Long-term impacts of farming systems on soil carbon and nutrient stocks

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Take home message

- Soil carbon and nitrogen inputs drive long-term soil C changes
- Most cropping systems continue to deplete soil carbon and nutrient stocks
- Changing crop mix and fertiliser input have small impacts on soil C compared to current baseline systems
- Crop intensity that increases crop biomass inputs can induce slightly higher soil C while lower crop intensity can reduce soil C
- Large applications of organic amendments can significantly increase soil C, but this was short-lived and no advantage in soil C was evident after 9-10 years
- Long-term pastures or pasture leys are the most effective way to enhance soil C stocks, but soil C will decline again in the cropping phase.

Introduction

Long-term management of soil fertility is critical to sustainable grain production systems, supporting the capacity to supply vital nutrients at the time the crops require them. Changes in soil stocks of carbon, nitrogen and phosphorus are a useful indicator of the trajectory of soil fertility under different management regimes. That is, if soil C, N and P is declining, being maintained, or increasing, is a very good way to assess the long-term sustainability of a cropping system.

Over the past decade the northern farming systems research project has implemented a range of different management strategies across 7 research sites spanning the northern grains region to see how these influence a variety of attributes of the farming system. Under the different systems, we have routinely collected soil samples to monitor change in key nutrient stocks every 3–5 years and calculated the total inputs and exports of key nutrients over the period from 2015–2025.

System treatments

Across a diverse range of production environments we have compared a regional *Baseline* system, designed to represent currently accepted best practice in that district, against systems that have altered:

a) the mix of crops grown by either increasing the frequency of legumes to 1 in every 2 crops (***Higher legume***) or diversifying crop choices by enforcing 2-year breaks between the same crop to alternate disease susceptibility and herbicide options (***Higher diversity***);

b) the intensity of the cropping system by either increasing it by reducing the soil water threshold to sow more crops and spend less time in fallow (***Higher intensity***) or by reducing it and only growing higher profit crops and fallowing until the soil profile is full (***Lower intensity***);
c) the supply of nutrients provided to crops by increasing the nutrient supply target each year so that it aimed for decile 9 yield potential (***Higher nutrient***) rather than median (decile 50) yield potential.
d) by applying a high rate of organic amendments (manure/compost) to increase the background soil organic matter and also applying a higher nutrient supply target – as above (***Higher fertility***) (only at Emerald and Billa Billa sites)
e) by introducing a grass-based pasture phase of either 3 years (***short***) or 10 years (***long***) to build soil health and fertility; this pasture was either provided with no extra nutrients (***Pasture ley***), was fertilised with extra nitrogen (***Pasture + N***) or augmented with a legume in the mix (***Pasture + legume***).

How has the cropping system impacted soil C?

The *Baseline* farming system, representing regional best practice, has either maintained or slightly reduced soil C status over the 10 years; the sites at Emerald and Billa Billa have seen a notable decline in soil C (Figure 1). Changing the crop mix used in the farming system (i.e. either *Higher legume* frequency or *Higher crop diversity*) has had variable and generally small (<0.2% change) impacts on soil C. A *higher diversity* cropping system has shown higher soil C at both the Pampas and Narrabri sites at some sampling points, but this was inconsistent and also not observed at other locations. *Higher legume* frequency has produced a similar change in soil C to the *Baseline* at most sites. At Billa Billa, the *Higher legume* system has induced a greater decline in soil C than the *Baseline* (Figure 1); this is likely due to subsoil constraints that have reduced the productivity of legumes compared to other crop options at this site.

Across all sites there was a notable difference in the soil C between the *Higher* and *Lower intensity* systems. The *Higher intensity* systems having about 0.2–0.3% higher soil C at the end of the 10 years. This is associated with less time in fallow and in some cases higher crop biomass inputs in the *Higher intensity* systems.

Soil C under the *Higher nutrient* systems, where fertiliser is supplied to meet a higher crop yield target to mitigate key nutrient deficiencies in all years, did not greatly differ from the *Baseline* (Figure 2). The only site with a small positive effect was at Emerald, which was one of the few locations where a positive crop biomass (and yield) response was measured due to the higher N (and P) supply. The lack of additional growth or yield at other sites meant there was little effective difference in crop biomass inputs, so soil C responses are also likely to track the *Baseline*.

Finally, at the Billa Billa and Emerald sites, the *Higher fertility* systems received an application of organic amendments (manure or compost) equivalent to an input of 20 t C/ha at the end of the first year after the first soil sampling. This large input of carbon should have increased soil C levels by about 0.4% initially. This increased C was evident in the subsequent sampling 3 years later, with the soil C about 0.20–0.25% higher than the equivalent system (i.e. the *Higher nutrient* system). However, in subsequent samplings this additional soil C seems to have diminished to a point where the final soil C after 10 years is the same in both the *Higher nutrient* and *Higher fertility* systems. This suggests that such amendments may not provide C inputs in a form that is as persistent as that which builds *in situ* via plant growth.

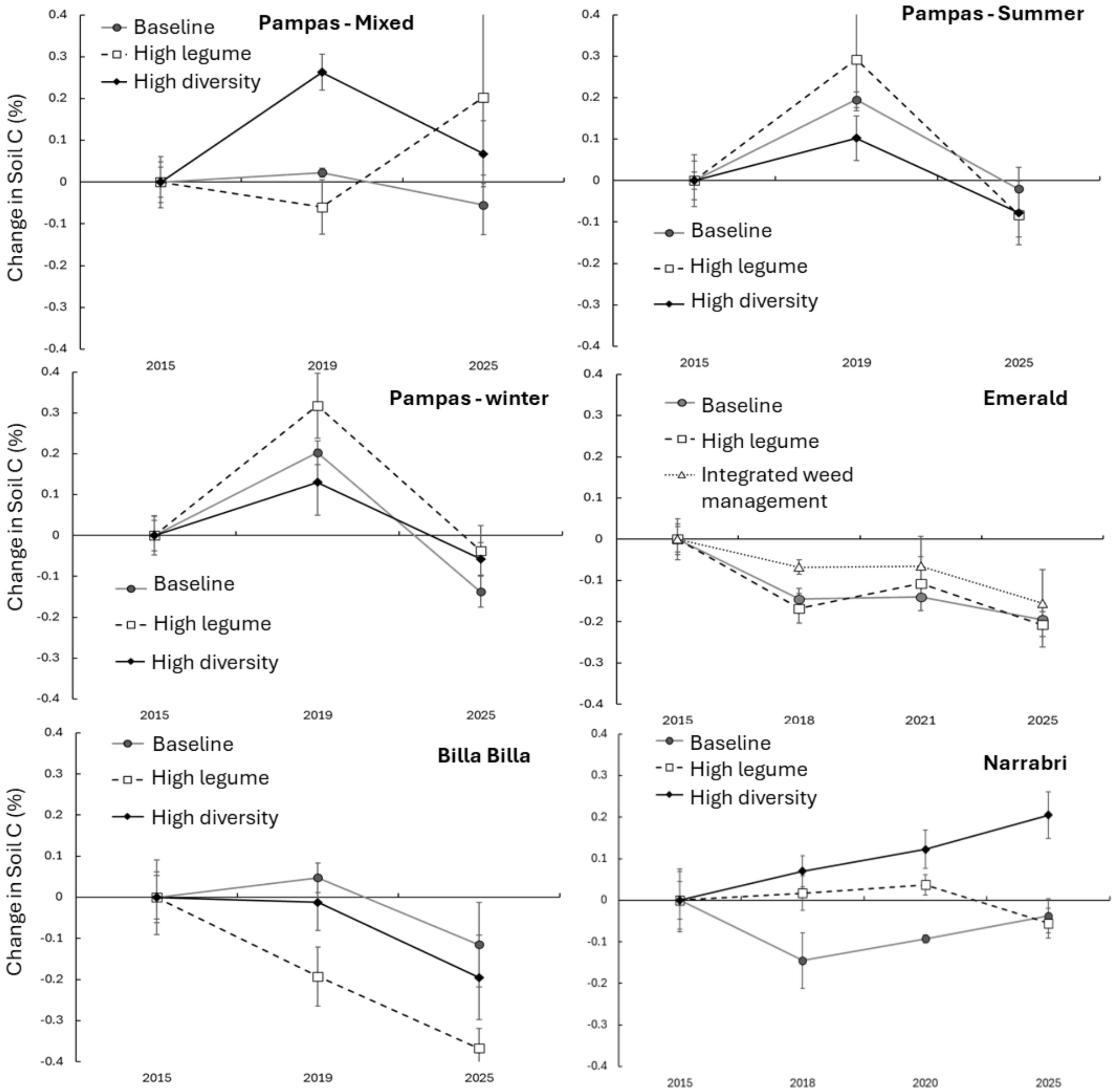

Figure 1. Influence of changes in cropping system on changes in soil organic C content (0–10cm, Walkley-Black) at farming systems experimental sites; *Baseline* (grey circles)– emulates district best-practice, *Higher legume* (hollow squares) involves growing a legume crop every 2 years, and *Higher diversity* (black diamonds) involves using a greater range of crops to induce 2 year breaks to manage crop diseases and herbicide use.

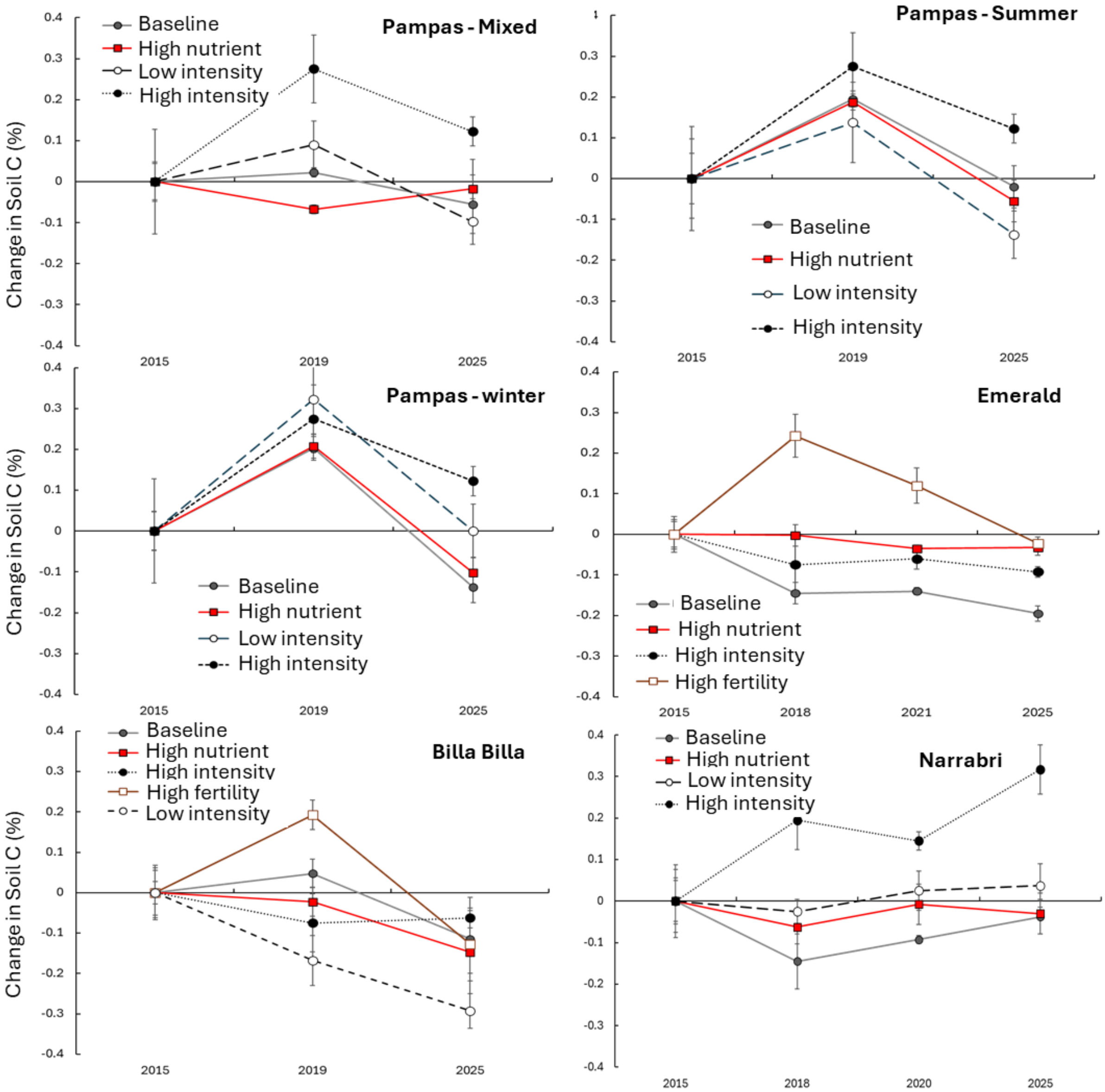

Figure 2. Influence of altering cropping intensity and soil nutrient supply on changes in soil organic C content (0–10 cm, Walkley-Black) at farming systems experimental sites; *Baseline* (grey circles) – emulates district best-practice, *Higher nutrient* (filled squares) involves increasing N budgets to meet decile 9 seasonal yield potential, *Higher fertility* (hollow squares), *Lower intensity* (hollow circles, dashed line) involves fewer crops over time as crops are only sown when the soil profile is filled, and *Higher intensity* (solid circles, dotted line) involves growing more frequent crops using a lower soil water threshold to trigger a sowing event.

How have farming systems influenced long-term N and P balance?

Net exports of N in grain exceeded inputs by 100–300 kg N/ha over 10 years in the *Baseline* farming system across most sites; except at Narrabri where some higher fertiliser inputs offset N removal (Table 1). *Higher diversity* farming systems had a similar N balance to the *Baseline* at each site. *Higher legume* systems generally had a less negative N balance by up to 200 kg N/ha compared to the *Baseline,* but this difference varied across sites. The N balance of the *Higher intensity* systems was generally more positive than the *Baseline* system because of more regular N inputs from fertiliser associated with more frequent crops and lower reliance on soil mineralised N to meet crop demand. Conversely, the *Lower intensity* systems that had longer fallows, and hence a larger proportion of crop N supply was provided from soil mineralisation, had a more negative N balance than the *Baseline* or *Higher intensity* farming systems. All these systems had no clear trend in terms of their influence on P balance, with most running deficits of between 20–80 kg P/ha over the 10 years.

The *Higher nutrient* input strategy had a more positive (or less negative) N balance than most systems at each site due to the higher fertiliser inputs required to target a higher crop yield potential (i.e. decile 9 yield compared to a decile 5 yield). The main exception was Billa Billa site that started with high levels of accumulated N in the soil profile, where little fertiliser N was required until this background was depleted to a point where N fertiliser was required at all. The *Higher nutrient* system also provided higher P inputs to match a higher crop yield potential (typically about 50–80% higher than the *Baseline* for each crop), which reduced the P deficit by around 20–30 kg P/ha over the whole 10 years.

Table 1. Balance of applied nitrogen (N) and phosphorus (P) as fertiliser or from legume N fixation minus removal in grain amongst cropping systems common across sites in southern Qld (Billa Billa, Pampas) and northern NSW (Narrabri, Nowley).

	Billa Billa	Narrabri	Nowley	Pampas - mixed	Pampas - summer	Pampas - winter
N balance over 10 years						
Baseline	-361	-108	+71	-128	-118	-251
Higher nutrient	-349	+254	+283	+43	-53	-78
Higher legume	-162	+63	+263	-167	-47	-265
Higher diversity	-388	-42	+149	-92	-178	-336
Lower intensity	-260	-191	-214	-64	-154	-164
Higher intensity	-455	+173	+121		57	
P balance over 10 years						
Baseline	-48	-22	-15	-79	-60	-53
Higher nutrient	-11	3	2	-60	-43	-27
Higher legume	-22	-31	-4	-58	-46	-72
Higher diversity	-40	-15	-33	-70	-60	-74
Lower intensity	-43	-23	7	-81	-27	-28
Higher intensity	-32	-26	-18		-35	

Ley pasture – crop rotations impact on soil C

While most of the continuous cropping systems have had small effects or differences in terms of soil C, the integration of a pasture phase has proven to be highly effective at building soil C. The long-term grass-based pastures grown for nearly 10 years have increased soil C by 0.3–0.5% at both the Billa Billa and Pampas sites; this equates to a rate of soil C sequestration of between 400 and 500 kg C/ha/yr. This increase in soil C was in excess of that observed 1–2 years after applying 20 t C/ha as manure or compost (i.e. around 40–60 t/ha of organic material). Higher N supply (*Pasture + N*) also boosted soil C contributions at the Billa Billa site, but this effect was less clear at the Pampas site.

After just 4 years of a shorter pasture phase there was a noticeable, but smaller, increase in soil C at both sites (Figure 3). However, after returning to a cropping phase soil C began to decline again at a similar rate to the *Baseline* cropping system. Hence, the difference was maintained between the continuously cropped and pasture-crop rotations, but the final soil C was significantly lower than in the longer pasture phase (Figure 3).

A key driver of this large difference between the cropping systems and the pastures is the amount of C residue being returned to the soil, the absence of fallow periods with more time plants were actively growing, and the higher inputs of below-ground biomass. Total biomass inputs were estimated to be nearly 3-times higher in the pasture systems than the *Baseline* cropping systems, and 2-times higher than the *Higher intensity* cropping systems.

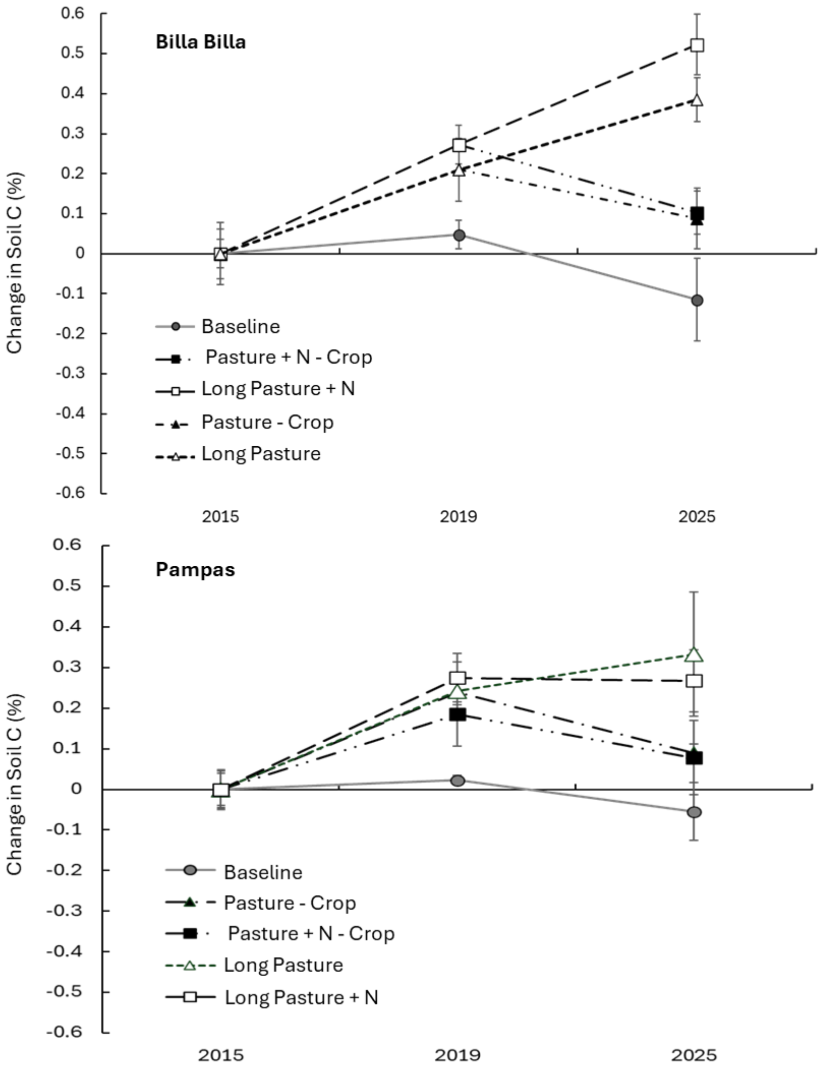

Figure 3. Effects of pasture leys on changes in soil organic C content (0–10 cm, Walkley-Black) at farming systems experimental sites; *Baseline* (grey circles)– emulates district best-practice, *Pasture-Crop* (filled symbols) involves a 4 year pasture phase followed by cropping, *Long pasture* (hollow symbols) has remained pasture the whole 8 years; pastures were either left unfertilised (triangles) or provided with fertiliser N (squares).

Conclusions

Changes in soil C, N and P stocks take a long time to emerge unless there are dramatic changes in organic matter or nutrient inputs. In most cases, small shifts in crop choice or fertiliser input strategies had relatively small impacts on the soil nutrient status over 10 years. Cropping intensity is the one management factor within a continuous crop system that seems to have a meaningful impact on soil C status over this period – higher crop frequencies with more biomass inputs having a positive influence, while lower crop frequencies with more time in fallow and lower organic matter inputs having a generally negative influence. Large additions of organic matter or amendments (i.e. >20 t C/ha) can provide rapid short-term boosts in soil C status, but without further applications this was diminished back to the same level as the *Baseline* farming system. Changing land use over several years via ley pastures was the only means by which soil C was increased substantially. Productive pastures with a source of N seemed more able to build soil C, and the longer the pasture remained the larger the increase.

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