INVESTIGATING SUMMER COVER CROPPING AND INTERCROPPING TO IMPROVE SOIL HEALTH, PRODUCTIVITY

KEY MESSAGES

- **Temporary intercropping, (when two crops are sown in the same paddock at the same time, before one is terminated) and synchronous intercropping (when two crops are sown and harvested at the same time) are promising methods for building diversity in cropping systems, especially where traditional cropping practices such as tillage or monocultures have led to a decline in soil fertility and soil carbon.**
- **Variable summer rainfall at the Burramine trial site highlighted the difficulty in establishing summer cover crops, with overall biomass production highly dependent on follow-up rainfall.**
- **Summer cover cropping was associated with an emerging trend for declined water availability at the time of winter crop sowing, as well as yield penalties.**
- **Temporary intercropping with vetch did not reduce the yield of wheat sown at the same time in this trial.**
- **While temporary intercropping showed a small additional biomass gain, there has been little-to-no impact on soil health or carbon to date.**
- **Future work needs to quantify the variability of biomass and yield production in these systems and relate this to soil nutrient and carbon cycling (resilience).**

BACKGROUND

Ensuring long-term soil sustainability is a major challenge for Australia's cropping systems.

Increasing plant diversity in the temperate cropping systems of the Northern Hemisphere, through intercropping (growing two or more crops at the same time, also known as companion cropping) and summer cover cropping, has been shown to build soil carbon and fertility with minimal impacts on yields. However, the water and climate dynamics of these Northern Hemisphere systems are fundamentally different to the hot, dry summers and winter-dominant rainfall that drives traditional cropping systems in southern Australia.

In the Riverine Plains region, cereal–canola or cereal–canola–legume rotations are typical, however farmers are looking to increase the level of diversity of their systems, to build soil resilience in the face of an increasingly variable climate.

This project was established to assess the suitability and impact of summer cover crops, temporary intercrops and synchronous intercrops for the Riverine Plains region.

SUMMER COVER CROPS

Summer cover crops are intended to replace either the whole, or part of, the traditional summer fallow. Summer cover crops may offer benefits of soil protection from erosion, as well as increased plant inputs to the soil. Having living roots in the ground, as opposed to just stubble, is seen as a key reason why summer cover crops may result in improved soil health and carbon. On the other hand, water used over the fallow and subsequent mineral nitrogen tie-up may result in a yield penalty for the winter crop sown after the summer cover crop.

INTERCROPPING (COMPANION CROPPING)

Intercropping, also known as companion cropping, is when two or more crops are grown at the same time. These can be planted and harvested at the same time (synchronous intercropping/companion cropping) or one crop can be terminated to reduce resource competition (temporary intercropping/companion cropping). Plant interactions in these systems can lead to overyielding, which is when there is a higher biomass or yield in the intercrop compared to respective monocultures, while planting cash crops alongside legumes can add nitrogen to the system. These benefits may then translate to improved soil health and increased carbon.

AIMS

Using a replicated field trial, this project aims to assess the scope for diverse cropping systems to build soil fertility and carbon, thereby building more resilient cropping systems.

Specifically, the project aims to:

1. Understand yield impacts (penalties or overyielding) of implementing summer cover crops, temporary intercropping and synchronous intercropping.
2. Identify the impacts of diverse cropping systems on soil health and soil carbon.

METHOD

A long-term trial site was established by Riverine Plains at Burramine in north east Victoria to monitor the effects of increasing plant diversity over the medium term (4–7 years). This site has been looking at the effects of summer cover crops and winter intercrops on yield and soil health.

TRIAL LAYOUT AND TREATMENTS

The site was originally established in 2019 as part of the Soil CRC project *Increasing plant species diversity in cropping systems*, with treatments focusing on locally grown summer cover crops, with additional species incorporated to ensure a mix of root mass and legumes.

The treatments were refined over time, and by 2023, the trial featured seven treatments, including a control, three species cover crop, nine species cover crop, temporary intercropping treatments (wheat and vetch), as well as a maximum diversity treatment with both summer cover cropping and winter intercrops (Table 1). Synchronous intercropping with canola paired with field and faba bean was then assessed in 2024. Treatments were replicated three times in plots measuring 8m (4 x 2) x 18 m^2. The summer cover crop and temporary intercrops are being repeated in 2025.

The summer cover crop treatments in this trial were sown when there was enough rainfall to germinate the crop; this was highly dependent on summer storms to provide enough moisture, as well as follow-up rainfall for biomass production. Summer cover crops were terminated after 8-12 weeks of growth using 570 g/L glyphosate at a rate of 2 L/ha in preparation for the winter crop. Winter crops were sown in autumn, according to the rotation specified in Table 1.

2023

In 2023, limited sowing opportunities and poor follow-up rainfall meant the summer cover crops failed to establish after being sown on 2 February.

In the winter crop phase, Illabo wheat was sown at a standard rate of 70kg/ha in all treatments, including the intercrop, while the vetch intercrop was sown at a rate of 40 kg/ha. All winter plots received 80 kg/ha MAP at sowing, with in-crop urea applied at 100-110 kg/ha.

Vetch in the temporary intercrop treatments was terminated with 700 g/L 2, 4-D at 1.5 L/ha on 26 July 2023.

Soil water and mineral nitrogen were assessed prior to winter crop sowing, at vetch termination and again at anthesis using 90 cm soil cores. Cores were sectioned into 10 cm increments and then aggregated into 0–10, 10–30, 30–60 and 60–90 cm depths for analysis, with mineral nitrogen results still pending. Soil health samples were also collected at each stage to 10 cm depth using a push corer and dried at 40°C, with the measurements summarised in Table 2. Wheat and vetch biomass were also sampled at vetch termination.

ANOVA analysis was used to determine statistical significance, using a 0.05 significance level.

Final yield was determined from header yields, and grain protein content was determined by a laboratory nitrogen and protein analyser.

2024

In 2024, summer cover crop treatments were sown on 11 January 2024 before being terminated on March 18.

For the 2024 winter crop rotation, canola (cv Hyola Blazer TT) was sown at a standard rate of 3 kg/ha on 10 April, 2024, while intercropped field peas (cv Morgan) and faba beans (cv Bendoc) were sown with an inoculant at 100 kg/ha and 150 kg/ha respectively. Fertiliser application rates were the same as for the 2023 trial.

Biomass was sampled just prior to termination.

Winter crop treatments were harvested using a plot harvester at crop physiological maturity.

Soil water and nitrogen measurements were repeated for the synchronous intercrop treatments, however, deep coring did not occur at anthesis for soil water and mineral nitrogen due to the high levels of biomass present.

Table 1 Treatments in the Burramine *Building soil resilience and carbon through plant diversity* trial, 2023 – 2024

TREATMENT	SUMMER CROP (2023-2024)	WINTER CROP ROTATION		
		2023	2024	2025
Control	Fallow	Wheat	Canola	Wheat
Three species summer cover crop	Sunflower, millet, cowpea	Wheat	Canola	Wheat
Nine species summer cover crop	Sunflower, safflower, sorghum, millet, cowpea, buckwheat, radish, turnip, sunnhemp	Wheat	Canola	Wheat
Temporary intercrop	Fallow	Wheat & vetch	Canola	Wheat & vetch
Peaola (synchronous intercrop)	Fallow	Wheat	Canola & field pea	Wheat
Beanola (synchronous intercrop)	Fallow	Wheat	Canola & faba bean	Wheat
Maximum diversity	Sunflower, safflower, sorghum, millet, cowpea, buckwheat, radish, turnip, sunnhemp	Wheat & vetch	Canola & field pea	Wheat & vetch

Note: the maximum diversity treatment is a combination of summer cover crop, temporary intercrop and synchronous intercrop treatments

Table 2 Soil health measurements used in the Burramine *Building soil resilience and carbon through plant diversity* trial

MEASUREMENT (UNITS)	DESCRIPTION
***Soil carbon (%)**	Soil carbon (soil organic carbon) is the concentration of carbon in the soil and is an indicator of ecosystem productivity. Higher carbon indicates the potential for more in-crop biomass production and higher soil microbial biomass.
***Soil nitrogen (%)**	A basic indicator of nitrogen available in the system as it does not differentiate between organic (in soil organic matter) and inorganic (ammonium, nitrate) nitrogen. Carbon to nitrogen ratios can be a useful soil health indicator.
Carbon: nitrogen ratio	Calculated as soil carbon divided by soil nitrogen. Soil organic matter formation occurs within an ideal carbon: nitrogen range of 10-20 and maintaining this range may help prevent degradation of soil organic matter through nitrogen tie-up.
Permanganate oxidisable carbon (mg carbon / (i.e. mg carbon/g soil) g soil)	Abbreviated as POXC. It is seen as a measure of organic matter that is labile (its form changes readily in soil) or is recently derived from plant material and is therefore a potential early indicator for soil carbon building.

*Determined via LECO laboratory analysis

RESULTS & DISCUSSION

2023

SUMMER COVER CROP BIOMASS PRODUCTION

In 2023, limited sowing opportunities and follow up rainfall meant the summer cover crops failed to establish, highlighting the difficulty of growing rain-fed summer crops in a winter-dominant rainfall environment.

TEMPORARY INTERCROP BIOMASS PRODUCTION

The wheat and temporary intercrop vetch were planted on 19 April 2023 into good soil moisture. At vetch termination on 26 July 2023, there was an average 3.05 t/ha wheat biomass in the control treatment (Table 3). This was significantly higher ($p < 0.05$) than the average wheat biomass measured in the temporary intercrop (1.44 t/ha) and maximum diversity treatments (2.70 t/ha). Vetch biomass averaged 1.09 and 1.24 t/ha in the temporary intercrop and maximum diversity treatments respectively. Wheat seeding rates in the intercrop treatment were the same as the control (70 kg/ha), with the lower wheat biomass in the intercrop likely reflective of the increased competition for resources by the vetch. By anthesis, there were then no significant differences between treatments in biomass, with values ranging from 3.7–4.0 t/ha.

YIELD

In 2023, the control produced an average wheat yield of 5.6 t/ha while the three species summer cover crop, nine species cover crop, temporary intercrop and maximum diversity treatments had average wheat yields of 6.1, 5.7, 5.9 and 6.0 t/ha respectively, with these differences not significant ($p > 0.05$). Grain protein content was between 10 and 11 percent for all treatments (not presented).

Table 3 Winter crop biomass and yield, 2023 at the *Building soil resilience and carbon through plant diversity* project trials at Burramine

TREATMENT	SUMMER CROP BIOMASS^	WHEAT BIOMASS (T DM/HA)	VETCH BIOMASS (T DM/HA)	AVE BIOMASS (T DM/HA)	WHEAT GRAIN YIELD (T/HA)
Sample date		Vetch termination, 26 July		Anthesis, 23 October	Harvest, 11 November
Control	Fallow	3.0	-	3.7	5.6
Three species summer cover crop	Nil	-	-	4.0	6.1
Nine species summer cover crop	Nil	-	-	3.8	5.7
Temporary intercrop	Fallow	1.4	1.0	3.7	5.9
Maximum diversity	Nil	2.7	1.2	3.8	6.0

^Summer cover crop growth was poor, and biomass was not measured

2024

SUMMER COVER CROP BIOMASS PRODUCTION AND WATER USE

In 2024, summer cover crops sown in mid-January established well and showed good early vigour, helped by summer storms, before conditions turned dry in February and March, reducing biomass production. Summer crop treatments were terminated in mid-March, after approximately eight weeks growth, to allow preparation for the 2024 winter crop season.

In 2024, the three species cover crop produced an average of 1.43 t/ha biomass, while the nine species summer cover crop produced an average of 1.29 t/ha biomass and the summer cover crop in the maximum diversity treatment produced an average of 1.28 t/ha biomass (Table 4). There was no statistically significant difference between treatments and biomass production was below the 2 t/ha recommended to prevent erosion.

Across the three replicates there was an average of 206 mm of soil water stored in the control prior to sowing of the 2024 winter crop. The results showed an average of 194 mm in the three species cover crop mix, 188 mm in the nine species cover crop mix and 174 mm in the maximum diversity treatment (Table 3). All summer crop treatments had significantly lower soil stored water than the control ($p < 0.05$), but there was no significant difference in stored water between the individual cover crop treatments. This shows how summer cover cropping can deplete soil moisture reserves ahead of the winter crop when rainfall isn't sufficient to refill the profile.

Table 4 Summer cover crop biomass, stored soil water prior to sowing the winter crop, winter crop biomass and yield, at the *Building soil resilience and carbon through plant diversity* trial at Burramine, 2024

TREATMENT	SUMMER BIOMASS AT TERMINATION (T DM/HA)	STORED MOISTURE 0-90CM (MM)	FLOWERING CANOLA BIOMASS (T DM/HA)	LEGUME BIOMASS (T DM/HA)	GRAIN YIELD (T/HA)
Control	Fallow	206	4.0	-	Canola: 1.9
Three species summer cover crop	1.4	194	3.6	-	Canola: 1.8
Nine species summer cover crop	1.3	188	3.4	-	Canola: 1.5
Temporary intercrop	Fallow	-	4.7	-	Canola: 1.9
Peaola* (synchronous intercrop)	Fallow	-	2.6	1.2	Canola: 1.8 Field pea: 0.6
Field pea	Fallow	-	-	1.6	Field Pea: 1.0
Beanola# (synchronous intercrop)	Fallow	-	2.6	2.0	Canola: 2.2 Faba bean: 1.3
Faba bean	Fallow	-	-	4.3	Faba bean: 2.5
Maximum diversity	1.3	174	2.5	1.1	Canola: 1.7 Field pea: 0.64

SYNCHRONOUS INTERCROP BIOMASS PRODUCTION

Average canola flowering biomass in the control treatment was 4 t/ha (Table 4). There were no significant differences in canola biomass between the canola-field pea, canola-faba bean and maximum diversity treatments with flowering biomass ranging from 2.5-2.6 t/ha.

Field pea flowering biomass in their monoculture was 1.6 t/ha, while average treatment field pea biomass was 2.25 t/ha in the canola-field pea treatment and 1.12 t/ha in the maximum diversity treatment ($p > 0.05$ between intercrop treatments).

When biomass (or yield) for a synchronous intercrop species is more than 50 percent of its monoculture counterpart, the system is overyielding. For 2024, the canola-faba bean system outperformed the monocultures.

YIELD

Average canola yield for the control in 2024 was 1.91 t/ha; this was not significantly different to the three species summer cover crop treatment (1.78 t/ha) and nine species summer cover crop treatment (1.45 t/ha). While the pairwise comparisons in this year are not able to be separated statistically, they do represent an emerging trend of suppressed yield due to cover crop growth when data is analysed across this trial and a paired trial with Central West Farming Systems (data not yet published). The synchronous intercrop yields were similar to the monoculture yields, indicating overyielding (Table 4).

SOIL HEALTH AND SOIL CARBON

Soil health measures related to carbon cycling have not shown any significant treatment differences since 2019. Mean soil carbon levels have varied between 1.1–1.5 percent over the duration of the trial, which is fairly typical of cropping soils in the region, with soil nitrogen ranging between 0.1 and 0.15 percent. At anthesis in 2023, there were no treatment effects on soil carbon, soil nitrogen, carbon to nitrogen ratio and permanganate oxidisable carbon (Figure 1). Results for flowering-maturity in the 2024 canola-intercrop season are pending analysis.

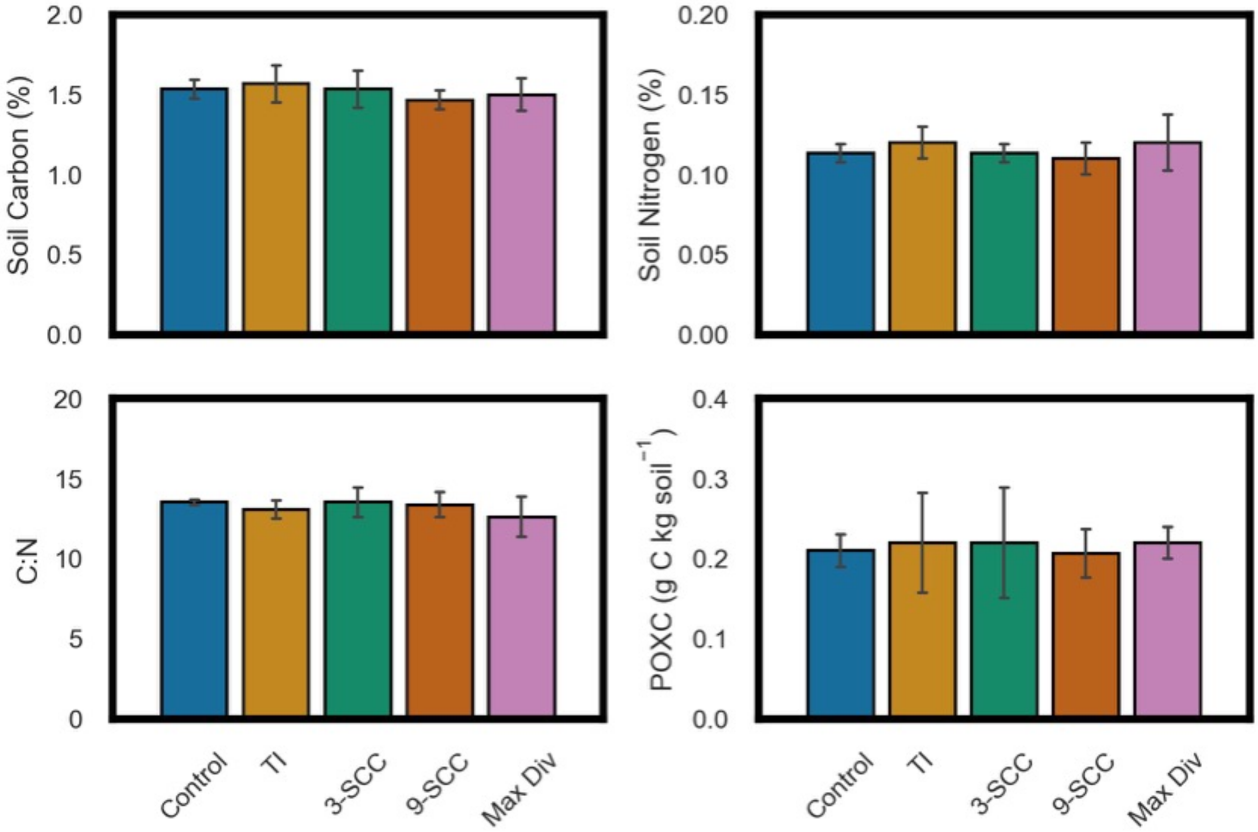


Figure 1 Soil carbon, soil nitrogen, carbon to nitrogen ratio (C:N) and permanganate oxidisable carbon for the control, temporary intercrop (TI), three species summer cover crop (3-SCC), nine species cover crop (9-SCC) and maximum diversity (Max Div) treatments at anthesis in 2023

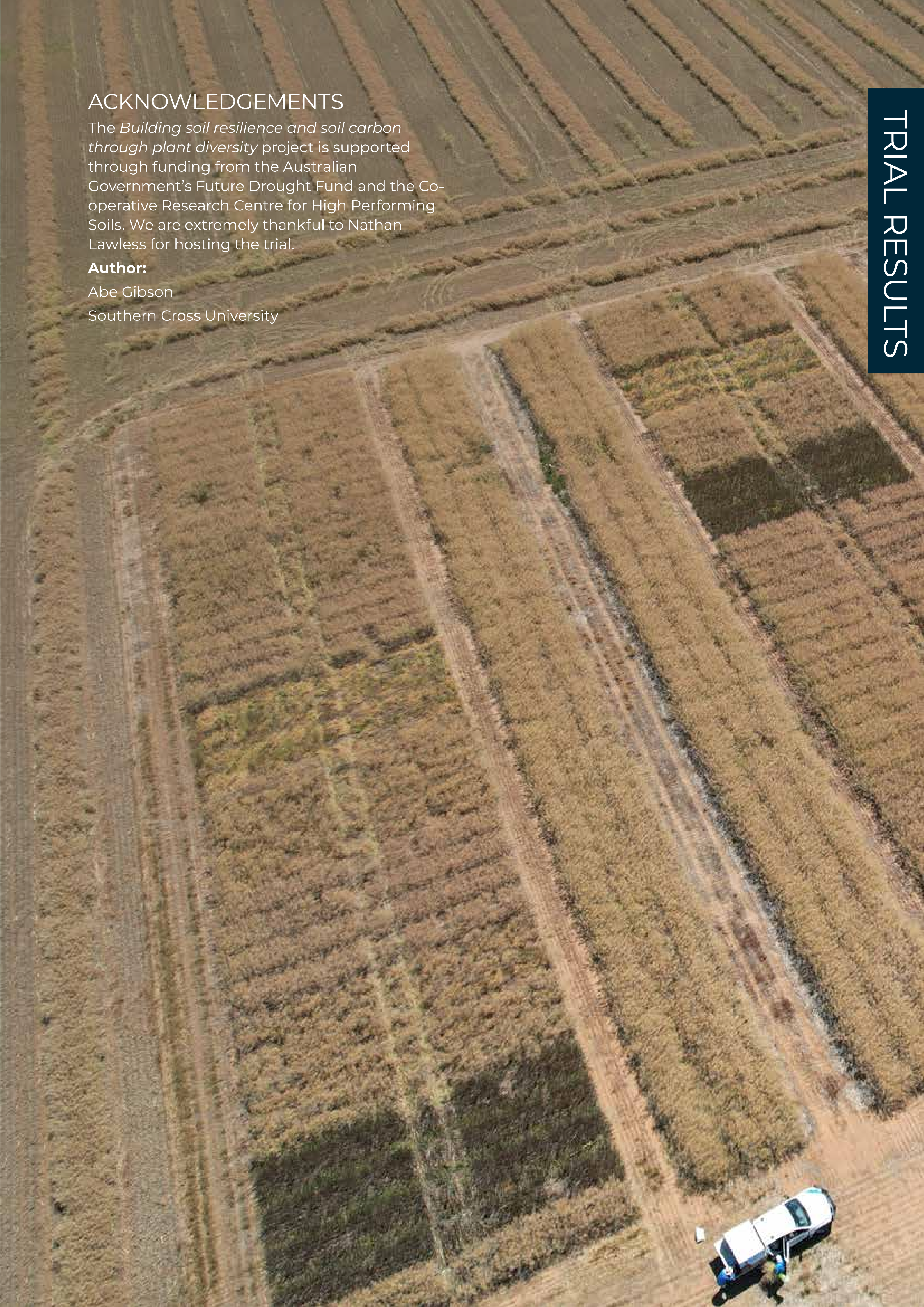
An increase in saturated hydraulic conductivity—the rate that water moves through the soil pore system when saturated—was observed in the summer cover crop treatments following a large biomass cover crop in 2021. We believe this may be due to improved soil aggregation—soil particles joining together and creating pore space for water and air to move through—due to the root growth and their exudates. This result is still to be revisited to determine the drivers of this change and if this effect has persisted.

OBSERVATIONS

Improving soil health and carbon requires a sustained increase in plant biomass production over multiple seasons. Establishing summer cover crops is difficult given the extreme water limitation over this period and so their impact on soil health has been limited in this trial. When they are established, there is an emerging trend for declined water availability at sowing and yield penalties. This is consistent with previous work looking at the importance of summer fallow rainfall and water and nitrogen use of summer weeds. Further, in this and similar trials conducted in other regions, summer cover biomass has often been less than the 2 t/ha recommended to protect the soil from erosion. In wet summers, biomass production above 3 t/ha can occur with some improvement in infiltration rates observed after this cover crop year. Therefore, while summer cover cropping is emerging as an opportunistic practice, farmers require further data to make informed decisions about the likelihood of success each season.

Temporary intercropping has not been shown to reduce yield of the main winter crop in this trial, supporting results from other studies. While temporary intercropping showed a small additional biomass gain in this trial, this has not impacted soil health or carbon. However, synchronous intercrops could have a role to play in building soil health by promoting more biomass production per unit of land area, while also providing plant-to-soil input diversity.

Due to the availability of moisture in the growing system, summer cropping and intercropping may be easier options to target for generating positive outcomes from plant diversity in Australian cropping systems, however ongoing work is required to optimise these systems for our conditions.



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Author:

Abe Gibson

Southern Cross University