

# Agronomic and management options to improve soil fertility and nutrient cycling

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## Key findings

- Chicken litter treatments (5 t/ha surface applied) recorded improved growth and vigour at all NDVI timings, however nitrogen was not the limiting factor in 2025 and water stress resulted in no yield benefit.
- Biochar when applied without chicken litter, performed similarly to standard practice management across all parameters measured in 2025.
- Background soil N was more than what was needed to produce the ~1.5 t/ha yields observed, meaning that differences in nitrogen rates likely had little to no effect in 2025. Biochar applied with a full rate, half rate or no inorganic fertiliser (IF) all performed similarly, as did chicken litter treatments when applied with a full or half rate of IF fertiliser.
- Sowing vetch with wheat did not impact wheat yield, however reduced grain quality, likely due to competition and water depletion caused by vetch growth in a season where water was already a limiting factor.

## Introduction

In low to medium rainfall areas, available water can become a limiting factor impacting not only crop growth and yield, but biological function, nutrient cycling and overall soil health. The sustainability and productivity of farming systems are dependent on the ability to sustain and enhance soil biological function to support the cycling of nutrients, disease suppression and the tolerance to abiotic stresses including temperature and drought conditions (Gupta et al, 2025).

A decline in soil fertility and natural capital is being observed on a global scale (Osman, 2014). To sustain or improve agricultural productivity to meet the growing food demand, it is essential that soil health and function be addressed (Strickland et al, 2019).

Despite the potential benefits of maintaining soil cover through increased stubble retention, the slow breakdown of residue often creates issues for farmers. The use of amendments to promote stubble breakdown is being investigated in a new long-term trial at Hart. Two products are included, which both assist with plant cell wall (cellulose) degradation by promoting microbial activity through two different approaches. Through this process, stubble load can be reduced and plant residues converted into useful forms of organic carbon including humus.

The use of organic amendments to improve soil cover, nutrient retention and cycling, water infiltration and water holding capacity are also being investigated. These amendments include biochar at various rates and chicken litter (year 1 only at 5 t/ha) with and without inorganic fertiliser. Soil and crop residual effects will be monitored for three years. In addition, this trial investigates the interaction between chicken litter application and the use of inorganic fertilisers.

We aim to quantify the economic and productivity potential of various treatments to improve system resilience. There is published evidence to show that biochar applied with either inorganic fertiliser or chicken manure can significantly improve yield while reducing fertiliser requirements (Bai & al, 2022), (Ye, Camps- Arbestain, Shen, & Lehmann, 2019) which will be tested in these trials.

The use of companion cropping to improve soil function through increased diversity, soil cover and nutrient cycling will be addressed through the inclusion of a treatment where vetch is under sown in cereal rotations and sprayed out at peak biomass. It is intended that vetch residue will remain as soil cover to provide additional benefits over summer months, in addition to its N fixation during the growing season.

A plot trial was established at Hart, SA in 2025 to evaluate agricultural practices to improve soil water and fertility in wheat (*Triticum aestivum*, cv. Calibre) over three growing seasons (Table 1).

Table 1. Trial details for 2025 soil water and fertility trial at Hart, SA.

|                                |                    |                   |  |
|--------------------------------|--------------------|-------------------|--|
| <b>Plot size</b>               | 1.75 x 10 m        | <b>Soil N</b>     | 120.4 kg N/ha  |
| <b>Location</b>                | Hart, SA           | <b>Fertiliser</b> | Seeding: DAP (18:20)<br>Zn 1% + Flutriafol @<br>80 kg/ha |
| <b>Seeding date</b>            | June 20, 2025      |                   |  |
| <b>Harvest date</b>            | December 3, 2025   |                   |  |
| <b>Previous crop</b>           | Bale awnless wheat |                   |  |
| <b>Growing season rainfall</b> | Decile 3 (223 mm)  |                   |  |

## Methodology

### *Trial design and treatments*

This project will be delivered across three growing seasons (2025, 2026 and 2027) and will follow a wheat, barley and lentil crop rotation, respectively. All treatments will be replicated three times across two stubble management strategies (standard and tall) to determine if soil fertility and water retention can be increased by management strategies which promote soil cover, microbial activity and nutrient cycling to improve the resilience of South Australian soils (Table 2).

This project was developed by Hart Field-Site Group and is one of several trials across the state forming part of the Future Drought Fund (FDF) funded SA Discovery Farms project, led by SARDI and Flinders University. Treatments for the field trial at Hart (Table 2) were developed in consultation with local growers and advisors considering soil improvement practices to advance soil health.

Table 2. Treatment list for 2025 soil water and fertility trial at Hart, SA.

| Treatment Number | Treatment   | Rate  |
|------------------|---|---|
| 1                | Standard practice   | Standard practice   |
| 2                | High tolerance to summer weeds                                  | No summer weed control  |
| 3                | Increased diversity: mixed species temporary companion cropping | Under sown with vetch (30 kg/ha)  |
| 4                | Stubble degradation enzyme (post-harvest)                       | Res + @ 1.2 L/ha  |
| 5                | Fungi promoting stubble break-down amendment (post-harvest)     | BioMAX Digest Inoculum @ 1 L/ha + BioMAX Digest Kicker @ 5 L/ha             |
| 6                | Biochar (with inorganic fertiliser)                             | 300 kg/ha (full synthetic rate)   |
| 7                | Biochar (no inorganic fertiliser)                               | 300 kg/ha   |
| 8                | Biochar (with half inorganic fertiliser)                        | Half synthetic rate + 20% biochar (of fertiliser rate = 6.5 kg/ha biochar)  |
| 9                | Organic amendment (with inorganic fertiliser)                   | Standard practice *   |
| 10               | Organic amendment (with half inorganic fertiliser)              | Half synthetic rate *   |
| 11               | Organic amendment + biochar (with inorganic fertiliser)         | 300 kg/ha biochar (full synthetic rate) *                                   |
| 12               | Organic amendment + biochar (with half inorganic fertiliser)    | Half synthetic rate + 20% biochar (of fertiliser rate = 6.5 kg/ha biochar)* |

\*Organic amendment applied = chicken litter @ 5 t/ha in year 1 only

Each treatment is replicated for two stubble management strategies (standard and tall)

#### Site management and environmental conditions

The trial was managed through the application of pesticides to ensure an insect, weed and disease-free canopy (excluding treatments with specific pest management plans). The 2025 growing season was characterised by below average rainfall (Decile 3, 223 mm) which should be considered when interpreting these results. The trial was not subject to stress from any other external or environmental factors.

#### Assessments

Prior to sowing in 2025, site characterisation including chemical analysis, bulk density, soil structure, water repellence, infiltration, soil strength (penetrometer), macrofauna, slaking & dispersion and carbon tests were undertaken. A PredictaB test and estimated soil water (GWC% and VWC%) for the site were also conducted. A visual percentage of ground cover and initial stubble dry matter (DM) was measured from five locations across the site. For subsequent years, stubble measured prior to sowing will be the total stubble, including the remaining residue from all years for each plot. For the duration of the project, soil temperature will be measured.

Plant counts were conducted in each plot to determine emergence (plants/m<sup>2</sup>). Normalised difference vegetation index (NDVI) was conducted to measure biomass at four separate timings; growth stage (GS) 13-21, GS 31, GS 43 and GS 65-69 utilising a handheld Greenseeker. During the growing season anthesis microbiome & full physical-chemical soil sampling was conducted. At harvest maturity, whole plant samples were taken to estimate harvest index (HI). Plots were harvested by a plot harvester and yield was determined. Post-harvest analysis was conducted to determine protein (%), screenings (%), test weight (kg/hL) and 1000 grain weight. Post harvest weed counts per plot will be conducted after summer rain when weed emergence is evident. Similar in-crop field measurements will be conducted in 2026 and 2027.

Trial data was analysed utilising REML spatial model (Regular Grid) in GenStat 24<sup>th</sup> Edition. Bonferroni critical difference values (Bonferroni CD) were calculated using average standard error of difference (SED) from the GenStat output and the relevant t critical value calculated in Excel. This number can be used to determine the difference required for a significant effect between treatments.

## Results and discussion

High starting soil N and below average growing season rainfall (Decile 3) limited treatment effects in the first season of this trial. Despite there being differences in biomass production (NDVI) and grain quality between treatments, yield effects were not observed.

This trial will continue for an additional two seasons, where it is anticipated that compounding treatment effects will become clear, particularly if favourable growing season conditions are experienced.

Prior to application, both the chicken litter and biochar were analysed for complete composition to determine the amount of additional nutrients being added into the system. By applying 5 t/ha of chicken litter, an additional 159 kg of N/ha was supplied (Table 3). Soil nitrogen stores were already high across the site (~120 kg N), meaning that despite chicken litter treatments (Treatments 9-12), recording improved growth and vigour at all NDVI timings (Table 4), water stress resulted in no yield benefit. The residual effect of a single chicken litter application will be measured in 2026 and 2027 growing seasons, where additional benefits may be observed as break down occurs and additional nitrogen becomes available.

*Table 3. Amount of nutrient applied with 5 t/ha chicken litter application.*

| <b>Nutrient analysed</b> | <b>Applied nutrient (kg nutrient/ha)</b> |
|--------------------------|--|
| Total Nitrogen           | 159.2                                    |
| Calcium                  | 96.6                                     |
| Iron                     | 5.4                                      |
| Magnesium                | 34.7                                     |
| Phosphorus               | 45.4                                     |
| Potassium                | 139.7                                    |
| Sodium                   | 30.6                                     |
| Sulphur                  | 32.4                                     |
| Zinc                     | 2.2                                      |

Biochar was applied at various rates and by multiple methods detailed in Table 4 (Treatments 6-8, 11 and 12), however when applied without chicken litter (Treatments 6-8), performed similarly to standard practice management across all parameters measured in 2025 (Table 4). Additionally, there was no short-term benefit of applying biochar with chicken litter (Treatment 11 and 12) when compared to treatments where chicken litter was applied standalone (Treatments 9 and 10). Unlike the chicken litter, which will be applied in the first year only, biochar treatments will be repeated for each season of the trial. Compounding effects of biochar application may be noticed in future years, as it is slow to break down within systems. Biochar is also known for its high surface area and water holding capacity, meaning that as levels within the system increase over the three seasons, soil and productivity differences may be observed.

Table 4. Results from first season of new long-term trial at Hart, SA. Shaded values in each column indicate best performing treatments. Any difference between two means greater than the Bonferroni critical difference value is significant at  $\alpha = 0.05$  after Bonferroni correction.

| Treatment  | NDVI 1              | NDVI 2              | NDVI 3             | NDVI 4              | Yield<br>t/ha | Protein<br>%       | Screenings<br>%   | Test weight<br>kg hL | 1000<br>GW          |
|--|---------------------|---------------------|--------------------|---------------------|---------------|--------------------|-------------------|----------------------|---------------------|
| 1,2,4,5 Standard practice (SP)   | 0.18 <sup>ab</sup>  | 0.39 <sup>abc</sup> | 0.56 <sup>a</sup>  | 0.30 <sup>abc</sup> | 1.51          | 13.3 <sup>c</sup>  | 7.1 <sup>a</sup>  | 76.0 <sup>bc</sup>   | 26.7 <sup>abc</sup> |
| 3 Increased diversity  | 0.19 <sup>cd</sup>  | 0.47 <sup>de</sup>  | 0.61 <sup>b</sup>  | 0.34 <sup>d</sup>   | 1.53          | 13.6 <sup>cd</sup> | 8.3 <sup>b</sup>  | 75.2 <sup>a</sup>    | 25.8 <sup>a</sup>   |
| 6 Biochar 300 kg/ha<br>+ full SP fertiliser  | 0.18 <sup>abc</sup> | 0.38 <sup>ab</sup>  | 0.54 <sup>a</sup>  | 0.29 <sup>ab</sup>  | 1.55          | 13.2 <sup>bc</sup> | 6.8 <sup>a</sup>  | 76.2 <sup>bc</sup>   | 26.5 <sup>abc</sup> |
| 7 Biochar 300 kg ha<br>(no additional fertiliser)                                  | 0.18 <sup>a-d</sup> | 0.40 <sup>a-d</sup> | 0.54 <sup>a</sup>  | 0.28 <sup>a</sup>   | 1.51          | 12.4 <sup>a</sup>  | 6.6 <sup>a</sup>  | 76.5 <sup>bc</sup>   | 27.0 <sup>abc</sup> |
| 8 Biochar 6.5 kg ha (as urea coating)<br>+ half SP fertiliser                      | 0.16 <sup>a</sup>   | 0.36 <sup>a</sup>   | 0.53 <sup>a</sup>  | 0.28 <sup>a</sup>   | 1.50          | 12.9 <sup>ab</sup> | 6.6 <sup>a</sup>  | 76.5 <sup>c</sup>    | 27.4 <sup>bc</sup>  |
| 9 Organic amendment<br>+ full SP fertiliser  | 0.19 <sup>bcd</sup> | 0.46 <sup>bde</sup> | 0.66 <sup>bc</sup> | 0.34 <sup>d</sup>   | 1.47          | 14.4 <sup>f</sup>  | 7.2 <sup>ab</sup> | 75.8 <sup>ab</sup>   | 27.1 <sup>bc</sup>  |
| 10 Organic amendment<br>+ half SP fertiliser                                       | 0.20 <sup>d</sup>   | 0.49 <sup>e</sup>   | 0.66 <sup>bc</sup> | 0.34 <sup>bcd</sup> | 1.47          | 14.1 <sup>ed</sup> | 7.3 <sup>ab</sup> | 75.9 <sup>abc</sup>  | 26.1 <sup>ab</sup>  |
| 11 Organic amendment + biochar 300 kg ha<br>+ full SP fertiliser                   | 0.20 <sup>d</sup>   | 0.51 <sup>e</sup>   | 0.66 <sup>bc</sup> | 0.35 <sup>d</sup>   | 1.56          | 14.2 <sup>ed</sup> | 6.6 <sup>a</sup>  | 76.1 <sup>bc</sup>   | 27.3 <sup>bc</sup>  |
| 12 Organic amendment + biochar 6.5 kg ha<br>(as urea coating) + half SP fertiliser | 0.20 <sup>d</sup>   | 0.53 <sup>e</sup>   | 0.68 <sup>c</sup>  | 0.34 <sup>cd</sup>  | 1.47          | 13.8 <sup>de</sup> | 6.6 <sup>a</sup>  | 76.2 <sup>bc</sup>   | 27.4 <sup>c</sup>   |
| <b>P-value</b>   | <b>&lt;0.001</b>    | <b>&lt;0.001</b>    | <b>&lt;0.001</b>   | <b>&lt;0.001</b>    | <b>NS</b>     | <b>&lt;0.001</b>   | <b>&lt;0.001</b>  | <b>&lt;0.001</b>     | <b>&lt;0.001</b>    |
| <b>Bonferroni CD</b>   | <b>0.02</b>         | <b>0.07</b>         | <b>0.06</b>        | <b>0.04</b>         | <b>0.43</b>   | <b>0.69</b>        | <b>1.18</b>       | <b>0.69</b>          | <b>1.2</b>          |

Both the chicken litter and biochar treatments were applied with varying inorganic fertiliser (IF) strategies to test if amendments could potentially reduce IF requirements (detailed in Table 4). There were no effects of varying IF rates noticed in 2025, likely due to already high background N as previously stated. Biochar applied with full, half or no IF all performed similarly, as did chicken litter treatments when applied with a full or half rate of IF fertiliser. Background soil N was more than what was needed to produce the ~1.5 t/ha yields observed across all treatments, meaning that differences in nitrogen rates likely had little to no effect on plant and grain production in 2025. Future soil tests may however highlight differences in applied nitrogen, as a result of reduced uptake in 2025 and nitrogen carryover across seasons. It is important to consider the dry conditions when interpreting these results, as nitrogen availability is likely to have a more pronounced effect when growing season conditions are conducive to increased plant growth and yield potential.

Carbon and nitrogen composition of both the chicken litter and biochar were tested prior to sowing (Table 5). While chicken litter contained a significantly higher percent of nitrogen, carbon levels were close to half that of the biochar. Carbon to nitrogen ratios (C:N ratio) impact nutrient cycling and the rate at which nitrogen becomes available. Chicken manure is nitrogen-rich and therefore decomposes relatively quickly, with a low C:N ratio. Conversely, biochar has an extremely high C:N ratio due to being majority carbon with very little nitrogen. While both products fall outside of the ideal C:N ratio (20:1-30:1) to balance mineralisation and immobilisation for nutrient release (Brust, 2019), applying the two amendments together may assist with slowing chicken litter nutrient release by increasing the C: N ratio of chicken litter standalone. This relationship will be further investigated over future years of the trial.

*Table 5. Carbon and nitrogen composition of chicken litter and biochar used in 2025.*

|                  | <b>Chicken litter</b> | <b>Biochar</b> |
|------------------|-----------------------|----------------|
| Total carbon %   | 35.5                  | 73.7           |
| Total nitrogen % | 3.18                  | 0.58           |
| C:N ratio        | 11:1                  | 127:1          |

Where species diversity was increased through the addition of a half rate (30 kg/ha) of vetch sown with wheat (Treatment 3), NDVI was higher than the standard practice treatment at all timings (Table 5). Despite there being no yield penalty of including vetch with a standard rate of wheat, reduced wheat grain quality was observed. Screenings, test weight and 1000 grain weight (GW) were all lower for the increased diversity treatment than standard practice, which can likely be attributed to increased competition and water depletion caused by vetch growth in a season where water was already a limiting factor.

In spring of 2025, all plots were characterised for their microbial population and diversity (results pending), to allow for soil biology treatment comparisons at the conclusion of the trial. This will provide valuable information about the potential effects of various management strategies imposed over multiple seasons to improve soil health, nutrient cycling and system resilience.

In 2025 Treatments 2, 4 and 5 were all managed as per standard practice (Treatment 1), as the stubble sprays and summer weed control treatments were not carried out until after harvest. For this reason, all Treatment 2, 4 and 5 plots were analysed as Treatment 1 this season so that results accurately reflected 2025 treatments. Additionally, stubble was not cut at different heights in 2024, meaning that stubble height treatments were not applicable for 2025 analysis. Plots were cut at two heights during the 2025 harvest, which will allow for all treatments and both stubble heights to be differentiated during statistical analysis in 2026.

## Summary

High starting soil N and below average growing season rainfall (Decile 3) limited treatment effects in the first season of this trial. Despite there being differences in biomass production (NDVI) and grain quality between treatments, yield effects were not observed. Chicken litter treatments (5 t/ha surface applied) recorded improved growth and vigour at all NDVI timings, however nitrogen was not the limiting factor in 2025 and water stress resulted in no yield benefit. Background soil N was more than what was needed to produce the ~1.5 t/ha yields observed, meaning that differences in nitrogen rates likely had little to no effect in 2025. It is important to consider the dry conditions when interpreting these results, as nitrogen availability is likely to have a more pronounced effect when growing season conditions are conducive to increased plant growth and yield potential. This trial will continue for an additional two seasons, where it is anticipated that compounding treatment effects may become clear, particularly if favourable growing season conditions are experienced.

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