis of the neutron probe data was performed at three dates: i) just prior to sowing of cotton (25/10/2018), during the key vegetative stage (10/01/2019) and just prior to harvest (04/03/2019). As with the other trials, an analysis was performed for each depth separately, with a variance structure fitted across depths. The analysis was performed using the count ratios since this is easier to convert to approximate VSM.

Table 3.1: Summary of the farming system treatments from the Yanco trial.

Treatment	Crop (winter 17)	Crop (summer 17-18)	Crop (winter 18)	Crop (summer 18-19)
Winter_Oat/Vetch	Oat/Vetch	Fallow	Fallow	Cotton
Winter_Barley	Barley	Fallow	Fallow	Cotton
Winter_Radish	Radish	Fallow	Fallow	Cotton
C4-Sum_Radish	Radish	Sorghum	Fallow	Cotton
C4-Sum_Barley	Barley	Sorghum	Fallow	Cotton
C4-Sum_Oat/Vetch	Oat/Vetch	Sorghum	Fallow	Cotton
Full-Cotton_Oat/Vetch	Oat/Vetch	Fallow	Radish	Cotton
Full-Cotton_Barley	Barley	Cotton	Barley	Cotton
Full-Cotton_Radish	Radish	Cotton	Oat/Vetch	Cotton
Full-Cotton_Control	Fallow	Cotton	Fallow	Cotton

3.5.1 Analysis - NMM Reading (25/10/2018)

The NMM reading on the 25/10/2018 was taken just prior to planting cotton on all plots. There was a significant difference between the farming system treatments at depth = 50-70cm ($P = 0.004$) and 70-110cm ($P = 0.013$) but not at depths 10-30 and 30-50cm. At the deeper depths, the Full-Cotton radish treatment had a significantly lower NMM count ratio than most other treatments. The count ratio predictions are presented in Figure 3.13.

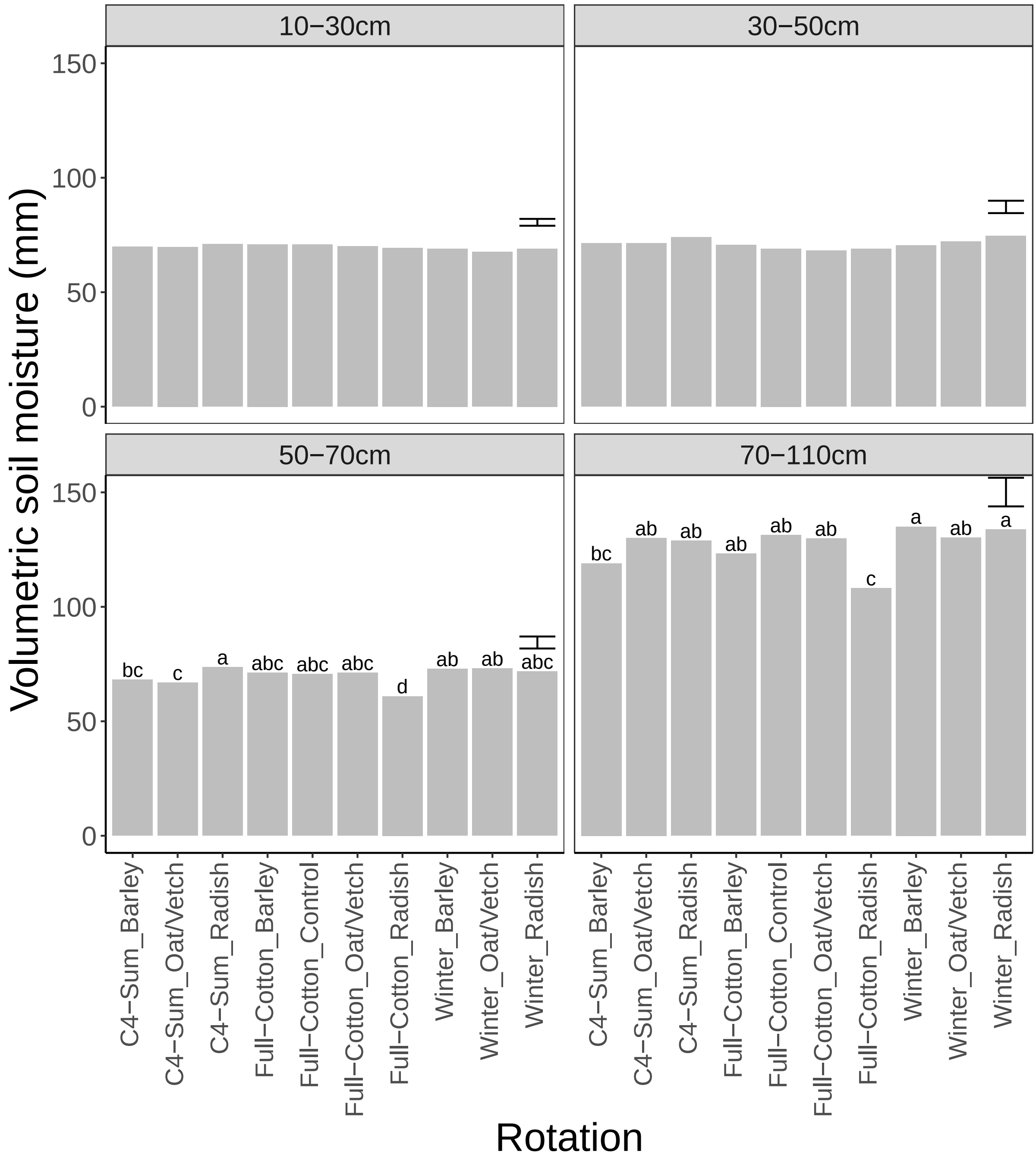

Figure 3.13: Predictions of volumetric soil moisture at Yanco (25/10/2018) from the neutron probes for each farming systems treatment at each depth. The vertical error bars denote the LSD value at each depth.

3.5.2 Analysis - NMM Reading (10/01/2019)

The NMM readings in this analysis were taken approximately at the time of flowering of the cotton crop to determine whether the PAW to the crop has changed since sowing due to differences in the farming system on each plot.

The analysis found that there was no significant difference between the farming system treatments except at depth = 70-110cm ($P = 0.028$). The predictions can be seen in Figure 3.14.

3.5.3 Analysis - NMM Reading (04/03/2019)

The date of the NMM readings is approximately around the time of harvest of cotton. There was no significant difference between the farming system treatments except at depth = 50-70cm ($P < 0.001$). The predictions can be seen in Figure 3.15.

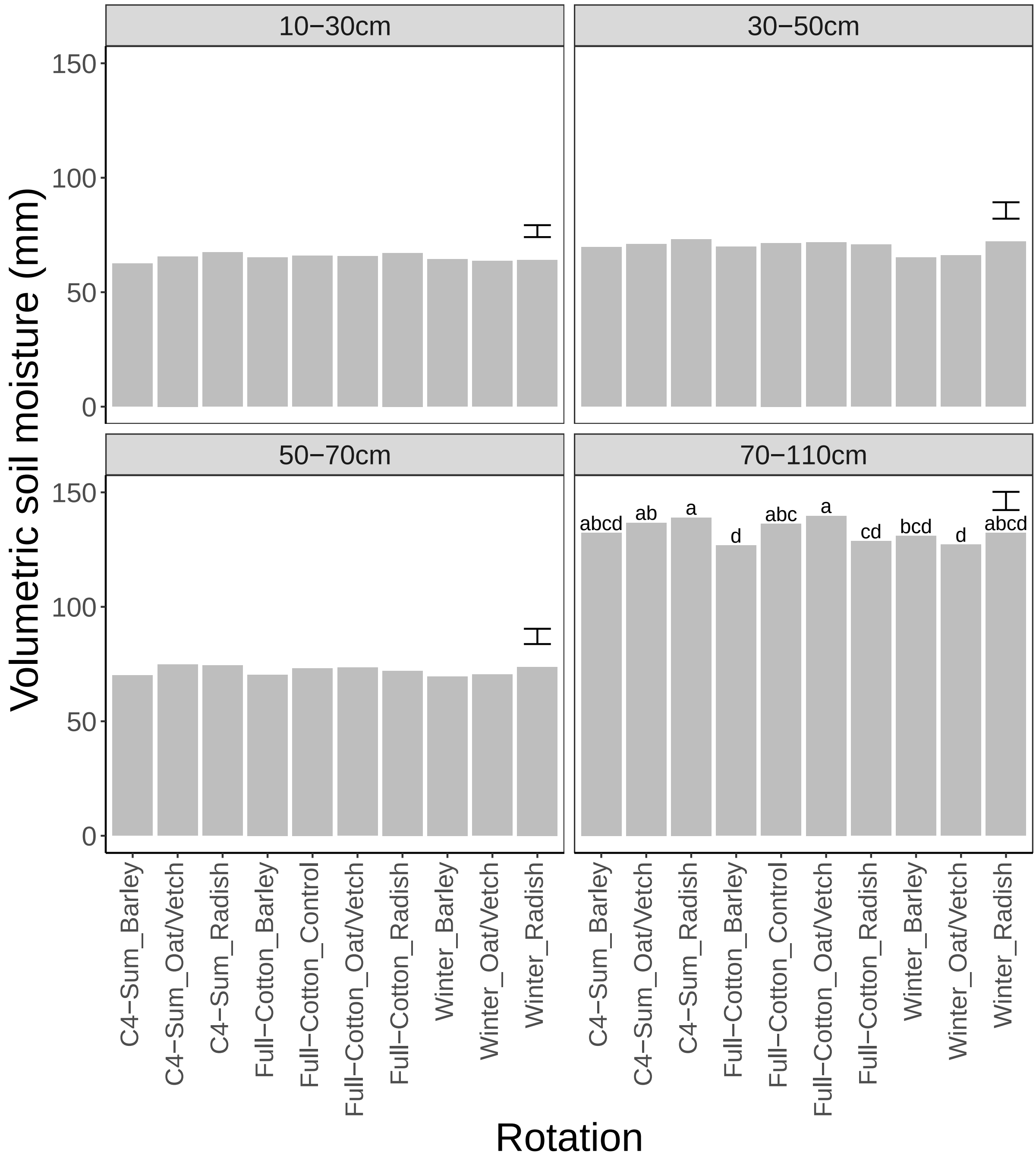

Figure 3.14: Predictions of volumetric soil moisture at Yanco (10/01/2019) from the neutron probes for each farming systems treatment at each depth. The vertical error bars denote the LSD value at each depth.

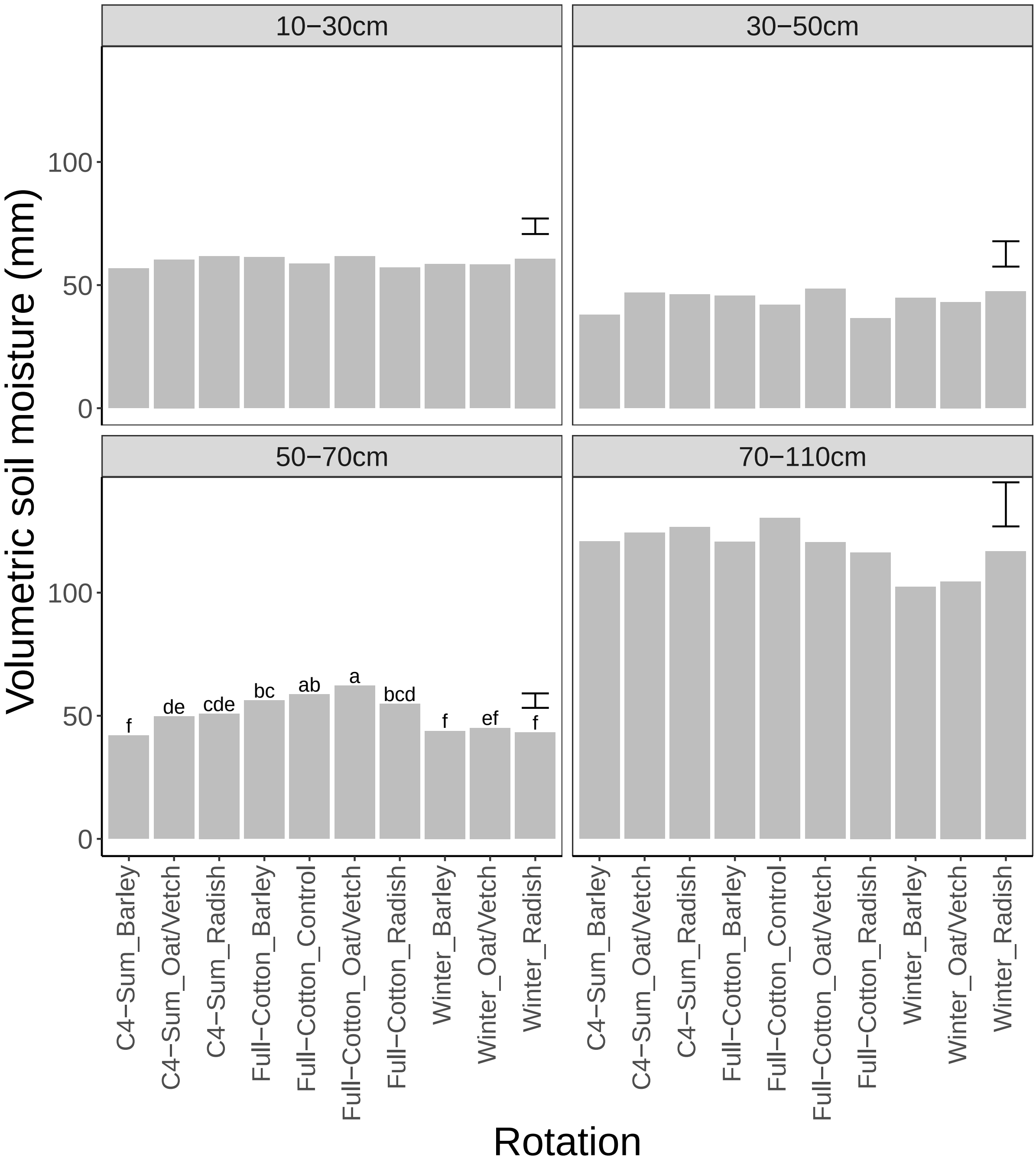

Figure 3.15: Predictions of volumetric soil moisture at Yanco (04/03/2019) from the neutron probes for each farming systems treatment at each depth. The vertical error bars denote the LSD value at each depth.

3.5.4 Total soil moisture across depths

This section summarises the analysis of volumetric soil moisture summed across all depths at sowing (25/10/2018), flowering (10/01/2019) and harvesting (04/03/2019) of cotton. A corh ($\rho = 0.39$) was found to be to most parsimonious residual variance structure. At the 10% significance level, there was a significant difference at sowing ($P < 0.001$), flowering ($P = 0.070$) and harvesting ($P = 0.027$) of cotton (Figure 3.16).

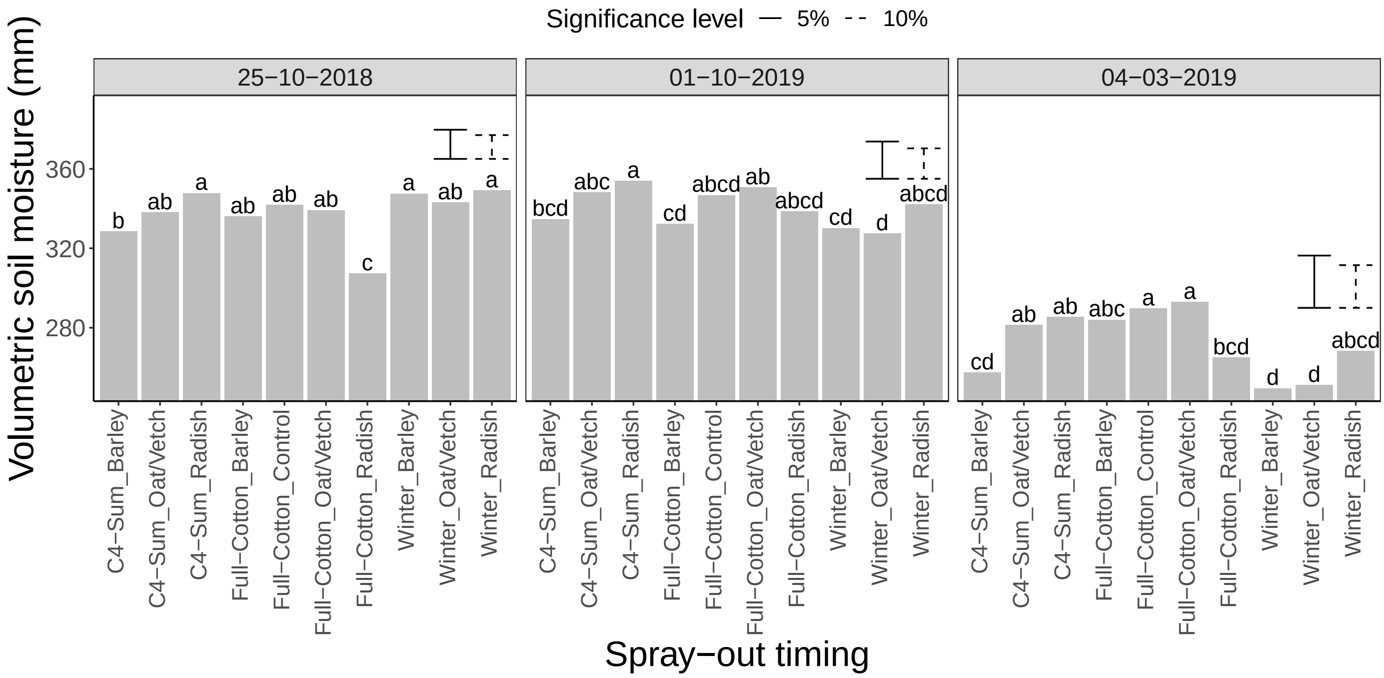

Figure 3.16: Predictions of total volumetric soil moisture summed across all depths at Yanco from the neutron probes for each rotation at cotton i)sowing ii)flowering and iii) harvesting. The vertical error bars denote the LSD values at the 5% and 10% significance levels. LSD lettering is at the 5% significance level.

3.6 Yanco 2019/20

On the 7th June 2019, Barley was planted as a cover crop on each plot from the Yanco cover crop trial. Each main-plot (defined as a set of three adjacent plots) was randomly allocated to receive either an early (GS31, sprayed 7th August 2019), mid (GS39, sprayed 3rd September 2019) or late (GS65, sprayed 30th September 2019) spray-out timing. In addition to this, there was a single plot within each rep that was randomly allocated to receive no spray-out timing (i.e. the control). The experimental unit is therefore a main-plot for the early, mid and late spray-out timing and a single plot for the control. The observational unit is the individual plot for all treatments. The experimental design was a randomised block design that was latinised with respect to the previously allocated farming system treatments to minimise any potential confounding effects with the farming systems trial performed previously on the same patch of land.

3.6.1 Analysis - NMM Reading (08/11/2019)

The 8th November lines up with when the cotton establishment began. The NMM readings on the 8th November 2019 indicate that the plots with a late spray-out timing had significantly lower water than the early and mid spray-out timing at depths 55-65cm, 65-80cm and 80-100cm (Figure 3.17). There was no significant difference between the spray-out timings at all other depths. There was no significant difference between the spray-out timings and the control at all depths.

3.6.2 Analysis - NMM Reading (17/12/2019)

The 17th December 2019 is the approximately when squaring began for cotton. The NMM readings on the 17th December 2019 indicate that there was no significant difference between the spray-out treatments at all depths (Figure 3.18).

3.6.3 Analysis - NMM Reading (13/01/2019)

The 13th January 2019 is approximately when flowering occurred for cotton. The NMM readings on the 13th January 2019 indicate that the control and early spray-out timing had significantly lower VSM than both the mid and late spray-out timing at depths 0-25cm, 25-35cm and 35-45cm (Figure 3.19). There was no significant different between the spray-out treatments at depths 65-80cm and 80-100cm.

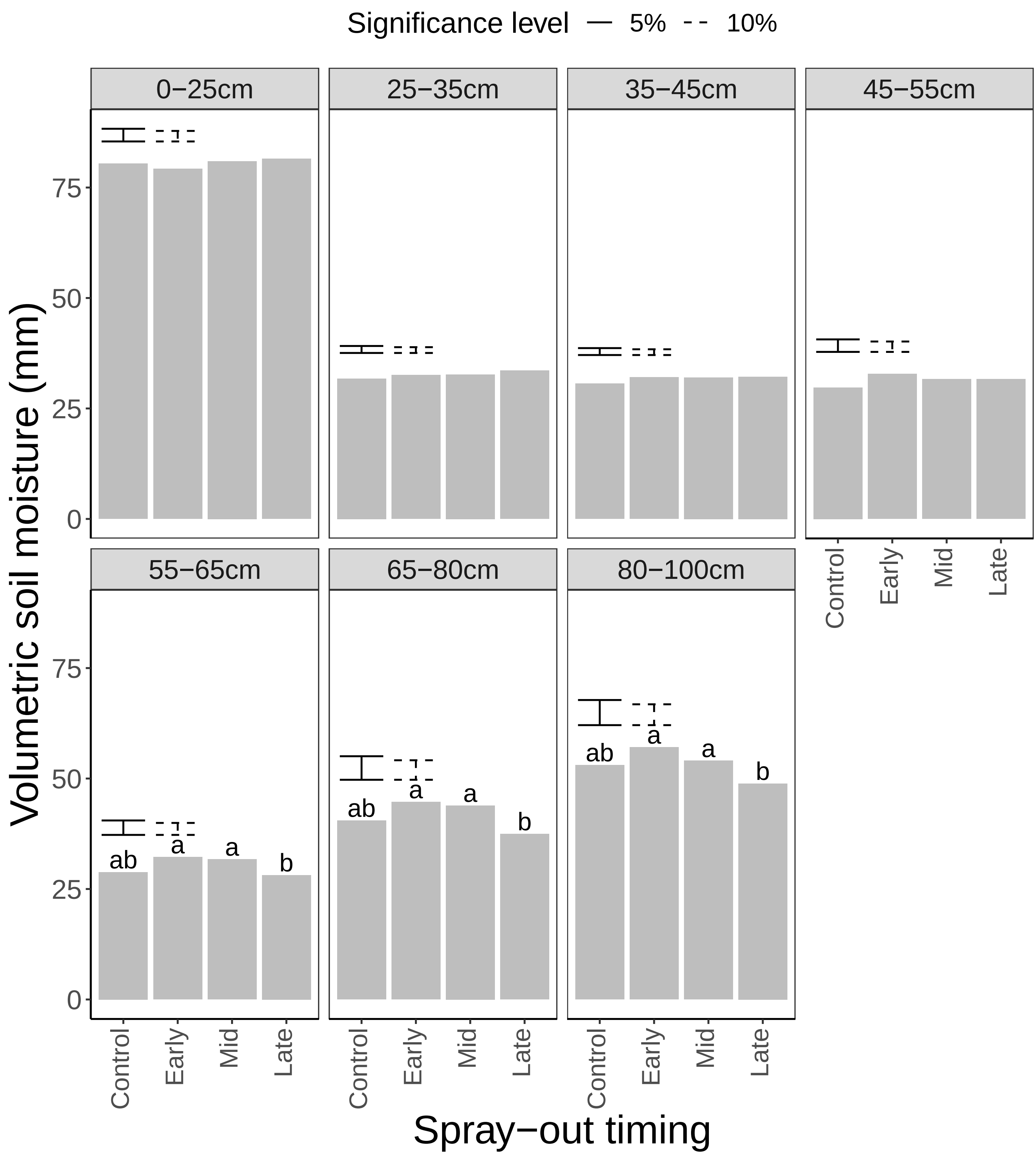

Figure 3.17: Predictions of volumetric soil moisture at Yanco (08/11/2019) from the neutron probes for each sprayout timing at each depth. The vertical error bars denote the LSD value at each depth. LSD lettering is at the 5% significance level.

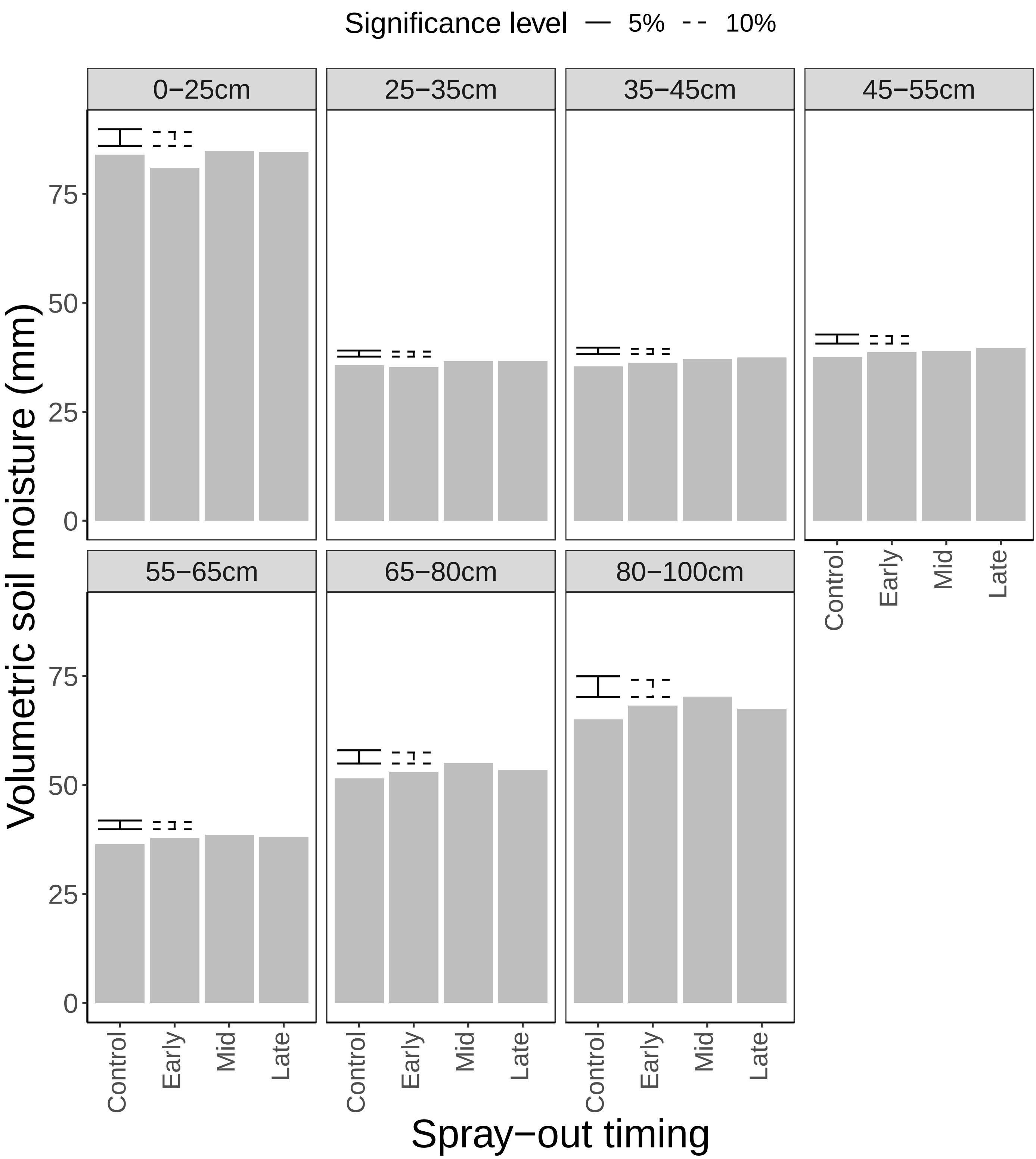

Figure 3.18: Predictions of volumetric soil moisture at Yanco (17/12/2019) from the neutron probes for each sprayout timing at each depth. The vertical error bars denote the LSD value at each depth. LSD lettering is at the 5% significance level.

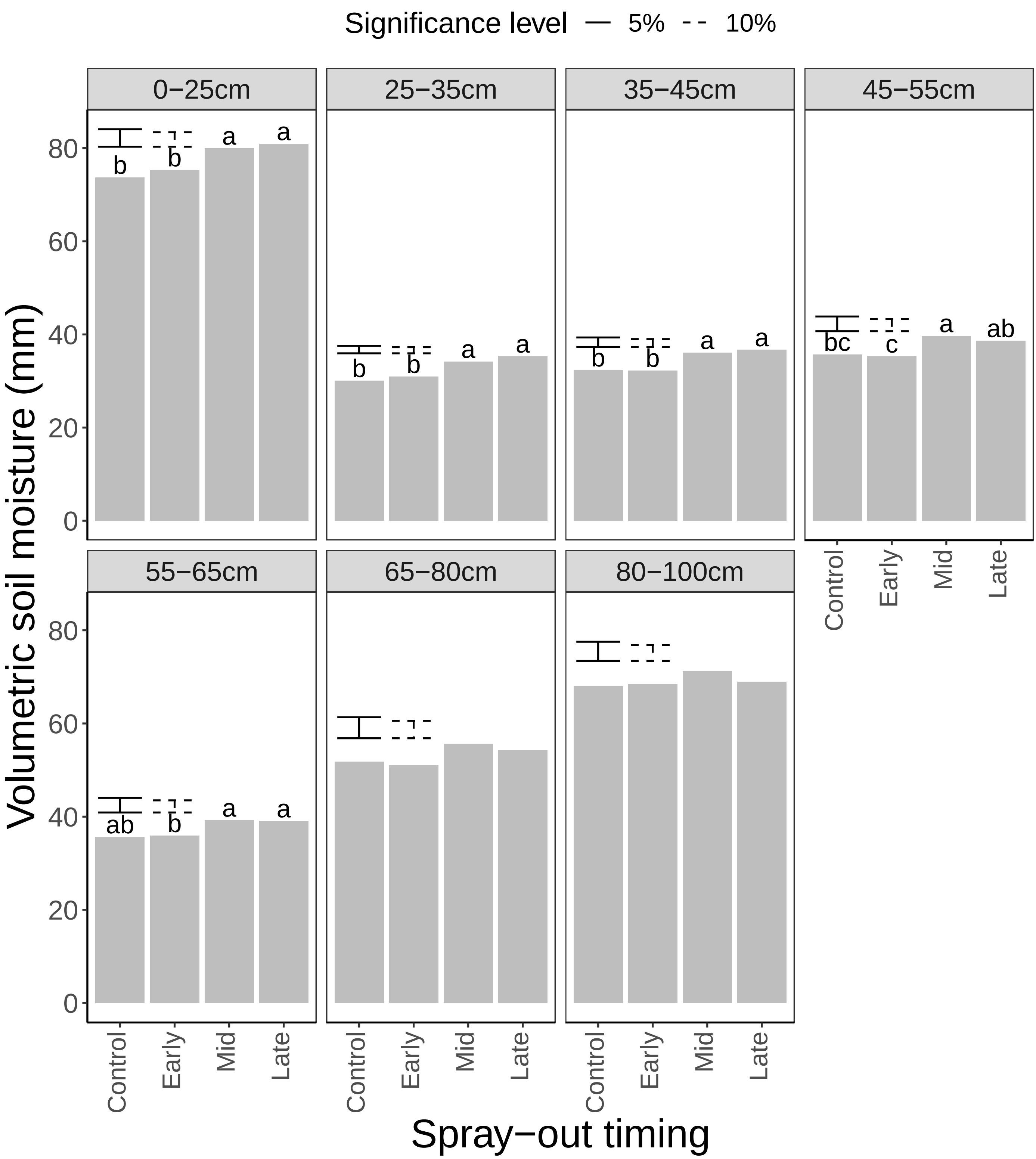

Figure 3.19: Predictions of volumetric soil moisture at Yanco (13/01/2019) from the neutron probes for each sprayout timing at each depth. The vertical error bars denote the LSD value at each depth. LSD lettering is at te 5% significance level.

3.6.4 Analysis - Total soil moisture across depths

An analysis of total volumetric soil moisture across all depths was also performed for the three key dates of cotton establishment (08/11/2019), squaring (17/12/2019) and flowering (13/01/2019). A `corh` residual variance structure ($\rho = 0.55$) was fit across the three dates. At the 10% significance level, there was a significant difference between the spray-out timings at i) establishment ($P = 0.099$), squaring ($P = 0.039$) and flowering ($P = 0.001$) with the early timing having significantly more VSM at cotton establishment than the late timing whilst at flowering the mid and late spray-out timings had significantly higher VSM than the control and early timings.

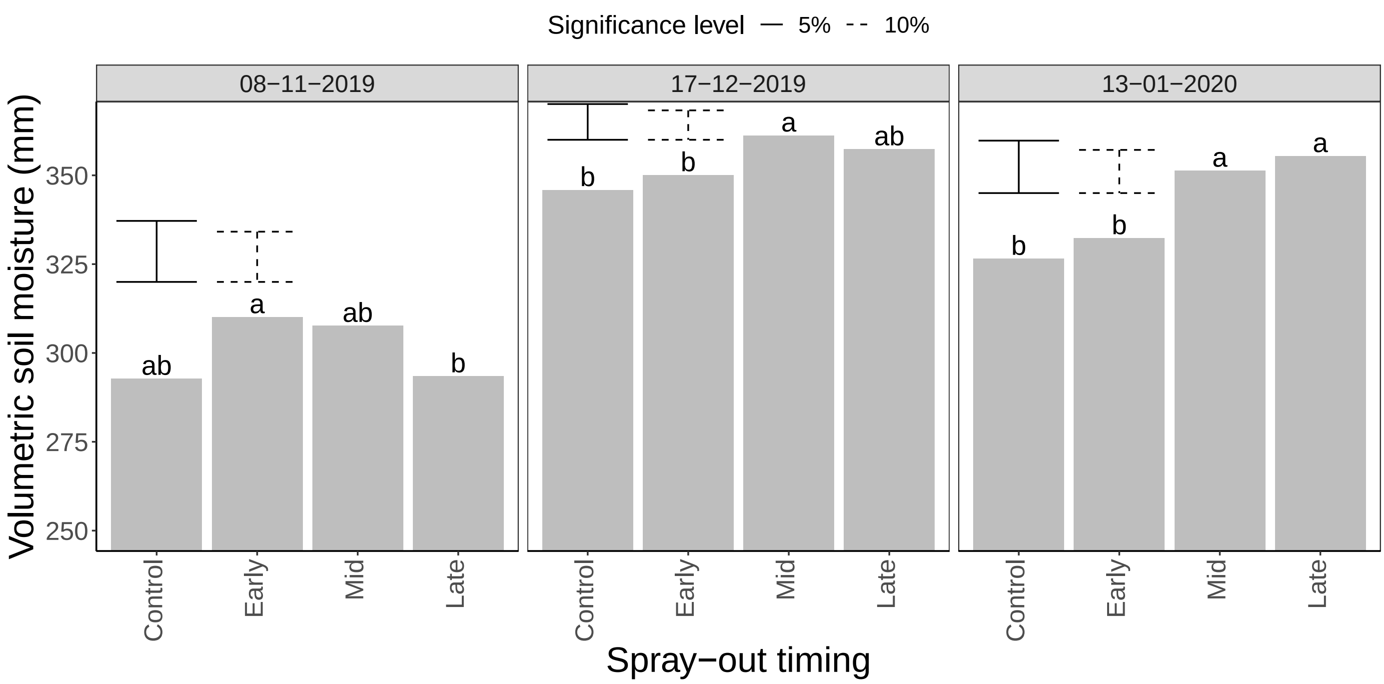

Figure 3.20: Predictions of total volumetric soil moisture summed across all depths at Yanco from the neutron probes for each sprayout timing at cotton i)establishement ii)squaring and iii) flowering. The vertical error bars denote the LSD values at the 5% and 10% significance levels. LSD lettering is at the 5% significance level.

3.6.5 Analysis - Cotton yield (2020)

Cotton was sown on all plots on the 9th October 2019. The analysis shows some evidence ($P = 0.039$) of the late spray-out timing resulting in significantly less yield than the control and the early spray-out timing (Figure 3.21).

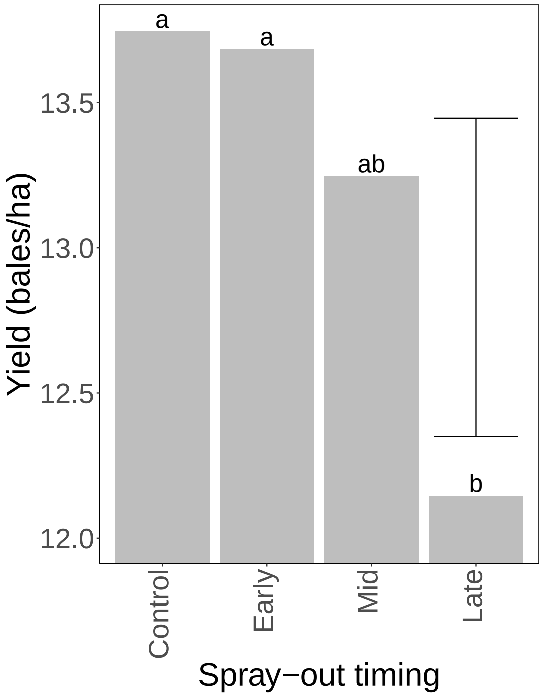

Figure 3.21: Predicted cotton yield after harvesting of the cash crop. There was a significant difference between the sprayout treatments ($P = 0.039$). The vertical error bar denotes the LSD value (LSD = 1.1 bales/ha) at the 5% significance level.

3.7 Undabri - NMM Readings - 2018/19

3.7.1 Analysis NMM readings (23/10/2018)

The NMM readings analysis at Undabri presented here explores the difference in the NMM readings from the 15/02/2018 (i.e. just after the cover crops were planted) and the 23/10/2018, which is roughly the time that cotton is normally be sown at Undabri. An ante-dependence variance structure of order 1 was fitted across depths. There was a significant treatment effect only at depths 60-90cm ($P = 0.010$) and 120-150cm ($P = 0.036$, Figure 3.22). There was a significant treatment effect when combining across all depths ($P = 0.044$, Figure 3.23).

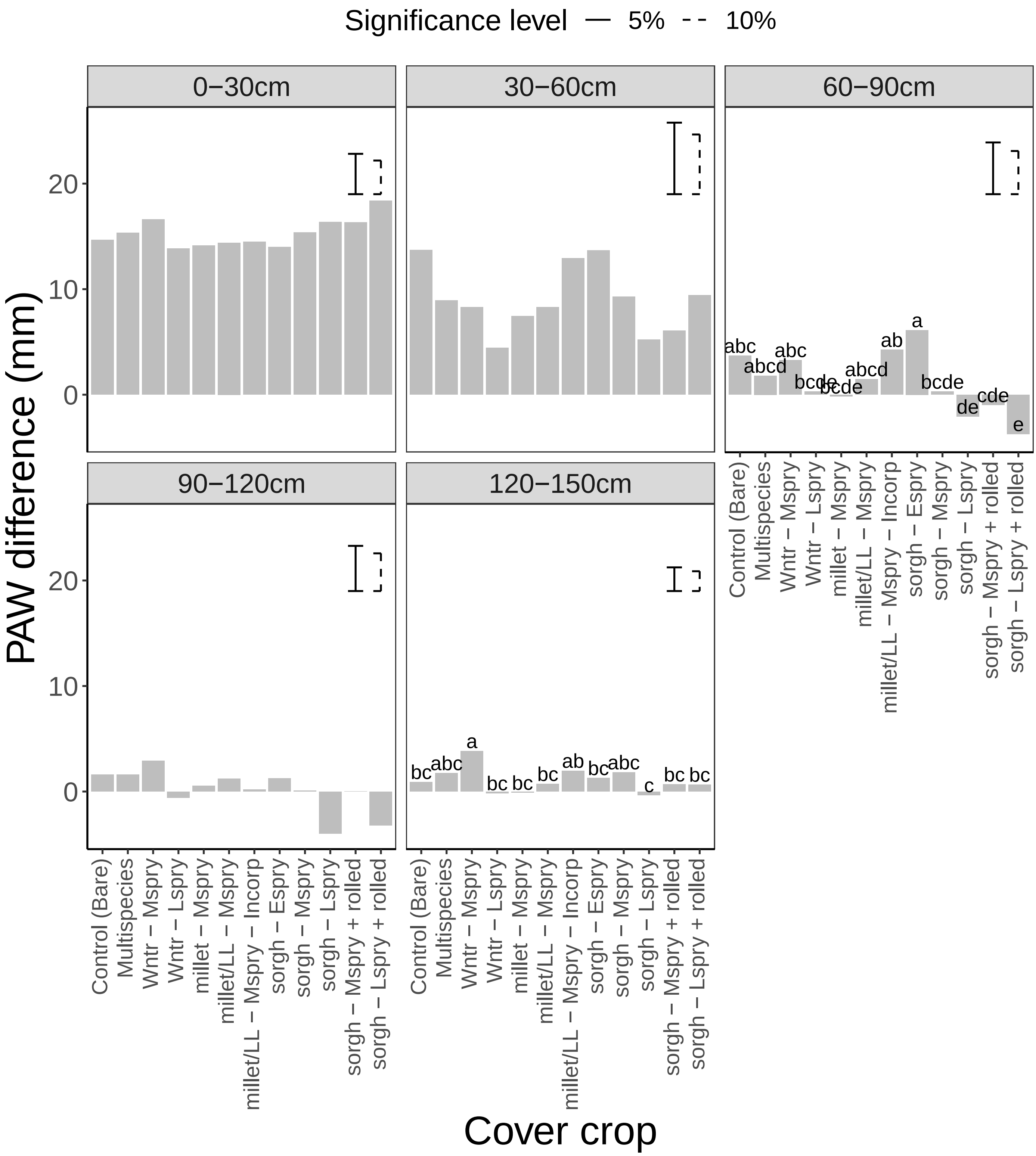

Figure 3.22: Predictions of the change in soil at Undabri (15/02/2018 - 23/10/2018) for each cover crop based on the NMM readings at each depth separately. The vertical error bars denote the LSD value for each depth at the 5% and 10% signifcance level. LSD lettering is at the 5% significance level.

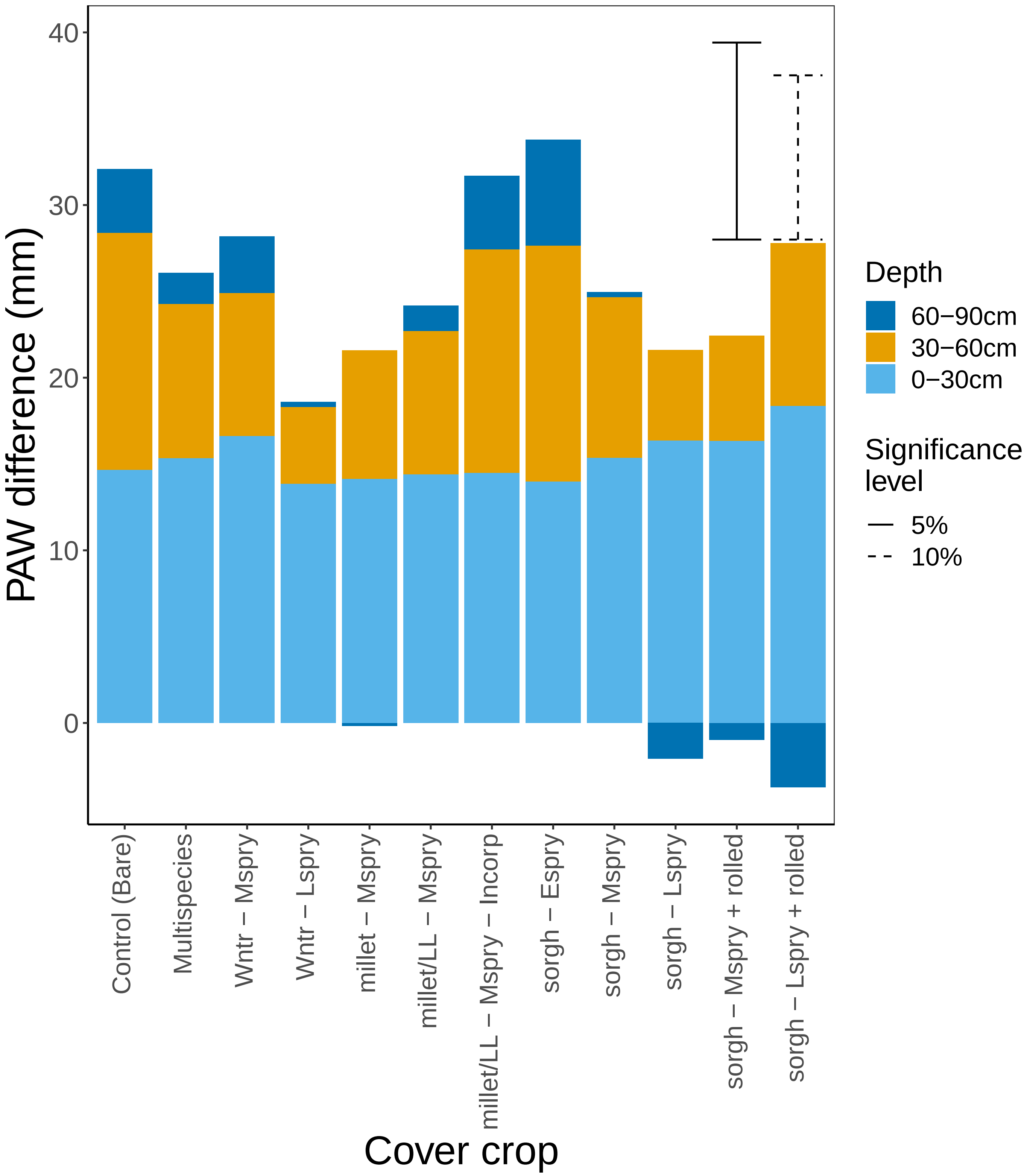

Figure 3.23: Predictions of change in total soil water (depth = 0-90cm) at Undabri (15/02/2018 - 23/10/2018, $P = 0.140$) based on the NMM readings. The vertical error bars represents the LSD value, which is 11.41 and 9.51mm at significance levels 5% and 10% respectively.

3.8 Murra Cul Cul - 2018/19

3.8.1 Analysis - NMM Reading (01/07/2019)

The analysis of the difference in volumetric soil moisture via the soil samples at Murra Cul Cul (05/12/2018 - 01/07/2019) found that there was a significant treatment effect at all depths ($P < 0.001, < 0.001, < 0.001, 0.001, 0.027$ for depths 0-30cm, 30-60cm, 60-90cm, 90-120cm and 120-150cm respectively). A heterogeneous ar1 variance structure was fit across depths. The control and the wheat cover crop treatments had a significantly higher change in volumetric soil moisture than all the sorghum cover crop treatments at depths 10-30cm and 30-60cm (Figure 3.26). These differences than extend to the analysis which estimates the difference in volumetric soil moisture across all depths ($P < 0.001$, Figure 3.27).

3.8.2 Analysis - Soil moisture readings (28/06/2019)

The analysis of the difference in volumetric soil moisture via the soil samples at Murra Cul Cul (03/12/2018 - 28/06/2019) found that there was a significant treatment effect at depths 10-30cm ($P < 0.001$), 30-60cm ($P < 0.001$) and 60-90cm ($P = 0.02$) with the control and the wheat cover crop treatments having a significantly higher change in volumetric soil moisture than all the sorghum cover crop treatments at depths 10-30cm and 30-60cm (Figure 3.26). These differences than extend to the analysis which estimates the difference in volumetric soil moisture across all depths ($P < 0.001$, Figure 3.27).

3.8.3 Analysis - Ground cover

To account for residual correlation across the different dates, an ante-dependence structure of order 2 was fitted across depths. Wald tests indicated that there was a significant cover crop effect at all recorded dates of ground cover. An arcsine transformation of ground cover was performed to account for heterogeneity of the residual variance within depths. The back-transformed predictions are provided in Figure 3.28.

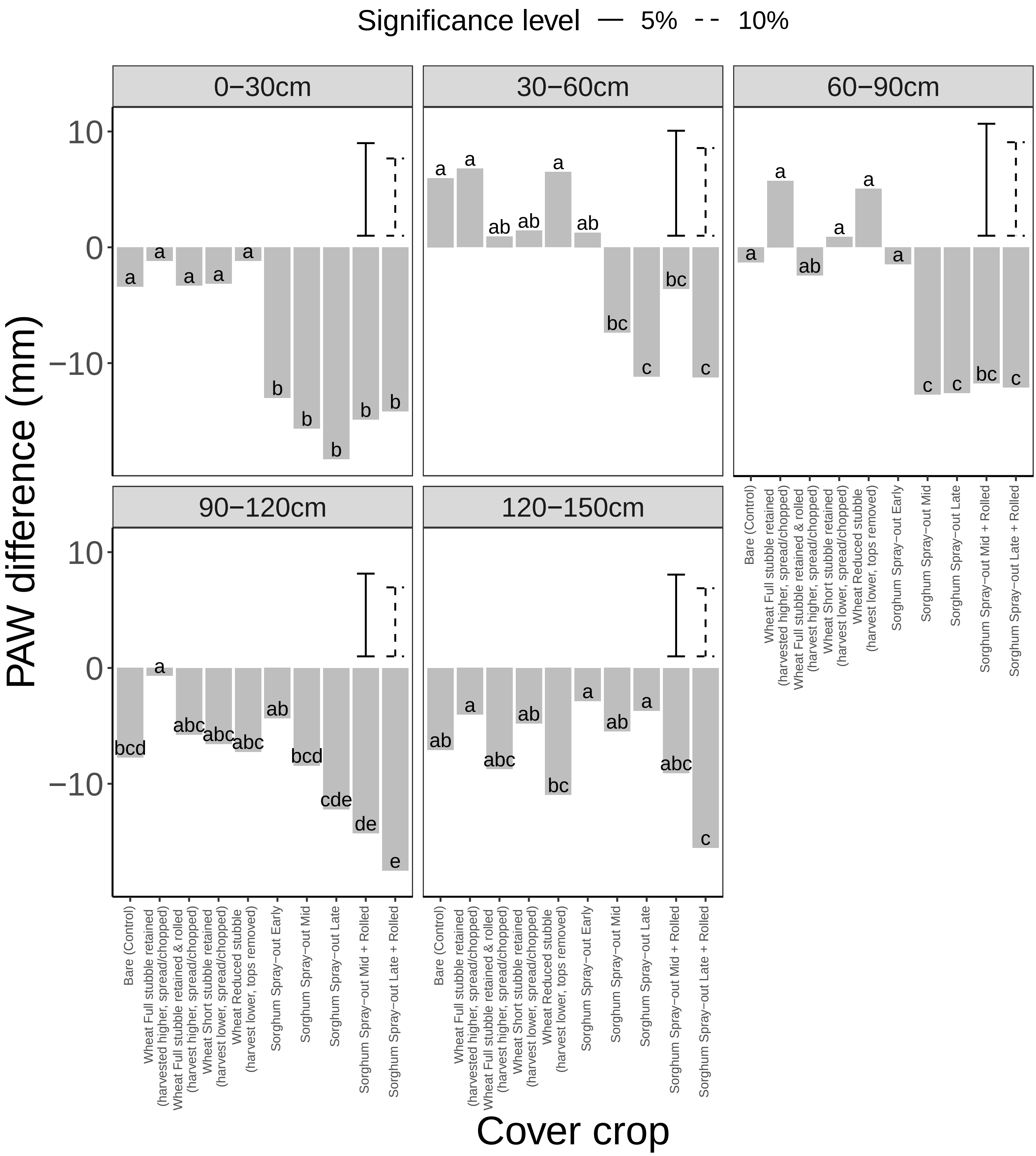

Figure 3.24: Predictions of the difference in volumetric soil moisture at Murra Cul Cul (03/12/2018 - 28/06/2019) for each cover crop based on the NMM readings at each depth separately. The vertical error bars denote the LSD value for each depth at the 5% and 10% significance level. LSD lettering is at the 5% significance level.

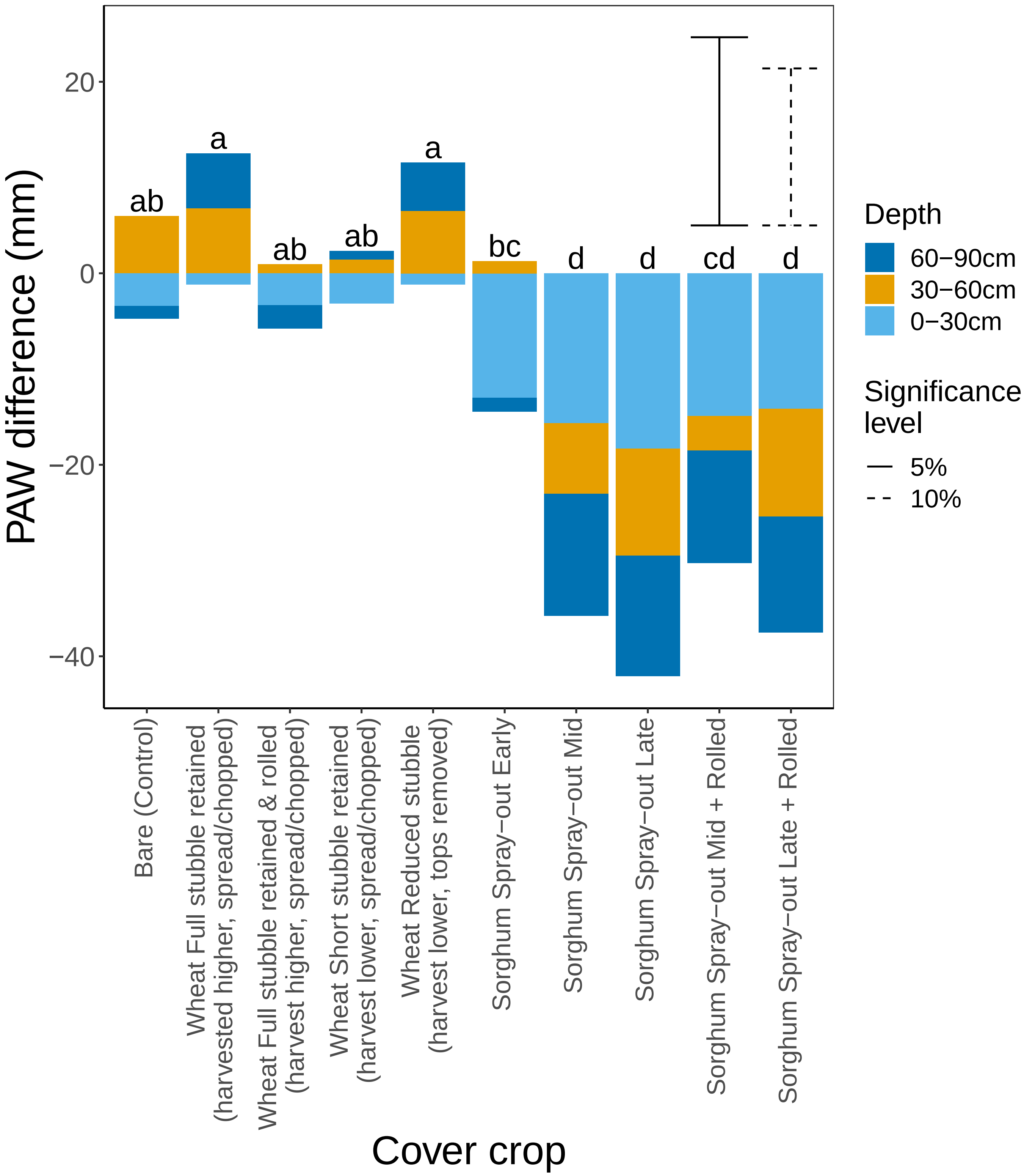

Figure 3.25: Back-transformed predictions of difference in volumetric soil moisture (0-90cm) at Murra Cul Cul (03/12/2018 - 28/06/2019, $P < 0.001$) based on the NMM readings. The vertical error bar denotes the LSD value, which is 19.7 and 16.4 at the 5% and 10% significance levels respectively. LSD lettering is at the 5% significance level

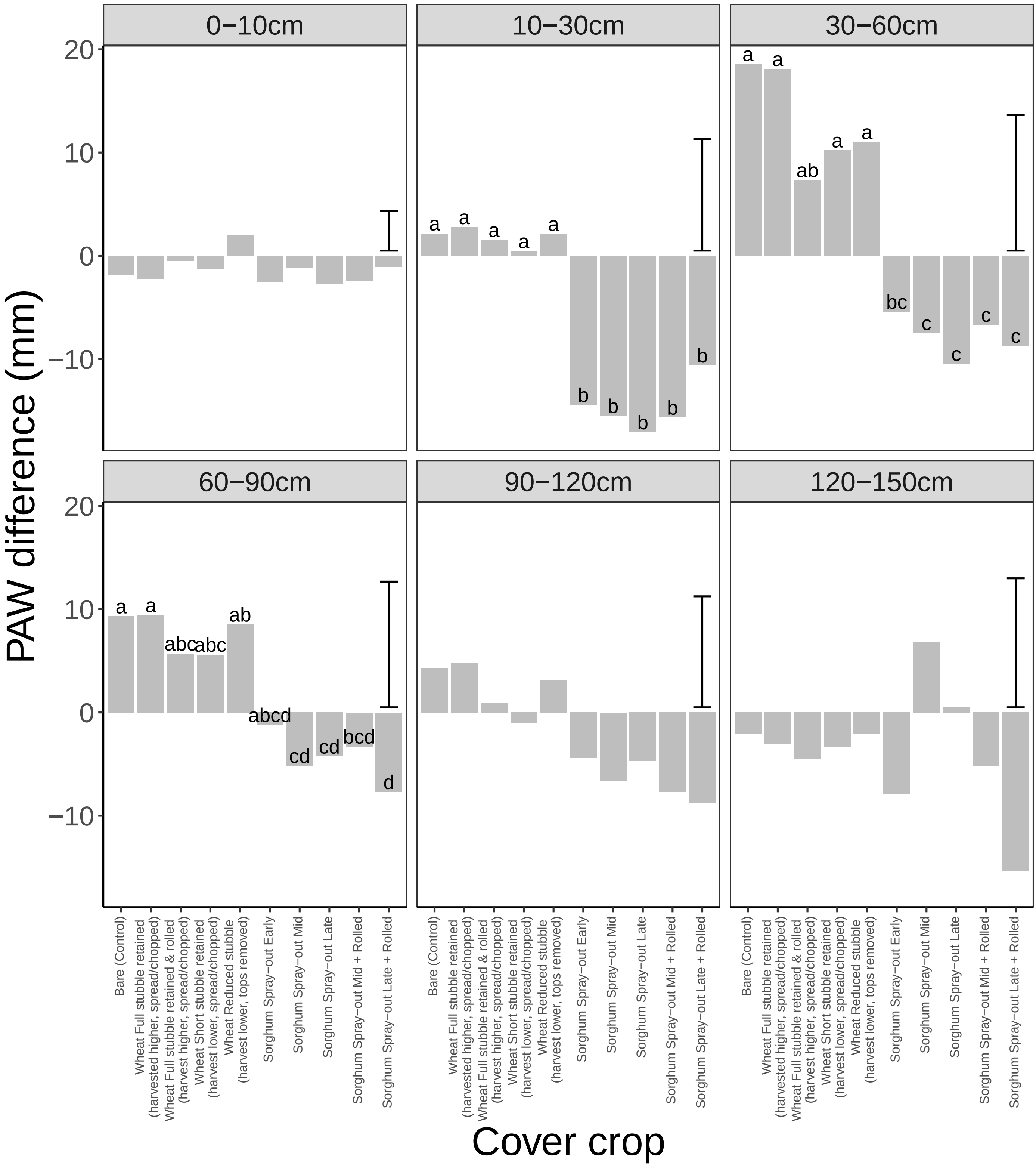

Figure 3.26: Predictions of the difference in volumetric soil moisture at Murra Cul Cul (03/12/2018 - 28/06/2019) for each cover crop based on soil sample readings at each depth separately. The vertical error bars denote the LSD value for each depth.

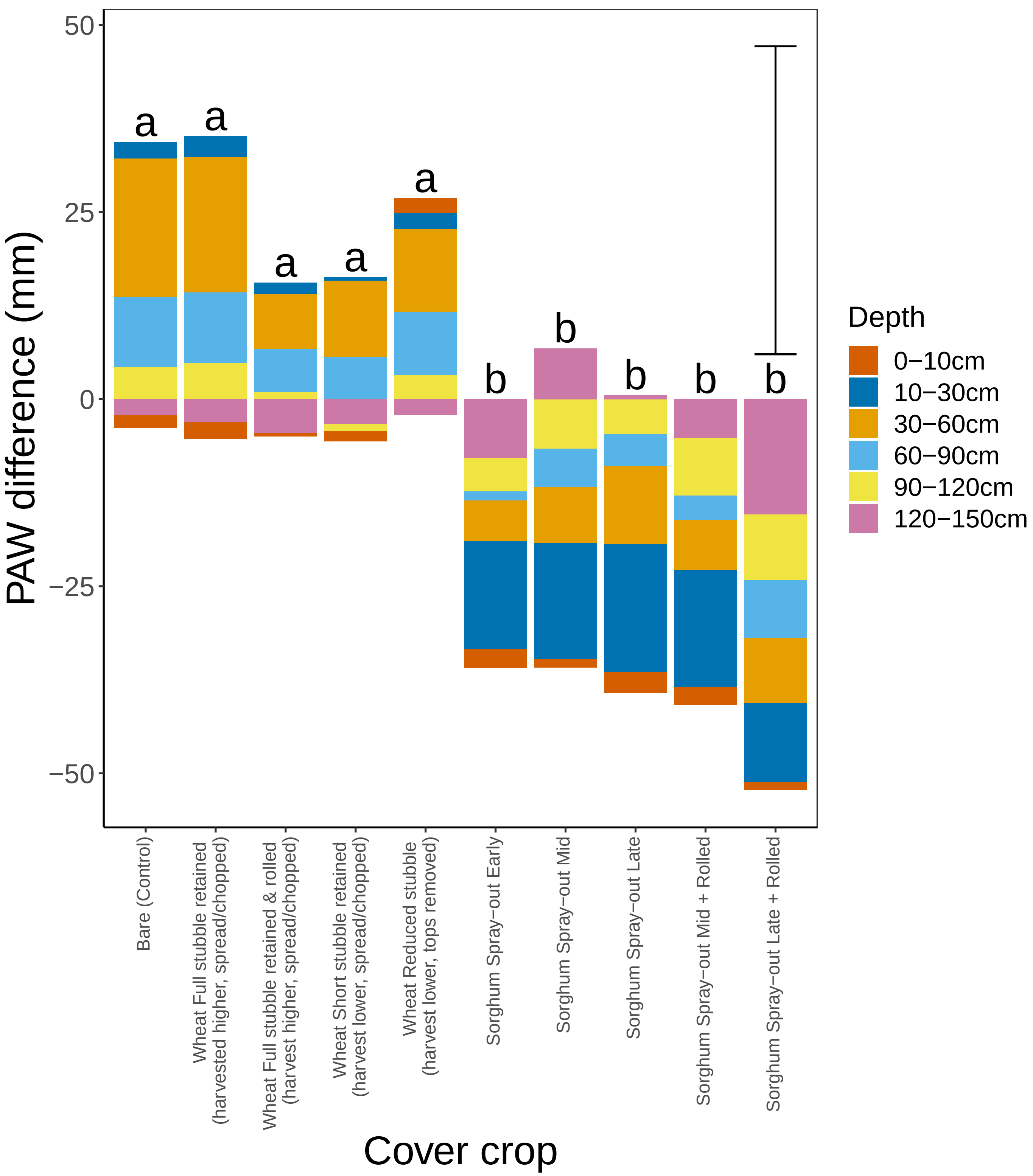

Figure 3.27: Predictions of difference in volumetric soil moisture at Murra Cul Cul (03/12/2018 - 28/06/2019) based on the soil sample readings. The vertical error bar denotes the LSD value (LSD = 41.1mm)

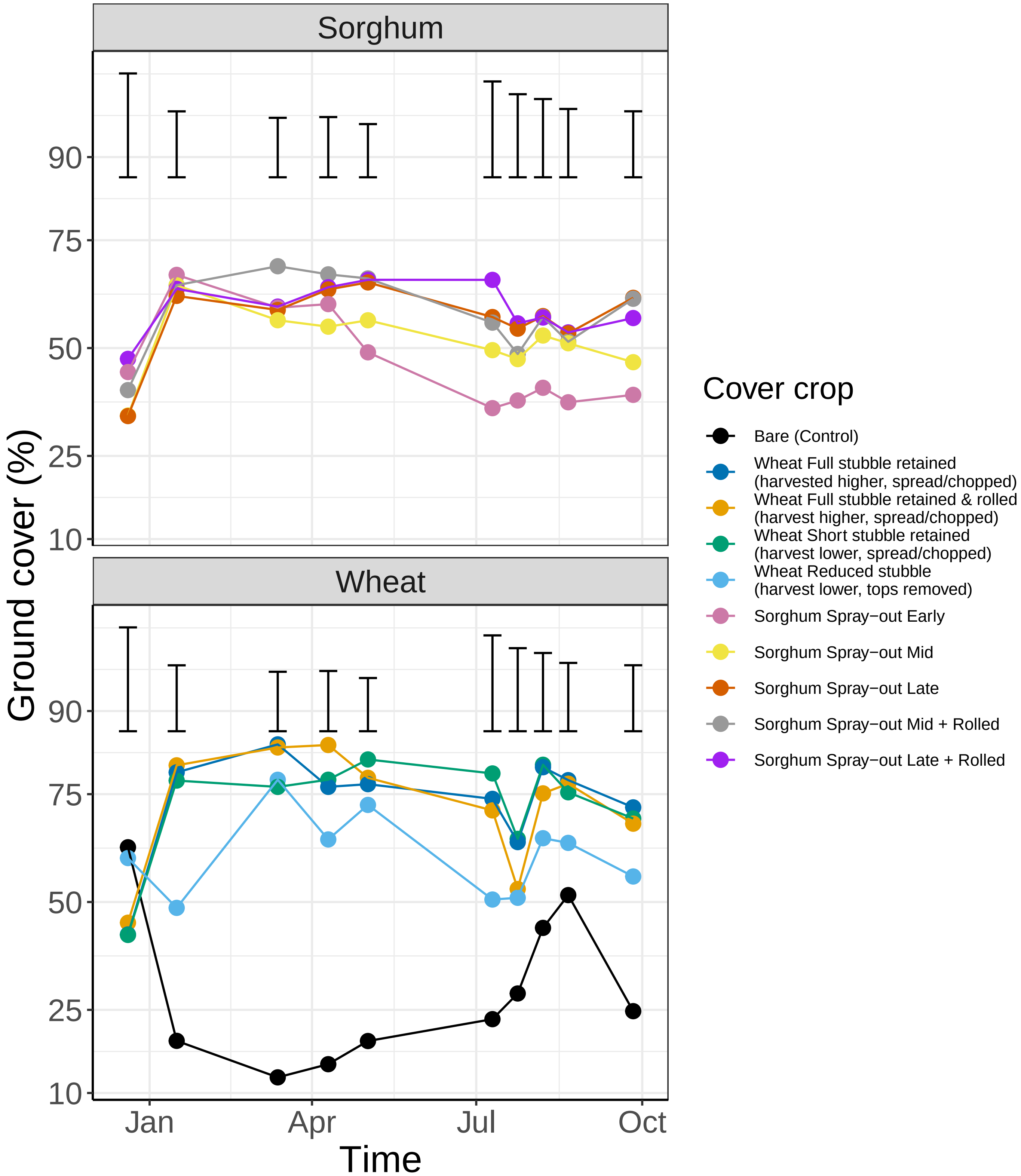

Figure 3.28: Back-transformed predictions of ground cover at Murra Cul Cul for each cover crop at a range of dates from December 2018 to October 2019. There was a significant time by cover crop treatment interaction effect. The vertical error bars denote the LSD value for each date that measurements were recorded.

3.9 Nareen - 2018/19

3.9.1 Analysis - NMM Reading (16/05/2019)

For the Nareen winter cover crops, the difference in NMM readings was calculated as the difference between the NMM readings just after planting the cover crops (25/07/2018) and the NMM readings around the planting time of wheat on all plots (16/05/2019). Wald tests found no significant difference between the cover crop treatments at any depth except for 90-120cm ($P = 0.041$). The predictions can be seen in Figure 3.29. There was no significant treatment effect when combining all depths (Figure 3.30)

3.9.2 Analysis - Soil sample reading (11/06/2019)

The analysis of the difference in the soil samples at Nareen found that there was no significant difference at any of the depths except for 0-10cm ($P = 0.02$, Figure 3.31). An ante-dependence variance structure of order 1 was fitted across depths to account for correlation in the residuals across depths. The analysis summing all depths found that there was no significant difference between each of the cover crop treatments (Figure 3.32).

3.9.3 Analysis - Ground cover

To account for residual correlation across the different dates, an ante-dependence structure of order 3 was fitted across depths. Wald tests indicated that there was a significant cover crop effect at all recorded dates of ground cover. An arcsine transformation of ground cover was performed to account for heterogeneity of the residual variance within depths. The back-transformed predictions are provided in Figure 3.33.

3.9.4 Analysis - Grain yield

Grain yields for wheat after harvesting the cover crop were very low (400-800 kg/ha) as it was an extremely dry season. There was no significant difference between the cover crop treatments in the comparison of grain yield. The predicted yields for each cover crop treatment can be seen in Figure 3.34.

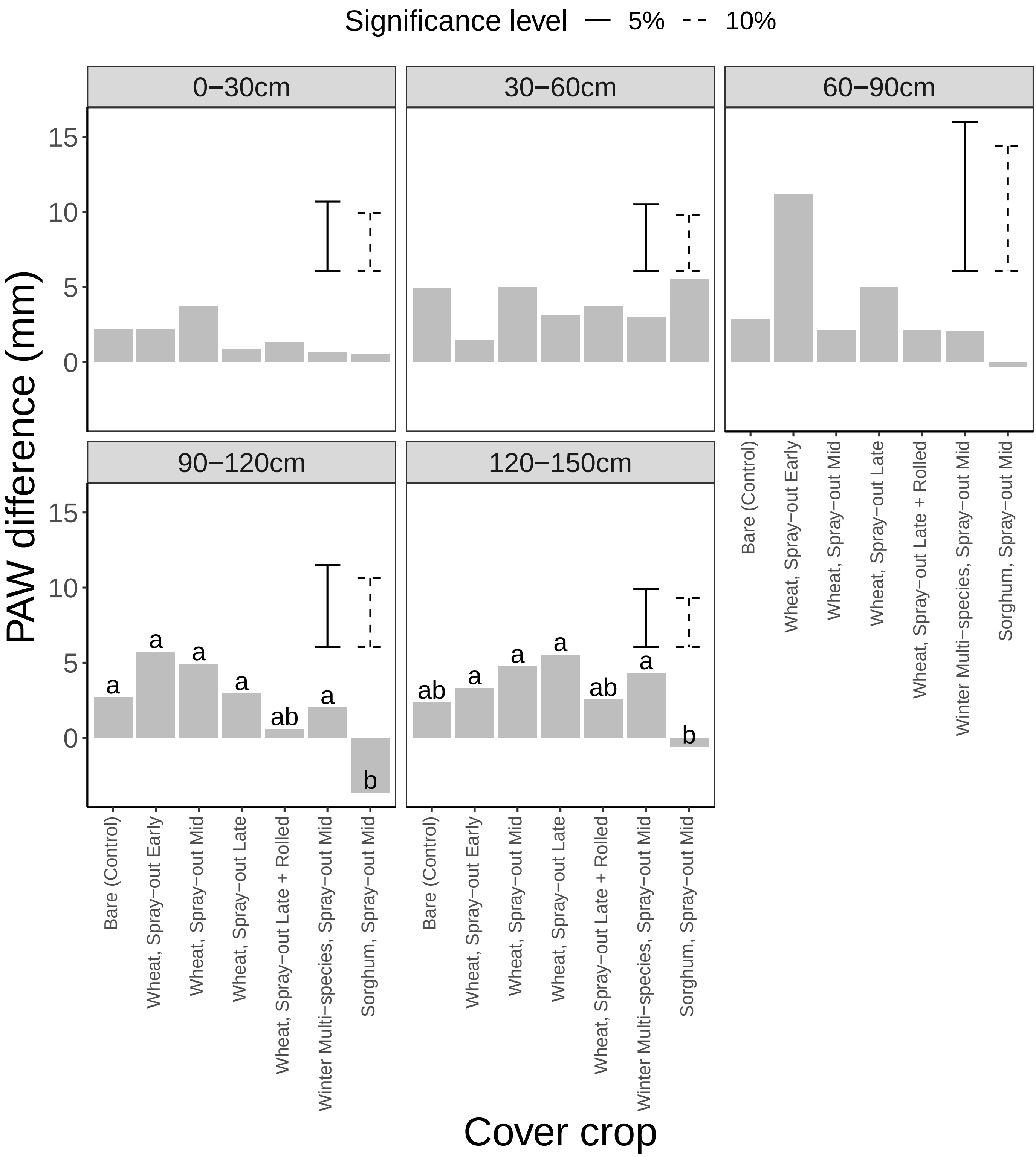

Figure 3.29: Predictions of the difference in volumetric soil mositure at Nareen from just prior to planting of wheat to around the planting of the cover crop (25/07/2018 - 16/05/2019). The vertical error bars are the corresponding LSD values at each depth at the 5% and 10% significance levels. LSD lettering is at the 5% significance level.

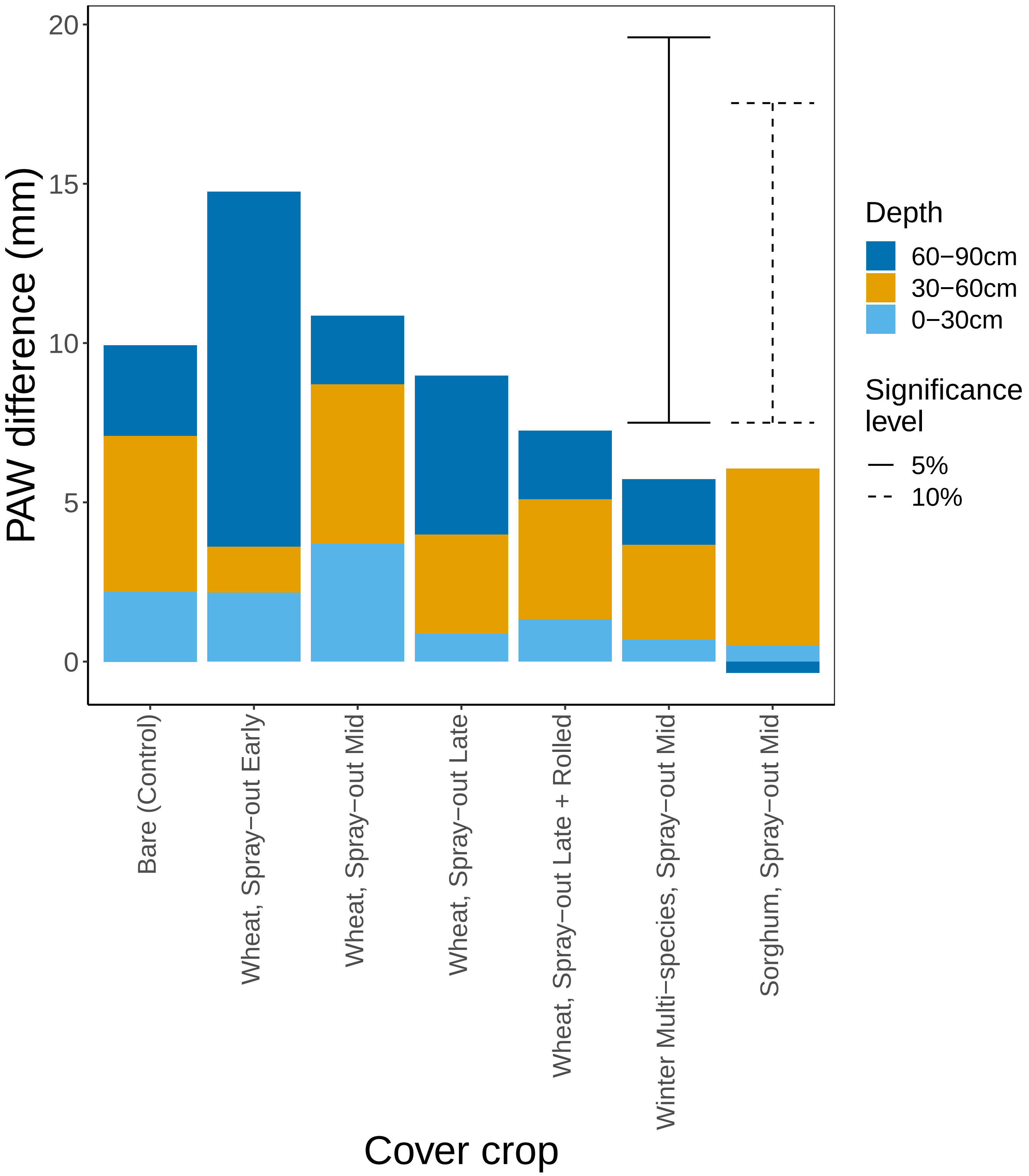

Figure 3.30: Predictions of change in total soil water at Nareen (25/07/2018 - 16/05/2019, $P = 0.712$). The vertical error bar denotes the LSD value, which is 12.1 and 10.0 at the 5% and 10% significance levels respectively.

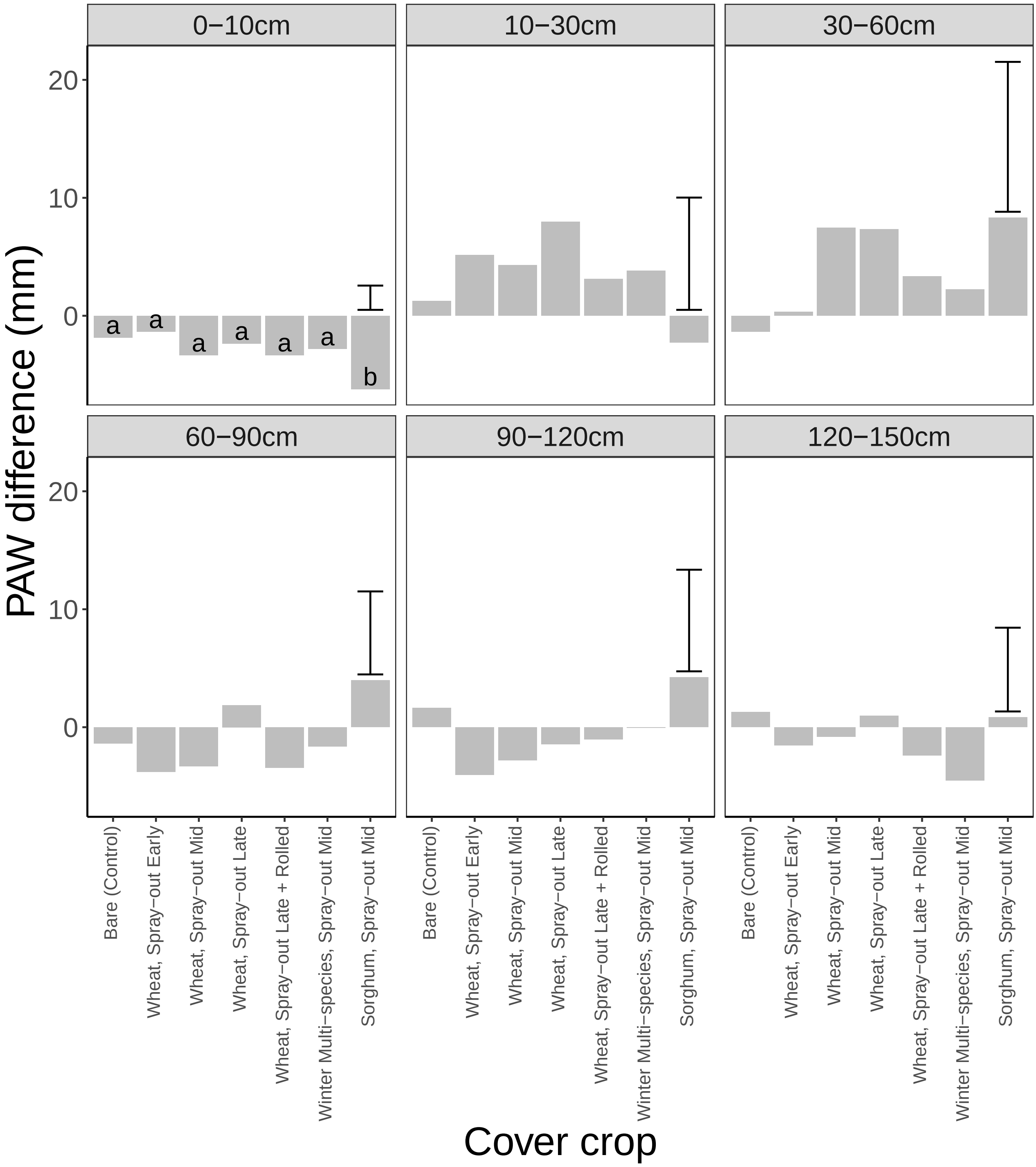

Figure 3.31: Predictions of the difference in volumetric soil moisture at Nareen (23/07/2018 - 11/06/2019) for each cover crop based on soil sample readings at each depth separately. The vertical error bars denote the LSD value for each depth.

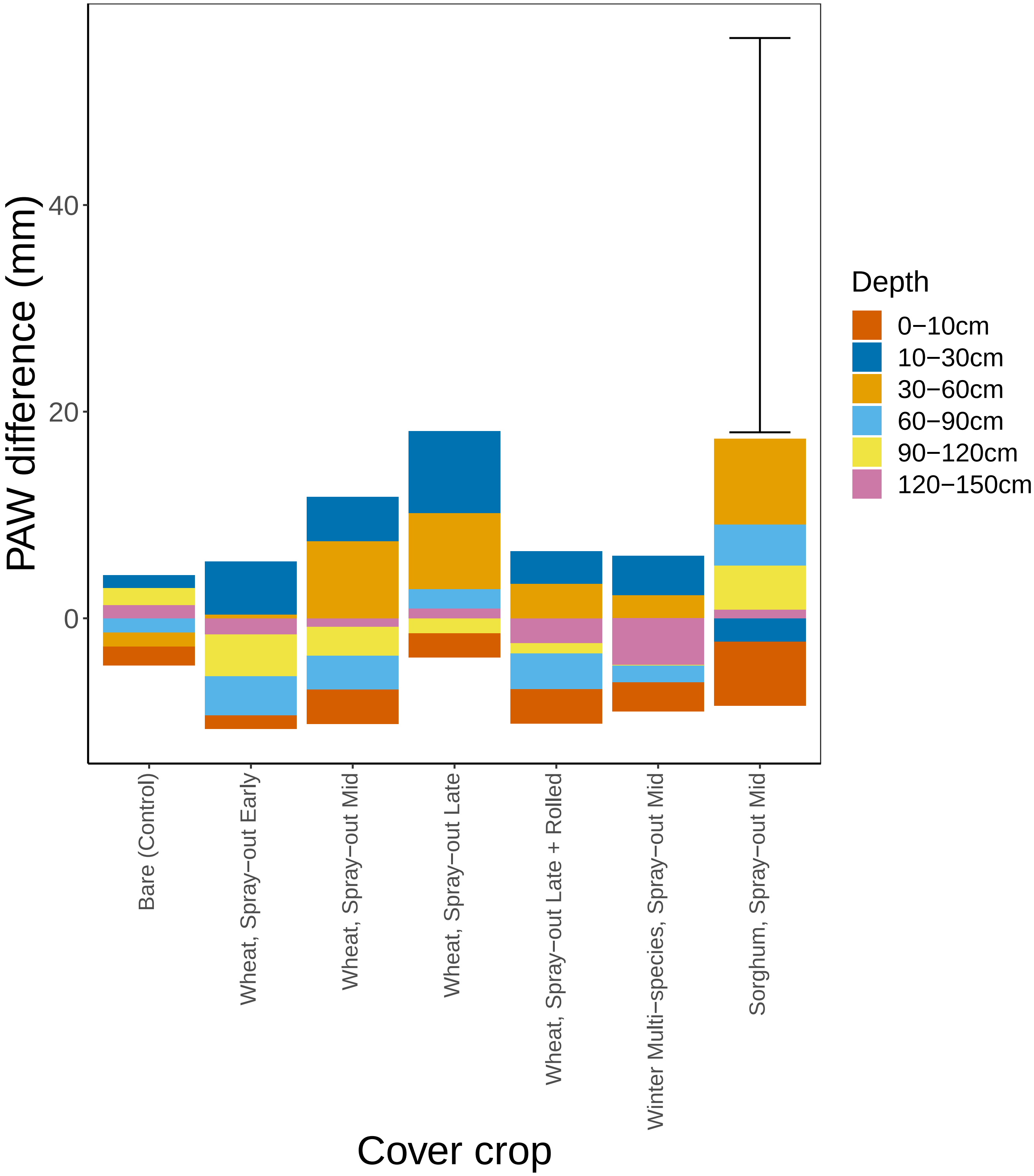

Figure 3.32: Predictions of the difference in volumetric soil moisture at Nareen (23/07/2018 - 11/06/2019) for each cover crop based on soil sample readings. The vertical error bar denotes the LSD value (LSD = 38.2mm)

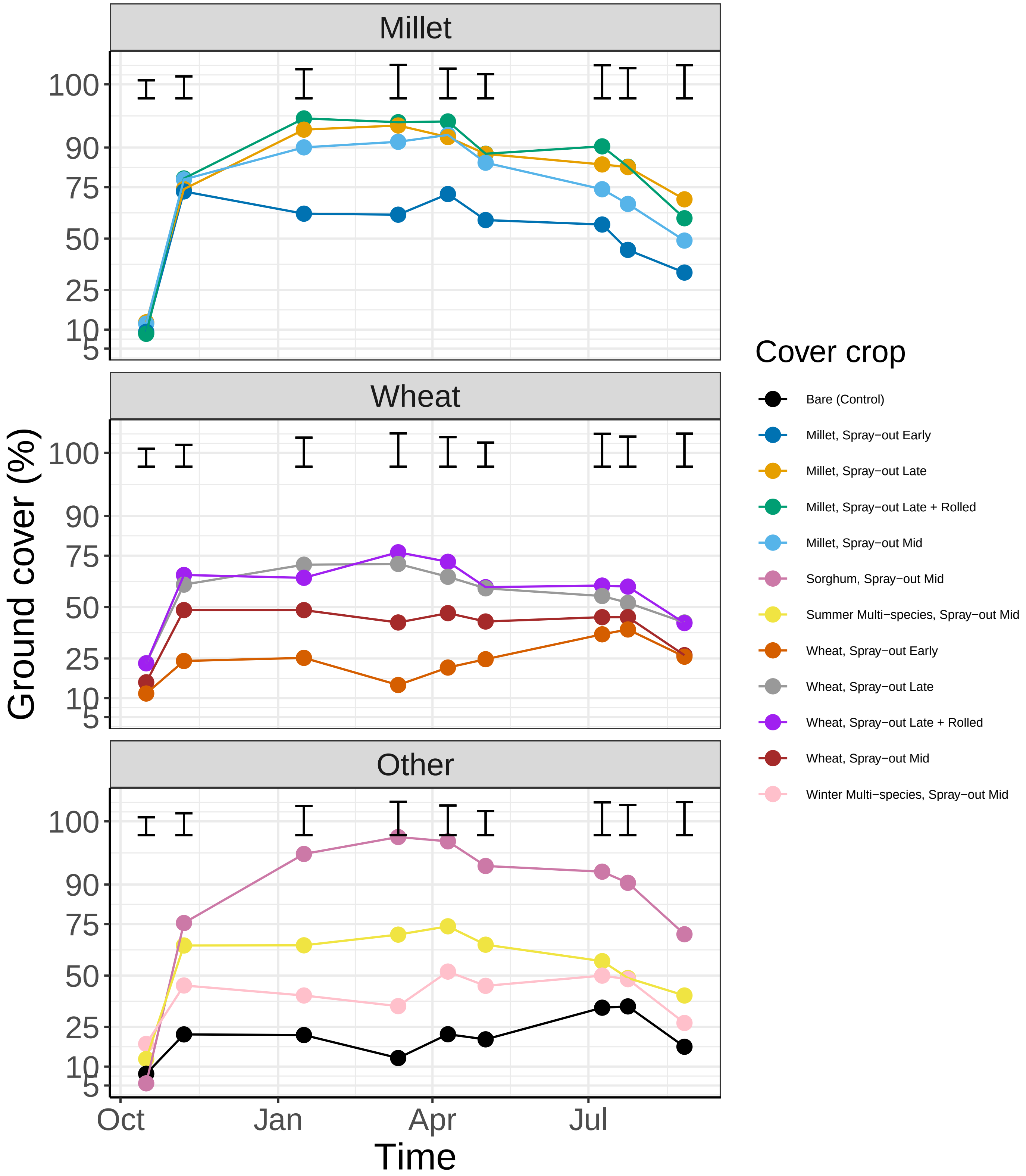

Figure 3.33: Back-transformed predictions of ground cover for each cover crop at a range of dates from October 2018 to September 2019. There was a significant time by cover crop treatment interaction effect. The vertical error bars denote the LSD value for each date that measurements were recorded.

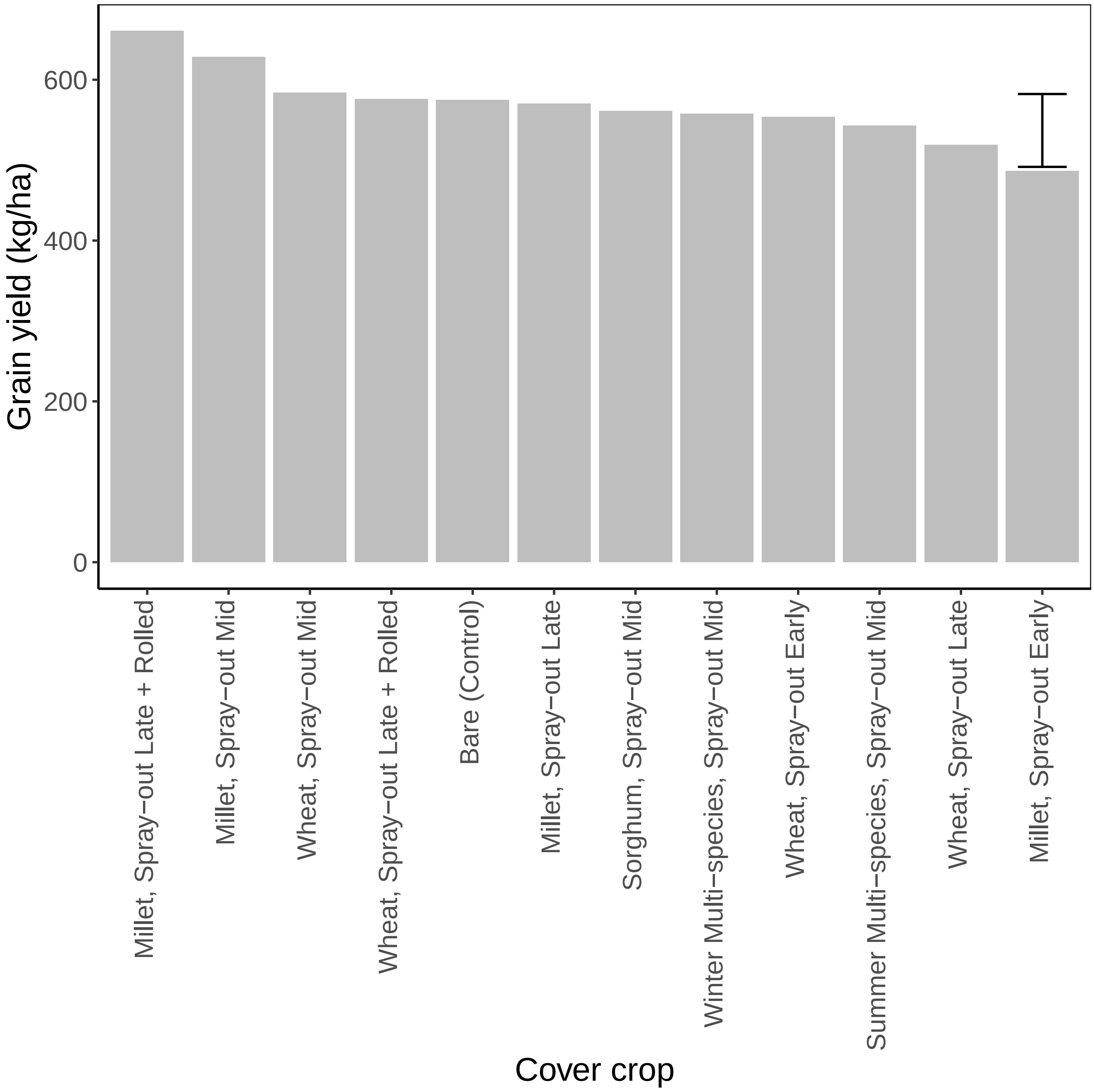

Figure 3.34: Predicted wheat yield after harvesting of the cover crop. The statsitical analysis found no significant difference between each of the cover crops ($P > 0.05$).

4 Discussion

4.1 Major findings

In terms of the change in volumetric soil moisture (equivalent to change in PAW), the results varied from across trials in terms of net water gain when using cover crops as opposed to a fallow period (i.e. the control). All of the trials showed no significant improvement in PAW by the time it came to plant the grain crop, with the exception being the Parkes short fallow trial (Figure 3.11). At Coorangy, the LSD value was 35.7mm, indicating that each of the treatments needed to have at least 35.7mm more PAW than the control to be considered statistically significant.

Since each of the treatments consisted of five replicates that were randomly allocated via a randomised block design, we can eliminate the possibility that the large LSD value was due to a lack of statistical power in the design. Thus the LSD value indicates that there was a large amount of variability in PAW difference across the five replicates of each treatment. An LSD value of 37.6mm at Yelarbon indicates that it less likely to be due to a single noisy trial. Thus the possibilities are i) The measuring equipment used is noisy or ii) The measuring equipment is precise and thus PAW is highly variable across the field trial(s).

If the measuring equipment is noisy, then it is recommended that more precise measuring equipment is used in future trials to estimate change in PAW. If the noise is due to large changes in PAW across the trial, then it may be more worthwhile to investigate why there such large differences in PAW across the trial. The analysis of the change in PAW via soil samples at Murra Cul Cul resulted in an LSD value of 41.1mm, indicating that the soil sampling approach is not necessarily more precise than using the NMM readings to calculate PAW.

Another key research question was to determine if the grain crop planted following the cover crop would result in more grain yield than a fallow period (i.e. the control). The analyses provided mixed results across trials, with the plots containing a cover crop resulting in significantly more yield for some trials (e.g. Coorangy). At other trials, the control had a significantly higher grain yield than the cover crop treatments (e.g. Canowindra). Finally, there were trials where there was no significant difference between the control and the cover crop treatments (e.g. Nareen).

4.2 Limitations and cautions regarding results

As previously mentioned, a measure of precaution was put in place for the analysis of the change in volumetric soil moisture that combined depths because within each trial, each depth had employed a different calibration. The caution comes from the fact that in some trials, there is potentially a large amount of error in the calibrations as they were based on soil samples with a limited range of volumetric soil moisture %. In future experiments involving calibrations, it is strongly recommended that a firm strategy is in place prior to sowing, that ensures that the full range of possible volumetric soil moisture percentages is incorporated into the calibrations from NMM readings to volumetric soil moisture. This will result in more accurate calibrations, providing more confidence in the conversions to total PAW. This issue was addressed in the 2018/19 trials, since soil samples were taken at multiple times, providing a larger sample size, but more importantly, a wider range of soil moisture percentages to calibrate with the NMM readings.

Another caution that should be noted is that the Parkes and Canowindra trials used the same experimental design at each trial. It has has been noted and explained to the researchers that in all future trials, a separate randomisation is required for each trial when the treatments are the same.

It has also been noted that, for future trials, it may be worth considering using the same treatments across multiple locations where feasible, allowing for the possibility to investigate interaction effects between treatments and environments. If there is no significant trial x environment interaction effects, then the data from multiple trials can be used to test for treatment main effects, which will strengthen the results of the analysis. In this particular project, the focus was on specific treatments that were chosen to match the trials and their locations that they were assigned to, and therefore each trial had a unique set of treatments.

5 Conclusion

Overall, the analyses in this report indicates that cover crops have the potential to improve PAW in certain conditions. The next step would be to determine under which circumstances do cover crops result in an improvement in PAW. It should be noted that for all the trials where an analysis on ground cover was performed, the control had less than 30% ground cover and that the cover crops had significantly higher ground cover than the control at all trials presented in this report. It is also evident that improvements in PAW do not necessarily coincide with improvements in grain yield for the corresponding grain crop, and thus further research is required to investigate additional possible benefits of cover cropping beyond PAW.

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