Soil organic carbon after long-term fertiliser N and P applications

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Abstract
Soil organic carbon (SOC) was measured at two depths where fertiliser nitrogen (N) and phosphorus (P) combinations had been applied to a long-term experiment after 16 years in north-eastern Australia. An opportunity cropping regime of grain sorghum and wheat or barley following a range of fallow lengths was used. With N fertiliser application, SOC in 0.0-0.1m was 0.84 Mg/ha higher than in nil N plots, whilst fertiliser P treated soil was 0.40 Mg/ha higher compared to no P application. From 0.1-0.3 m, neither fertiliser N or P was statistically significant. For the sum of SOC to 0.3 m depth, N treatment only was significant.

Cumulative estimates of stover and below-ground carbon input were estimated from harvested grain yields. Fertiliser N increased estimated C input in 8 of 14 years; the largest responses in grain sorghum sown on short fallows (≈ 6 months). There was little or no N fertiliser effect on sorghum yield or C input following long-fallow (≈ 14 months). For winter cereal crops, P fertiliser increased estimated C input over all fallow lengths, whilst responses to N fertiliser were influenced by fallow-length. Cumulatively, the interaction between fertiliser N and P significantly increased estimated stover and below-ground C input.

Key Words
Sorghum, wheat, barley, net primary productivity

Introduction
Soil organic C (SOC) is a functional balance between plant residue deposition rate (stover, roots and rhizodeposition) and the decomposition rates by soil biota of organic matter. Following conversion of native vegetation to annual cropping across north-eastern Australia, SOC declined due to decreased plant residue input and increased aeration accelerating microbial soil organic matter oxidation (Dalal and Mayer 1986). Loss of SOC on many soils with > 30 years cultivation increased fertiliser N and P requirement to improve crop growth and grain yield (Dalal and Probert 1997; Lester *et al.* 2008).

Across a subtropical cereal belt from about 32°S to 22°S in north-eastern Australia, grain sorghum (*Sorghum bicolor*) and wheat (*Triticum aestivum*) are the dominant summer and winter grain crops respectively and hence provide most plant C return into the soil from grain crops. Estimates of plant C input can be derived from harvested grain yield and harvest index (HI) providing an estimation of above-ground biomass (grain + stover). The C mass within it can then be used to estimate below-ground C input (Johnson *et al.* 2006). With fertiliser N and P being applied routinely, the effect of differing N and P supplies on HI and hence the amount of plant residue returned to the soil, and the cumulative impact of fertiliser inputs on soil C content require investigation.

Methods
Site description and crop agronomy
A long-term N x P fertiliser experiment commenced in 1985 on a haplic, self-mulching, endohypersodic, black Vertosol (Isbell 2002) first cultivated > 44 years earlier, at "Colonsay" a property on the Darling Downs, southern Queensland (27°28'S, 151°23'W). Full descriptions of the site, crop agronomy and experimental procedures have been provided by Lester *et al.* (2008). Treatments are within a factorial randomised complete block design with three replicates. Four rates of N (0, 40, 80 or 120 kg N/ha) as urea (46% N) at each of four rates of P (0, 10, 15 or 20 kg P/ha) as triple superphosphate (20.7% P) as main-plot treatments were applied to each crop. Additionally, a split-plot component has to keep abreast of changing fertiliser and cropping management, and widen the scope of the investigations has altered since the

experiments' start. The cumulative N fertiliser inputs from 1985 to 2002 are summarised in Table 1. For a total of four crops in sequence from 1990 to 1994/95, the split-plot component employed was a regime of "nil" or "+40" kg N/ha applied within a main-plot. This increased cumulative N fertiliser applied by 160 kg N/ha compared to the "nil" N. In 1991/92, 60 kg N/ha was applied across the whole experiment during routine farm operations and no additional fertiliser N was applied that year.

Table 1. Cumulative N fertiliser inputs (kg N/ha) from 1985-2002 at Colonsay.

Main-plot		Split-plot		Other		∑ N Fert (kg N/ha)
Fert N (kg/ha/crop)	Number of applications	Fert N (kg/ha/crop)	Number of applications	Fert N (kg/ha)	Number of applications	
0	0	0	0	60	1	60
0	0	40	4	60	1	220
40	15	0	0	60	1	660
40	15	40	4	60	1	820
80	15	0	0	60	1	1260
80	15	40	4	60	1	1420
120	15	0	0	60	1	1860
120	15	40	4	60	1	2020

Soil sampling and carbon determination

Soil samples were collected from all replicates in June 2003 at 0-0.1 m and 0.1-0.3 m from cumulative N fertiliser input of 60 (-N) and 1260 kg/ha (+N) at 0 (-P) or 20 kg P/ha.crop (+P). The sampling methodology was adapted for residual bands of fertiliser P and has been described by Wang *et al.* (2007). Briefly, soil samples for 0-0.1 m were collected at five equidistant positions along the 50 m plots at a 90^0 angle to the plant row direction using a trenching shovel to homogenise residual P fertiliser bands. Samples below 0.1 m were collected using a 32 mm tube and hydraulic core sampler. Sixty samples were collected at each depth.

After drying for 48 h at 40°C, initial grinding was to < 2 mm; subsamples were then ground to ≤ 0.5 mm for C analysis. Following pre-treatment for inorganic carbonates, SOC was measured by a LECO CNS-2000 analyser (LECO Corporation, Michigan, USA) with conversion from mass to area achieved using 1.01 g/cm^3 for 0.0-0.1 m and 1.06 g/cm^3 for 0.1-0.3 m depth bulk densities (Dalgliesh and Foale 1998).

Estimation of stover yield and below-ground plant C input

Grain was mechanically harvested and grain yield (kg/ha, Y_{GY}) calculated on a harvested area basis adjusted to maximum accepted grain moisture level for receival of 12.5% for wheat and barley, and 13.5% for sorghum. Harvested grain yield (kg/ha) was used to estimate stover (Y_S as kg/ha) as:

$Y_S = Y_{GY} * [(1/HI) - 1]$ (1)

With potential differences among plant species, and the effects of management and environmental conditions we considered that HI should not be constant across N and P treatments. After conducting a literature review evaluating the above factors on HI, a HI of 0.43 has been used for sorghum crops in which low N supply has limited grain yield (i.e. under short-fallow); and 0.46 with adequate N supply. Following a long-fallow, P fertiliser significantly increased sorghum grain yield (Lester *et al.* 2008), and a HI of 0.45 was used where no P fertiliser had been applied and 0.46 for adequate P input (≥ 10 kg P fertiliser/ha). An assessment of the N or P supply effects on winter cereal HI in this production region, showed little or no effect hence a constant 0.42 has been used for all treatments (Dalal *et al.* 1995).

Johnson *et al.* (2006) determined that the average C concentration of above- and below-ground biomass is 0.4 kg/kg. This value has been applied in converting harvested grain yield (Y_{GY}) and stover (Y_S) into grain C (Y_{GC}) and stover C (Y_{SC}). Below-ground C input results from both root biomass and rhizodeposition (Johnson *et al.* 2006). For grain sorghum, barley and wheat Johnson *et al.* (2006) concluded that below-ground plant C (combined root and rhizodeposition, Y_{BGC}) input could be estimated as a function of above-ground C (i.e. grain C (Y_{GC}) + stover C (Y_{SC})) using a ratio of 0.60 representing combined root and rhizodeposition. This has been applied to all crops, with total plant residue C input being sum of stover C (Y_{SC}) and below-ground C (Y_{BGC}).

Statistical analyses
GenStat 10th Edition calculated the ANOVA and nonlinear regression analysis. Statistical significance is reported for $P \leq 0.1$. With no significant differences from P fertiliser ≥ 10 kg P/ha.crop, treatments were consolidated to a “+P” effect of ≥ 10 kg P/ha.

Results
Soil organic carbon under differing N and P supplies
Figure 1 shows SOC at three depths (0-0.1, 0.1-0.3 and ∑0.0-0.3m) for the four sampled treatments (±N by ±P). With heterogeneous variances between 0.0-0.1 ($\sigma^2 = 0.15$) and 0.1-0.3 m depths ($\sigma^2 = 6.69$), these were separately analysed. In the 0.0-0.1 m layer, SOC was significantly influenced by N (P=0.006) and P fertilisers (P=0.097), with the interaction not significant. With fertiliser N input, mean SOC was 0.84 (+/- 0.20 sed) Mg/ha higher compared to nil (11.96 Mg/ha). Effects of P input were smaller with 12.18 Mg/ha under nil P and 12.58 Mg/ha where P was applied. Neither fertiliser treatment had any significant effect at 0.1-0.3 m. For the combined depth of 0.0-0.3 m, SOC with fertiliser N was 1.28 (+/- 0.48 sed) Mg/ha higher (P=0.038) than the nil; whilst P and N x P treatment had no effect.

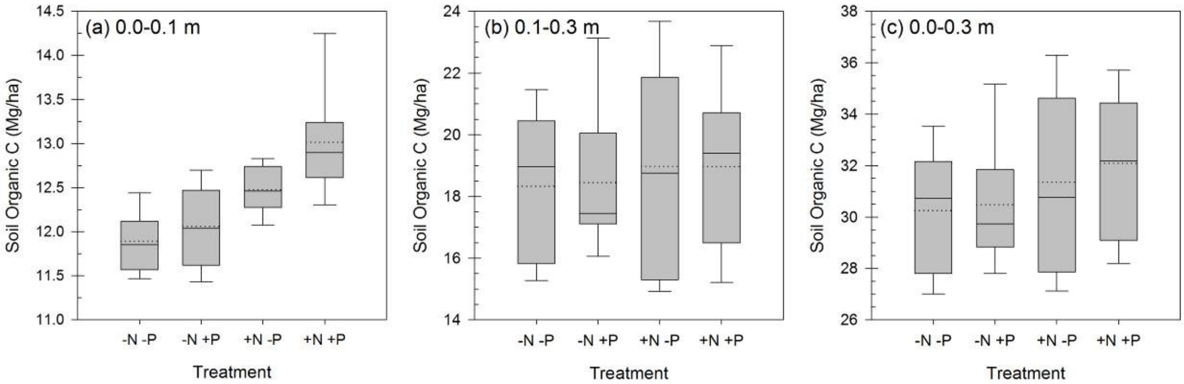

Figure 1. Soil organic C (Mg/ha) at 0.0-0.1, 0.1-0.3 and sum to 0.3 m in treatments with or without N and P fertiliser application at Colonsay, Darling Downs, Southern Queensland in June 2003. Box represents 25th, median and 75th percentile, whiskers below and above indicate 5th and 95th percentile. Dotted line is mean value.

Cumulative estimated stover and below-ground C input
The interaction between N and P fertiliser significantly increased cumulative estimated stover and below-ground C input from 1985-2002 (P=0.062) (Figure 2a). Without fertiliser N input (cumulative 60 kg N/ha) cumulative estimated stover and below-ground C input was 49 300 kg/ha. This increased rapidly with increasing N fertiliser supply. As cumulative fertiliser N input reached 820 kg/ha, P fertiliser at ≥ 10 kg P/ha further increased cumulative C input over nil P by 4400 kg/ha (7%). Maximum cumulative estimated stover and below-ground C input with P application at cumulative N application of 1260 kg ha was 73940 kg/ha, whilst for nil P it was 67580 kg/ha. Higher cumulative N input had no further effect.

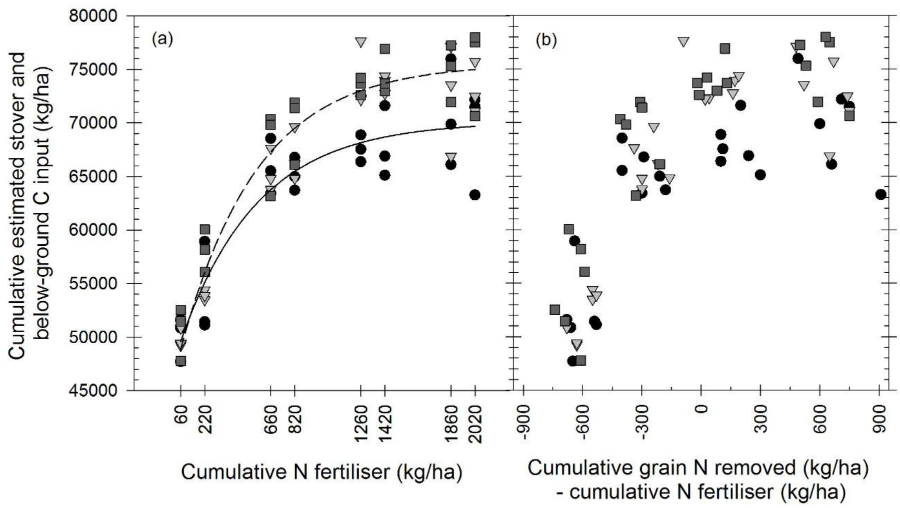

Figure 2. Cumulative estimated stover and below-ground C input (kg/ha) vs (a) cumulative N fertiliser (kg/ha) and (b) cumulative grain N removed (kg/ha) – cumulative N fertiliser (kg/ha) at 0 (●), 10 (▼) or 20 (■) kg P/ha at Colonsay for 16 crops from 1985 to 2002. Regression lines are solid for 0 kg P/ha (●) (= 70130 – 23080 * (0.998050^x)) and dashed for combined 10 (▼) and 20 (■) kg P/ha (= 75576 – 30060 * (0.998050^x)); r^2=0.904.

While the maximum stover and below-ground C input was at 1260 kg/ha N fertiliser (Figure 2a), lower cumulative N fertiliser inputs of 660 and 820 kg N/ha generated about 90% of maximum residue C input. Based on an N mass balance of cumulative grain N removed minus fertiliser N applied, those C inputs occurred under N deficit of between 200 and 400 kg N/ha (Figure 2b). Higher cumulative N inputs (≥ 1260 kg N/ha) where max C input was achieved (with P input) are closer to net balance between fertiliser N applied and grain N removed (Figure 2b) (Lester *et al.* 2010). These estimates are not necessarily inclusive of net N mineralisation (a surrogate of which is present in the nil N treatments), hence additional research opportunities in studying the system N balance and cycling exist.

Soil organic C levels at Colonsay were similar to other continuous cropping studies indicating the potential for fertiliser N input to assist in supporting SOC levels compared to N-limited cropping systems within Australia's northern grains region (Dalal *et al.* 1995) and other semi-arid regions of the world (Potter *et al.* 1997). Other subtropical studies reinforce that adequate and balanced fertilisation of N together with P and/or K (if limiting crop growth) can improve grain yields and may stabilize or enhance sequestration of atmospheric C into SOC environments. This was the case at this is P responsive site, where N and P together had higher SOC in the surface compared to just applying N alone.

Conclusion

Higher crop yields from adequately fertilised crops are necessary for a positive contribution to SOC and for net C sequestration. From 0.0-0.1 m SOC was higher where both N and P fertilisers had been applied compared to nil input. Variability in SOC concentration increased substantially below 0.1 m depth compared to the 0.0-0.1 m layer, confirming care must be taken in undertaking SOC determinations on multiple depths. Fertiliser N only was a significant influence with higher SOC at 0.0-0.3 m compared to nil N. Cumulatively, estimated stover and below-ground C inputs increased as cumulative fertiliser N increased, and P fertiliser addition at higher N supply levels had an additive effect.

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