SOIL WATER STORAGE: INCREASED ACCESS AND TOOLS FOR ASSESSMENT

KEY MESSAGES

- **Soil water content (how much water is in the soil) and matric potential (how tightly water is held by soil) was measured four-hourly at Burramine between March 2023 and December 2024 under summer fallow and summer cover crop treatments, followed by winter crops.**
- **Plant available water capacity (PAWC) in the sub-soil was found to be 30 mm greater under the cover crop treatment than under the control.**
- **Higher PAWC in the cover crop treatment was attributed to a greater number of soil pores at the top of the B horizon. While the cause is unknown, it may be due to more roots at depth and/or greater sub-soil drying over summer, creating cracks.**
- **There was no difference in PAWC between the cover crop and control plots in the topsoil.**
- **While promising, these results are from one trial on one soil and more work is needed to determine the cause and if the effect occurs at other sites and soils.**

BACKGROUND

Duplex soils, with a loam topsoil overlaying a clay sub-soil, are common throughout the eastern Riverine Plains of the Murray Valley. The clay B horizon in these soils has a low bearing capacity when wet, which predisposes the soils to compaction if trafficked and/or cultivated in a wet, plastic condition. Sodicity exacerbates these processes.

The nature of the clays in these soils means that they are not able to "repair" themselves when this occurs, unlike clays that shrink and swell strongly and where a deep drying cycle will restore structure and porosity. While structure and porosity in such non-shrink/swell clays may be re-built by plant roots and microbial activity, it takes time to create macropores and to "glue" soil particles into stable aggregates.

AIM

The aim of this trial was to identify whether summer cover-cropping in the winter-dominant rainfall environment of northern Victoria increased the plant available water capacity (PAWC) in the medium term by improving root-soil interaction and soil structure.

METHOD

SITE AND SOIL

Summer cover cropping treatments were established in January 2020 at a trial site near Burramine, Victoria, as part of the Soil CRC-funded project *Plant-based solutions to improve soil performance through rhizosphere modification*. In 2023, the project *Soil water storage: Increased access and tools for assessment* was established at the site, adding value to the existing research site.

As part of this project, pairs of soil water content and soil water (matric) potential sensors were installed in each of the three replicate plots of two of the existing treatments;

- Control (canola in winter 2023, wheat in winter 2024), and
- Three-species summer cover crop (millet, cowpea, sunflower in summer 2023–2024) plus winter crops as per the control treatment).

Agronomic management of these treatments is described in the article *Investigating summer cover cropping and intercropping to improve soil health (resilience) and productivity on* pages 82 of this publication.

During 2022, poor conditions for establishment and subsequent waterlogging led to failure of the 2022 canola crop. To make the most of residual soil water millet was sown across the whole site early in the summer of 2022–2023. However, neither the millet nor the subsequent summer cover crop established well.

Soil assessment showed the Burramine field site to be a Brown Sodosol with an acidic sub-surface, a strongly compacted sub-surface and sub-soil, and a strongly dispersive sub-soil and topsoil in places (Tables 1 and 2).

Table 1 Soil chemical properties at the Burramine site (mean, n=3)

DEPTH	PH_{WATER}	$EC_{1:5}$	ORGANIC CARBON	CEC	ESP	Ca:Mg	P(COLWELL)
(cm)		(dS/m)	(%)	(cmolc/kg)	(%)		(mg/kg)
5-15	5.9	0.04	0.71	6.5	3	2.6	48
25-35	7.5	0.06	0.45	15.6	5	1.1	5
45-55	8.1	0.13	0.39	20.2	7	0.8	6

Table 2 Soil physical properties at the Burramine site (range or mean, n=3, SWC; soil water content)

DEPTH	DISPERSION @10MIN	COARSE SAND	FINE SAND	SILT	CLAY	AIR-DRY SWC	BULK DENSITY	SATURATED SWC*	FIELD CAPACITY SWC*
(cm)	-	(%)	(%)	(%)	(%)	(% v/v)	(g/cm3)	(% v/v)	(% v/v)
5-15	none-moderate	4	44	26	31	1.7	1.56 (n=48)	41	36
25-35	slight-strong	2	27	18	56	3.9	1.63 (n=35)	38	33
45-55	slight-strong	1	19	17	66	4.9	1.69 (n=4)	36	31

*Derived from bulk density, particle density of 2.65 g/cm^3 and assumed air-filled porosities of 0% (saturated) and 5% (field capacity)

SOIL WATER MEASUREMENTS

Soil water content and matric potential sensors were installed in pairs at multiple depths throughout the soil profile in each replicate plot of the control and cover crop treatments. Soil water content was measured using Wet150® (Delta T, UK) sensors in the topsoil and EnviroPro® (Entelechy, Australia) sensors in the sub-soil. Watermark® (Irrometer, California) sensors were used to measure matric potential (how tightly water is held by soil). Measurements were logged every four hours. Water content sensors were calibrated using soil samples obtained across a range of depths and moisture contents and measured gravimetrically.

Plant available water capacity (PAWC) was estimated from the difference between the upper and lower limits of plant available water obtained using both laboratory and field methods. In the first field method, profile water content (PWC) was estimated from the sum of the calibrated water content sensor readings at a site. PAWC was then determined from the difference between the PWC measured 24–48 hours after the wettest observed conditions (drained upper limit, DUL, on 26 August in 2023) and the driest observed conditions (crop lower limit, CLL) under the wheat (2023) and canola (2024). Dry conditions in 2024 meant the soil profile was not filled and DUL was not observed that year.

In the second field method, and the two lab methods, PAWC was estimated from the difference in soil water contents at matric potentials representing field capacity (-10 kPa) and permanent wilting point (-1500 kPa). These soil water contents were estimated from soil water retention curves fitted using a Fredlund-Xing model to paired soil water content and matric potential measurements obtained under drying conditions from:

1. paired sensor readings in control and cover crop plots - second field method
2. soil core samples from control plots using Hyprop (Meter Group, USA) and Filter paper lab methods

RESULTS & DISCUSSION

YIELDS

Above average wheat yields in both treatments in 2023 reflected good starting moisture and above average in-crop rainfall (413 mm April–November) (Figure 1, Table 3). Above-ground biomass in the cover crop treatment in 2023–2024 represented about 25 percent of the cumulative summer cover crop biomass grown since 2020, highlighting the need for timely and sufficient summer rainfall for achieving summer cover crop growth. Canola yields in 2024 were around average, reflecting below average rain over summer through to September, but with sufficient late rain to finish the crop.

In 2023, wheat yield was greater in the cover crop treatment (6.1 t/ha) than in the control (5.6 t/ha), while in 2024, the canola yield was lower in the cover crop treatment (1.8 t/ha) than in the control (1.9 t/ha) (Table 3), though these differences were not significant. Based on a simple water balance that assumed no runoff or deep drainage, water use by the wheat in the cover crop treatment was 30 mm higher than in the control in 2023, whilst water use by the canola in the cover crop treatment was 23 mm lower than in the control in 2024. Assuming 20 kg wheat grain per ha per mm and 12.5 kg canola grain per ha per mm, these observed water use differences correspond to yield differences of 0.6 t/ha in wheat and -0.3 t/ha in canola — this is close to the yield difference observed for the wheat in 2023, but not for the canola in 2024.

Canola yields from the cover crop and the control treatments in 2024 were similar, despite the cover crop treatment starting with a 30 mm drier profile at sowing (Figure 2) and using 23 mm less water over the season. The lack of yield difference is attributed to the indeterminate nature of canola and its ability to compensate for early drought stress if rain occurs after the start of flowering, as well as deeper extraction of water in the cover crop treatment.

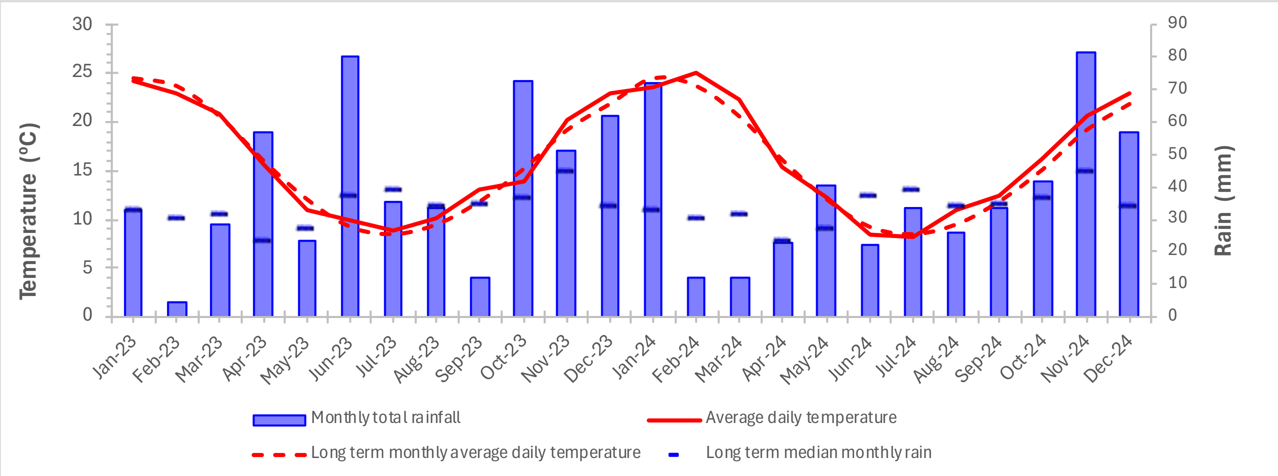

Figure 1 Monthly total rainfall (mm) and daily average temperature (°C) at the Burramine site 2023–2024

Table 3 Treatment mean yield and biomass. Means in rows followed by the same letter are not significantly different (P<0.05, n=3).

	CONTROL			COVER CROP		
Year & season	**Crop**	**Biomass (t/ha)**	**Yield (t/ha)**	**Crop**	**Biomass (t/ha)**	**Yield (t/ha)**
2022–23 summer	Fallow	-	-	Millet, cowpea, sunflower	0	-
2023 winter	Wheat	14.0	5.6 a	Wheat	14.0	6.1 a
2023–24 summer	Fallow	-	-	Millet, cowpea, sunflower	1.2	-
2024 winter	Canola	7.6	1.9 a	Canola	6.2	1.8 a
2020–24 cumulative biomass (winter & summer)		38.6 (38.6 & 0)			39.7 (35.2 & 4.5)	

Note: statistical analysis was done using a pairwise comparison in 2024 and ANOVA amongst all site treatments in 2023, with data sourced from the *Building soil resilience and carbon through plant diversity* Soil CRC project.

PLANT AVAILABLE WATER

There was no difference in the PAWC of the topsoil (0–25 cm) between the control and the cover crop treatment. However, in the sub-soil (25–85 cm) PAWC was larger in the cover crop treatment than in the control by about 30 mm (Table 4). The soil water retention curves for the topsoil and sub-soil (Figure 3) suggest different soil pore volumes in the sub-soil of the control and cover crop plots caused the difference in sub-soil PAWC.

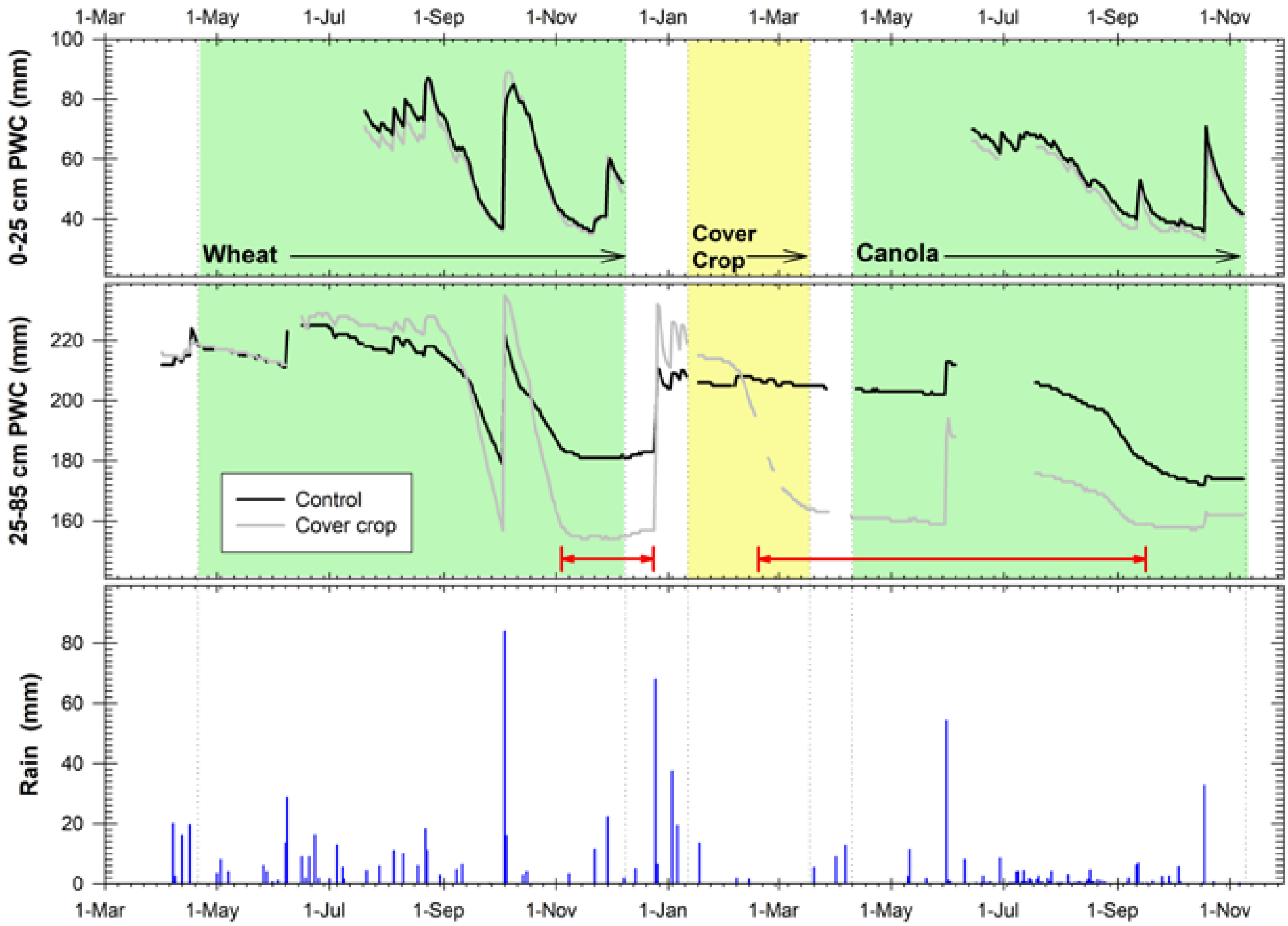

Figure 2 Mean profile water content (PWC) of the topsoil (0-25 cm) and sub-soil (25-85 cm) in the control and cover crop treatments at Burramine 2023–2024, compared with daily rainfall at the site. The horizontal red arrows indicate periods when the PWC of the sub-soil under the control and cover crop treatments were significantly different (P<0.05).

Table 4 Plant available water capacity (PAWC, mm) estimated using a range of methods. DUL; drained upper limit, CLL; crop lower limit.

PAWC METHOD		LABORATORY		FIELD	
		Hyprop	Filter paper	Paired sensors	Soil water sensors
Soil depth (cm)	Treatment	Difference between SWC at -10 kPa & -1500 kPa (mm)			DUL – CLL (mm)
0-25	Control	46	38	42	47
	Cover crop	--	--	41	48
25-85	Control	39	67	67	43
	Cover crop	--	--	**104**	**73**
0-85	Control	85	105	109	90
	Cover crop	--	--	145	121

This difference in PAWC is explained by an examination of the soil water retention curves from the sub-soil of the two treatments. The soil water retention curve describes the relationship between how much water is in a soil (soil water content) and how tightly that water is held by that soil (soil matric potential) (Figure 3). In wet soil, water is available to plants in large pores, so it does not take much energy for the plant to "suck" water into roots. As soil dries, water is only available to plants in progressively smaller pores which hold it at greater negative matric potentials (= suction), and it takes more energy to extract it. Soils with different texture and structure have different quantities of large, medium and small soil pores, and therefore differently shaped soil water retention curves and different plant water availability.

There was no difference between treatments in the water retention curves for the topsoil (Figure 3-left), indicating that the distribution of pores in the topsoil of the control and cover crop treatments were the same and unaffected by the treatment. However, the sub-soil of the cover crop treatment had a higher water content at saturation (matric potential < 4 kPa; Figure 3-right) indicating a greater volume of macropores (pores >75 μm diameter) or cracks. The sub-soil of the cover crop treatment also had a lower water content at the dry end of the curve (matric potentials >80 kPa, Figure 3-right), indicating more micropores of less than about 4 μm diameter. The greater difference between wet and dry soil in the cover crop treatment indicates a larger volume of pores in the suction range that was available to plants and thus greater plant available water capacity. These differences might have been caused by greater soil micro-cracking during summer and/or more root biomass under the cover crop treatment.

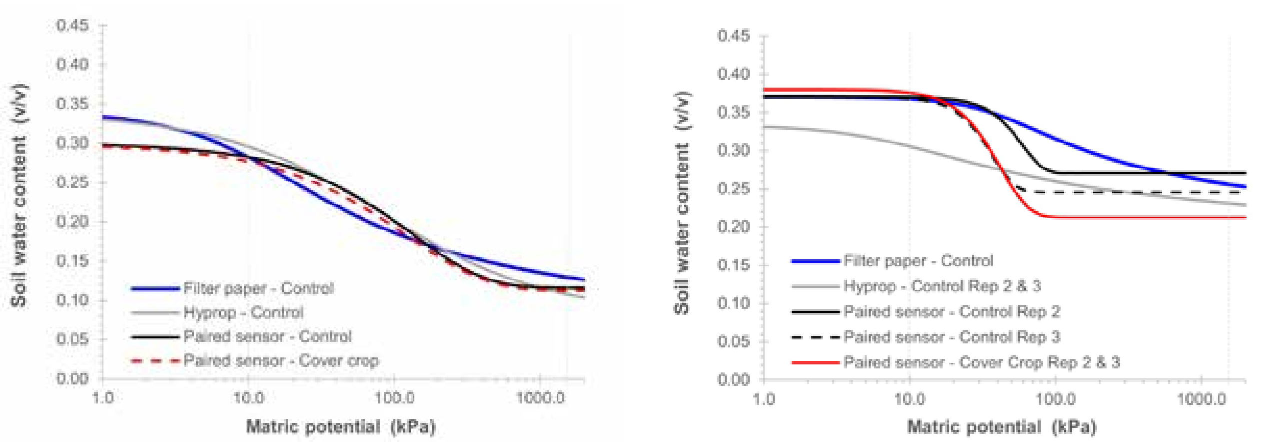

Figure 3 Soil water retention curves for the topsoil (10 cm depth, left) and sub-soil (30 cm depth, right) at Burramine developed using two lab-based methods (Filter paper and Hyprop) and one field method (paired sensor). Unless stated in the legend, curves are the mean of three replicates.

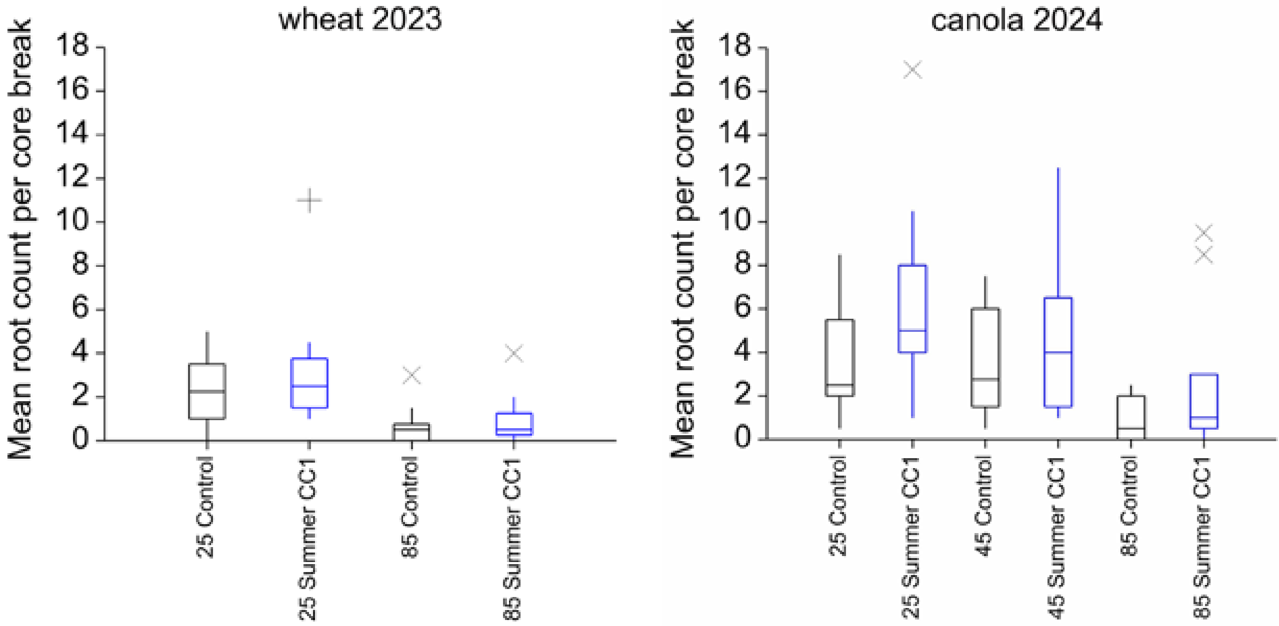

Figure 4 Mean number of roots observed across both faces of soil cores broken at 25, 45 or 85 cm depth at the milk development stage of the wheat crop (24 October 2023, n=12 cores per treatment and depth) and the end of canola flowering (25 September 2024, n=18 cores per treatment and depth) in the control and cover crop (Summer CC1) treatments. The middle line of each box represents the median.

ROOT GROWTH

The water content sensor readings indicated the maximum rooting depth was around 75 cm for both crops and treatments, though root observations at flowering in 2023 and 2024 showed some roots at 85 cm depth. These observations clearly showed that under the wheat in 2023 and the canola in 2024, roots were present in every sample at 85 cm in the cover crop treatment but not in the control (Figure 4). This supports the observation of greater water extraction from deeper soil by the wheat and canola in the cover crop treatment.

CONCLUSION

We don't know what created the changes to the subsoil in the summer cover crop treatment plots that allowed the winter crops to extract more soil water than the winter crops growing in the control plots. However, we think there are two likely possibilities:

1. greater drying over summer in the sub-soil of the cover crop plots, allowing the heavy clay sub-soil to crack and create zones of weakness for the following winter crop to exploit;
2. and/or extra root biomass input by the summer cover-crop treatment to the sub-soil, creating soil structures and macropores that allow for deeper root growth and water extraction by subsequent winter crops.

There also appears to be greater water entry to depth in the cover crop treatment.

Over the long-term, the combined effect of these changes in the summer cover crop treatment should be a decrease in waterlogging and run-off which should also lead to an increase in average yields through greater crop water availability.

Canopy management will be critical for achieving any benefit, as any advantage from good soil water availability early in the season will be lost if large canopies are allowed to develop and use all the water prior to grain filling. Row spacing and seeding rates need to be matched to expected "target" yields, with sufficient pre-plant fertiliser to establish the crop and then later application(s) matched to in-crop rainfall.

Results from one trial on one soil do not justify wide adoption of summer cover cropping as a technique for increasing PAWC on constrained soils. Validation is needed on a wide range of soils, with further investigation to determine how the observed effect on sub-soils is generated, as well as an examination of crop sequencing effects.

However, conservation agriculture principles (minimum tillage, stubble retention, controlled traffic and avoiding bare fallows) are proven to increase PAWC and should be adopted where practicable. An example of how adoption of these principles can improve productivity and farm profitability on similar soils in the southern Riverina to this study can be found at www.researchgate.net/publication/371701131_DPI_Primefact_-_CaseStudy_-_Sustainable_cropping_systems

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