Increasing soil organic carbon increases soil nitrogen: Implications for crop production on sandy soils

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Take Home Messages

- Increasing soil organic carbon can increase grain yield and plant available nitrogen (N) at seeding.
- The amount of plant available N at seeding varies from year-to-year, and depends on the amount of summer rain.
- Increasing soil organic carbon can increase nitrous oxide (N_2O) emissions, however losses from sandy soils are negligible.
- We recommend regularly soil sampling to assess soil N availability prior to seeding.

Background

Increasing soil organic carbon is promoted as a strategy for sequestering carbon dioxide (CO_2) and mitigating anthropogenic greenhouse gas (GHG) emissions. Increasing soil organic carbon can benefit crop growth, however, there is a risk that it may also enhance emissions of another potent GHG, N_2O. Understanding how increasing soil organic carbon effects both crop production and soil N_2O emissions is needed when assessing the effectiveness of soil carbon sequestration to abate agricultural GHG emissions.

Increasing soil organic carbon may influence the amount of N fertiliser required for crop production by altering the amount of N available from soil organic carbon mineralisation. Fertiliser application is the largest single variable expense for grain growers in Australia. Better matching N fertiliser inputs to crop demand not only increases cropping profitability, but also decreases the risk of N leaching and soil N_2O emissions.

The overall objective of this project was to investigate if increasing soil organic carbon i) alters N fertiliser requirements for crop production and ii) increases N_2O emissions.

Materials & Methods

The study was conducted at the Liebe Group's Long Term Research Site at Buntine, which includes a variety of replicated treatments aimed to alter soil organic carbon. The current study utlilised field plots that were either tilled annually with or without the addition of organic matter (OM) every three years. In May 2011, the Tillage treatment contained 0.5% C in the surface 10cm, while the OM+tillage plots contained 1.2% C.

Crop yield response to a range of N fertiliser applications (0, 25, 50, 75 and 100 kg N/ha) was compared between the OM+tillage and Tillage treatments for two growing seasons. In 2013, replicated (3) plots were planted to barley (5 June) with 40 kg/ha of triple superphosphate (8 kg P/ha) drilled with the seed. In 2014, a different set of plots were used and planted to oats (6 May). The N fertiliser (urea) treatments were applied by hand four weeks after seeding in both years. Soil mineral N (increments to 60cm depth) were measured prior to seeding, and four weeks after seeding (immediately prior to N fertiliser application) by extracting field moist soil samples with 1 *M* potassium chloride.

Soil N_2O emissions were also measured for two years and commenced 6 June 2012 following seeding. The experimental design includes two organic matter treatments described above (Tillage, OM+tillage) by two N fertiliser rates (0, 100 kg/ha) by three replicates. Fluxes were measured using soil chambers (one per plot) connected to a fully automated system that measured N_2O emissions subdaily using gas chromatography.

All data were statistically analysed using Genstat for Windows, 14th edition. Analysis of variance was used to determine whether grain yield and cumulative N_2O fluxes were affected by organic matter or N fertiliser.

Results

Rainfall

In 2013, the Buntine study site received 269mm (189mm during growing season), which was close to the average annual rainfall (Decile 5), but with very low rainfall in June. In 2014, the study site received 234mm (185 mm during growing season), which was less than the average annual rainfall for the area (Decile 2).

Effect of soil carbon on grain yield

Progressively adding OM to the soil during the last 10 years increased grain yield in 2013 and 2014 (Figure 1; $P<0.05$). In 2013, applying N fertiliser did not affect yield for either OM treatment ($P>0.05$), so barley grain yield was 3.2 t/ha for the Tillage treatment (averaged across N fertiliser rates) and 3.9 t/ha for the OM+tillage treatment (averaged across N fertiliser rates). In 2014 applying N fertilizer decreased oat yield for both OM treatments, and ranged from 0.2 to 0.7 t/ha depending on the treatment ($P<0.05$; Figure 1b).

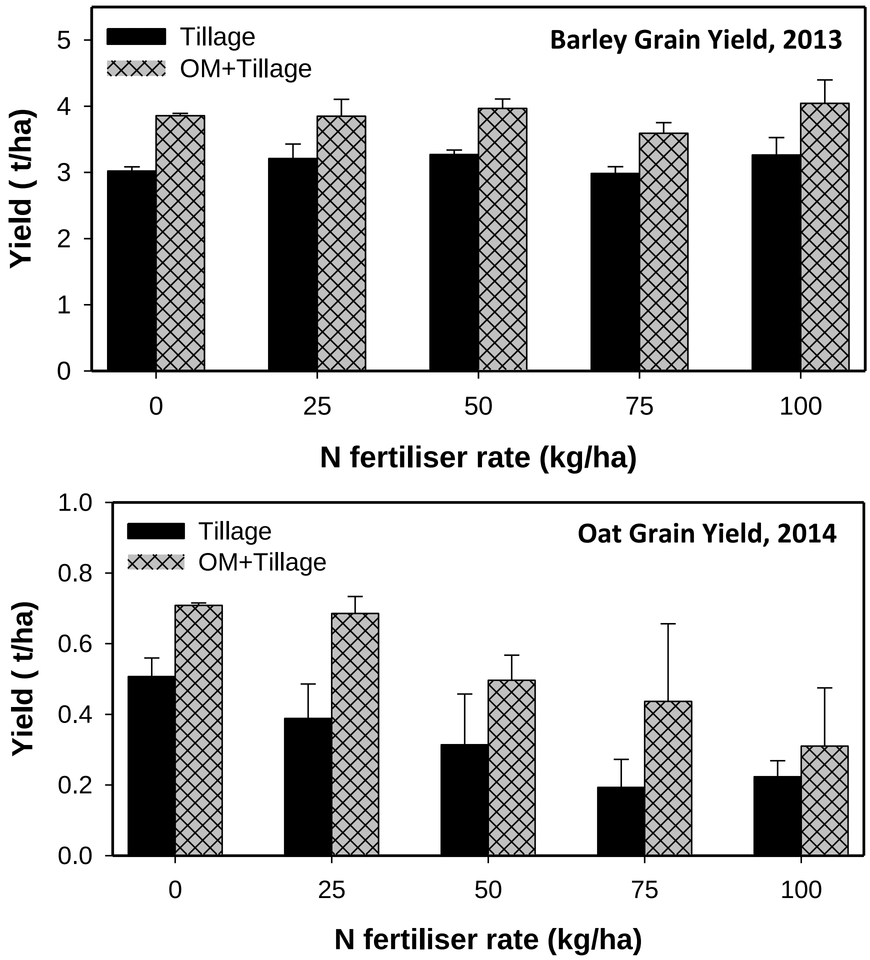

Figure 1. Grain yield (t/ha) response to different nitrogen fertiliser application rates for the Tillage and OM+tillage treatments at the Long Term Research Site (Buntine). Yields represent means (± standard errors) of three replicates, except in 2014 where one replicate (OM+Tillage only) was omitted due to crop lodging. Note: OM, organic matter; the change in y-axis between each panel.

Effect of soil organic carbon on soil mineral N

The amount of mineral N (nitrate plus ammonium) in the soil profile (0–60cm) was greater in the OM+tillage than in the Tillage treatment at seeding in both study years, but not necessarily at four weeks after seeding (immediately prior to N fertiliser application; Table 1). The difference in mineral N content between the two

OM treatments at seeding was attributed to the surface 20cm of soil. Four weeks after seeding the amount of mineral N in the surface soil tended to increase, except for OM+tillage in 2013. The amount of mineral in the soil profile at seeding in 2013 was at least 4-fold greater than 2014, which we expect was due to greater summer rainfall in 2013, in comparison to 2014, stimulating soil N mineralisation prior to seeding.

Table 1. Soil mineral N contents with soil depth. Values represent means (and standard errors) of nine replicates.

Soil depth (cm)	2013 OM+tillage (kg N/ha)	2013 Tillage (kg N/ha)	2014 OM+tillage (kg N/ha)	2014 Tillage (kg N/ha)
		Seeding†		
0–10	47 (5.8)	17 (2.9)	9.4 (0.8)	3.8 (0.6)
10–20	31 (3.4)	26 (5.3)	7.4 (1.8)	4.8 (2.2)
20–40	13 (1.0)	10 (0.6)	2.6 (0.1)	2.7 (0.6)
40–60	4.6 (0.8)	2.4 (0.7)	1.2 (0.2)	1.8 (0.2)
		Four weeks after seeding‡		
0–10	37 (7.5)	22 (2.2)	4.3 (0.2)	2.9 (0.8)
10–20	19 (2.6)	21 (3.8)	6.7 (2.2)	4.8 (0.3)
20–40	13 (0.5)	12 (1.1)	8.4 (1.8)	8.2 (0.3)
40–60	4.8 (0.6)	4.5 (0.4)	5.1 (2.0)	7.7 (1.2)

†Soil samples collected on the 6/6/2013 and 7/5/2014. ‡Soil samples collected on the 3/7/2013 and 3/6/2014.

Effect of soil carbon on N_2O emissions

Increasing soil carbon in Western Australia's sandy soils is likely to increase soil N_2O emissions, however these losses are relatively insignificant and represent 0.1% of the N fertiliser applied. Total N_2O losses after two years were ranked: OM+tillage, plus N fertiliser (413 g N_2O-N ha^{-1}) > OM+tillage, no N fertiliser (203 g N_2O-N ha^{-1}) = Tillage, plus N fertiliser (41 g N_2O-N ha^{-1}) = Tillage, no N fertiliser (11 g N_2O-N ha^{-1}) ($P<0.05$).

Comments

The addition of OM led to a 40% yield increase in a low-yielding year (2014), and a 27% increase in grain yield in a high yielding year (2013), when N fertiliser was not applied. The observed increase in yield in response to the OM additions is consistent with yield responses previously recorded at the study site by the Liebe Group. At the same time, increasing soil organic carbon has as also increased soil mineral N. These findings suggest that increasing soil carbon has the potential to lower N fertiliser inputs required to produce grain.

Increasing soil carbon increased soil N_2O emissions by 2.5-times in the present study when N fertiliser was applied. However, the range of annual N_2O emissions (0.14–0.28 kg N_2O-N/ha/yr depending on the year) were conservative in comparison to values reported for other cropped sites in Australia and overseas. Globally, and across a variety of climatic regions, annual N_2O losses from cropped mineral soils have ranged from 0.3 to 16.8 kg N_2O-N/ha/yr. The annual N_2O emissions reported for Buntine is within the range of values that have been previously reported for other cropped soils in the Western Australian grainbelt.

While increasing soil C has increased N_2O emissions, these losses are relatively low. Land management practices that increase soil carbon in Western Australia's cropping soils should therefore continue to be encouraged as it will benefit grain yield. At the same time, growers should modify N fertiliser inputs to reflect changes in plant available N resulting from improvements in soil carbon content. Such practices have the potential to improve grain yield and profitability from sandy-textured soils, while minimising soil N_2O emissions.

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