The effect of cover crops on physical, chemical and microbial properties of a sandy loam soil and baby leaf spinach yield

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Abstract
Cover or green manure crops have become an important component of sustainable agricultural systems due to their contribution to improving soil condition, fertility and crop growth. This contribution has become vital to intensive vegetable production due to loss of organic matter and soil degradation from erosion. The aim of this experiment was to determine the effect of five short-term winter cover crops on microbial diversity; physical and chemical properties of soil, and on a following baby leaf spinach crop (*Spinacia oleracea*). The cover crops used were tillage radish (*Raphanus sativa*), Caliente mustard 199™ (*Brassica juncea*), oats (*Avena sativa*), field peas (*Pisum sativa*) and a mixture of oats and field peas. The cover crops had an effect on soil microbial diversity, chemical and physical properties. All cover crops except mustard significantly increased labile organic carbon ($P<0.05$); radish significantly decreased penetration resistance ($P<0.05$) and the mixture increased soil moisture content ($P<0.05$). Aggregate stability and bulk density were unaffected. The microbial diversity and abundance of the soil changed with cover crops. Cover crops significantly increased the yield of the subsequent baby leaf spinach crop ($P<0.05$), the highest increase being the radish (3.63 t/ha) and mustard (2.75 t/ha) cover crops. Baby leaf spinach yield was highly correlated with biomass of cover crops ($P<0.05$), accounting for 85.4% (R^2) of variation. The use of cover crops allows farmers to do more with less inputs, increasing crop productivity across Australia.

Keywords
Soil condition, soil biology, crop rotations.

Introduction
Little carbon input occurs in vegetable cropping due to short growth cycles that produce relatively small roots, shoots or root exudates compared with perennial crops. Seedbed preparation requires intensive cultivation to prepare the soil for sowing. At harvest, further soil disturbance is needed and plants are generally entirely removed. This has led to 85% of vegetable growers having extremely low (< 0.5% to 2.5%) levels of soil organic matter (Rogers 2012). Intensive vegetable cropping include soil degradation through erosion, loss of fertility and pollution of water sources through leaching of nutrients, loss of soil organic carbon, loss of soil microbial diversity and abundance, decrease in aggregate stability and a reduction in earthworm numbers (Haynes and Tregurtha 1999).

To mitigate the detrimental effects of intensive vegetable cropping, cover crops can be incorporated into cropping rotations. Cover crops protect the soil from erosion and from loss of plant nutrients through leaching and runoff. Rotations which include cover crops have been identified as an essential component in sustainable cropping systems. Cover crops can increase soil organic matter and microbial diversity, improve soil structure and water holding capacity. They also reduce erosion, leaching as well as disease and pest pressure (Wright and Hons 2005; Aziz et al. 2013).

Methods and materials
A field experiment was established on a commercial irrigated vegetable farm in Cowra, New South Wales. The experiment was conducted on permanent bed structures with grey-brown sandy loam soil. The experimental layout was a randomised complete block design with four replicates whereeach plot was 1 m × 10 m.. Initial soil samples and testing were completed before sowing the cover crops. Soil tests included soil labile carbon (potassium permanganate oxidisable carbon (PPOC) method), soil total carbon (Elemental Vario MAX CNS analyser), bulk density, volumetric water content, penetration resistance (dynamic core penetrometer), water stable aggregates (soil slaking using image recognition) and microbial diversity (Illumina sequencing).

The cover crops used in this experiment were tillage radish (*Raphanus sativa*), Caliente mustard (*Brassica juncea*), oats (*Avena sativa*), field peas (*Pisum sativa*) and a mixture of oats and peas. Control plots were left as fallow.

Cover crops were sown on 30 March 2016, and biomass samples were taken once a month throughout the growing season. The crops received irrigation to assist with germination based on the commercial schedule, after this they were treated as a dry land crop. Cover crops were terminated with Glyphosate 540® herbicide at 25 mL/L 14 weeks after sowing. On 3 August, following crop death, the crops were mulched using rubber flails. Two weeks later cover crops were incorporated into the soil. Soil tests were taken again following incorporation. A baby leaf spinach crop was sown 29 August, and seven weeks later on 9 October yield was recorded by 1 m^2 biomass cuts, recording fresh and dry weights. Data was analysed using GenStat 18th edition. Variance between soil properties pre- and post- cover crop incorporation and between treatments was analysed using two-way analysis of variance (ANOVA) in randomised blocks. The impact of cover crop biomass and soil properties on baby leaf spinach yield was analysed using regression.

Results and discussion

The use of short-term cover crops in this vegetable production system resulted in improvements to the soil condition and higher yield of a subsequent baby leaf spinach crop.

Yield

The spinach yield (t/ha) was increased (P<0.001) in the radish by 3.63 t/ha and mustard 2.75 t/ha treatments compared with the control (Figure 1). Baby leaf spinach yield after radish was also significantly higher than after mustard (P<0.005).

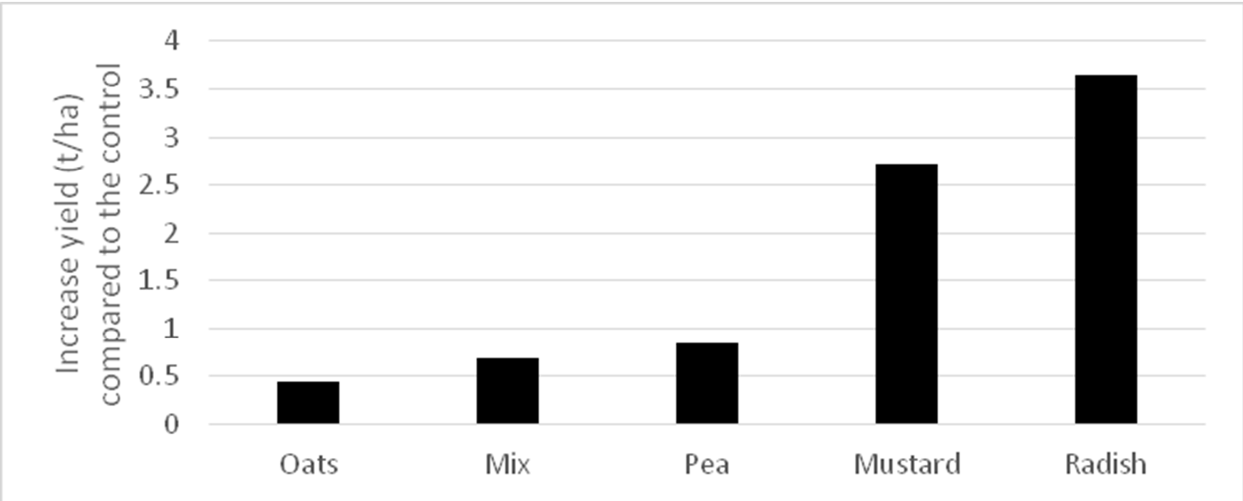

Figure 1. The increase in baby leaf spinach yield (t/ha) compared to control from cover crop treatments. Radish and mustard significantly increased yield (P<0.05 and l.s.d = 0.914).

Increase in labile carbon

The radish, field pea, oat and mix cover crops resulted in a significant (P<0.05) increase in soil labile carbon (Figure 2a). Labile carbon is linked to important soil properties such as cation exchange capacity (CEC), soil structure and microbial biomass (Moody et al. 1997). Increase in labile carbon provides energy for soil organisms, enhanced nutrient cycling, increased nutrient retention and improvement to soil structure, infiltration and aeration (Brennan et al. 2013).

Penetration resistance

Tillage radish significantly decreased soil penetration resistance (P<0.001) from 1.062 to 0.3473 MPa. A decrease in penetration resistance is linked to an increase in yield as it alleviates compacted soil constraints on root and shoot growth.

Water holding capacity

The soil volumetric water content increased where radish, oats, field peas and mixture (field peas and oats) cover crops were sown (Figure 2b). Increases in water content by cover crop mixtures have been attributed to reduced run-off (Brooker et al. 2015). The increase in soil water content is considered a major benefit of cover crops, increasing the available water supplyfor the subsequent vegetable crops.

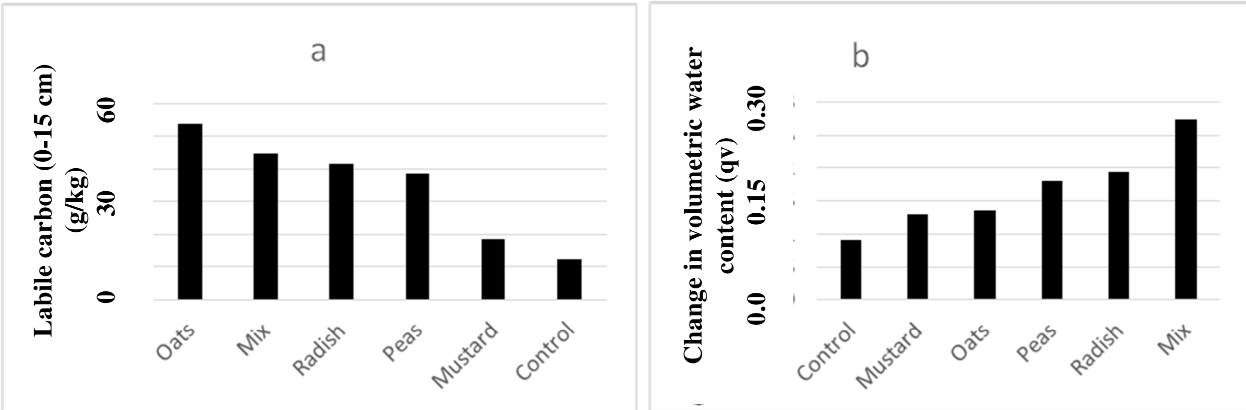

Figure 2. (a) Change in labile carbon (0–15 cm soil sample) (g/kg) (*P*<0.05, l.s.d = 29.84) and (b) change in volumetric soil water content (*P*<0.05, l.s.d = 0.13) after the growth and incorporation of cover crops.

Cover crops can change soil microbial communities. Microbial diversity in soil habitats is critical for the maintenance of soil quality. In this experiment, microbial communities were affected by the species and growth of cover crops. For example, the mustard cover crop had 800 fewer species of bacteria compared to the other cover crops. This may be due to bio-fumigation effects of the mustard cover crops that release glucosinolates that are hydrolysed to isothiocyanates when incorporated into the soil. Isothiocyanates can suppress microbial communities. This is supported by the krona graph of eukaryotic diversity (Figure 3), which has bacteria included, showing mustard has 7% of the soil microbial community consisting of bacteria, compared to pea with 22% and mix with 18%. In ratio UniFrac analysis, the model takes into consideration a genomic mean, muting the operational taxonomic units (OTUs) that are close to the mean and accelerating the OTUs that are more abundant than the mean. This analysis suggests that the pea cover crop resulted in the bacterial community being more evenly distributed, while radish had more species that are considerably more abundant than the mean.

Figure 3. The microbial diversity in the soil following the (left) radish cover crop and (right) pea cover crop.

Conclusions

Incorporating short-term cover crops can benefit the soil condition of vegetable cropping systems. Adding cover crops residues to the soil may improve soil structure, water holding capacity and organic carbon. Improvements to the soil condition can enhance soil health and sustainability of vegetable cropping systems.

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