Role of Nitrogen Fertilization in Sustaining Organic Matter in Cultivated Soils

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This article summarizes work published by Ladha et al. (2011) using data from long-term studies around the world to evaluate the impact of commercial fertilizer N on SOM. The results show that commercial fertilizer N leads to a slower decrease in SOM content, or may cause a small increase, after a new soil equilibrium is reached following N application.

Soil organic matter is essential for sustaining food production and maintaining ecosystem services . (i.e., resources and processes that are supplied by natural ecosystems) and is a vital resource base for storing C and N. The impact of long-term use of commercial fertilizer N on SOM, however, has been questioned recently. We tested the hypothesis that long-term application of N results in a decrease in SOM. We used data from 135 studies of 114 long-term experiments located at 100 sites throughout the world, over time-scales of decades under a range of land-management and climate regimes, to quantify changes in SOC and SON.

Today, commercial fertilizer N supplies approximately 45% of the total N input for global food production, and world use is approximately 100 million metric tons (M t) (FAO, 2010). It is projected that annual total global N use will grow to approximately 112 M t in 2020, and approximately 171 M t in 2050.

Soil organic matter is a key indicator of soil fertility, provides an energy source for heterotrophic soil micro-organisms and is an important source of plant nutrients; particularly, but not exclusively, N. However, SOM changes with cultivation and fertilizer N inputs; normally, it decreases with cultivation without N fertilization and may increase with fertilizer N amendment (Brye et al., 2003). Potentially, there can be two mechanisms whereby fertilizer N affects SOM: (i) fertilizer N may augment SOM (Glendining and Powlson, 1995; Khan et al., 2007; Mulvaney et al., 2009; Powlson et al., 2010;) by promoting plant growth and thereby increasing the amount of litter (plant residue) added to soil compared with soil not receiving N and (ii) fertilizer N may lead to enhanced loss of SOM by accelerating its rate of oxidation or decay of litter and indigenous organic material.

If commercial fertilizer N does decrease SOM, a spiral of decline in soil functioning and crop productivity would be expected. It is therefore important to determine whether the long-term use of commercial fertilizer N does indeed lead to a general decline in SOM. Here, we address a pressing question of importance to global agriculture and food production: Does the long-term use of commercial fertilizer N lead to a decline in SOM in our soils?

A total of 917 and 580 observations for C and N, respectively, derived from 135 studies at 114 long-term experimental sites were included in the analyses. Carbon or N was reported either (i) as gravimetric concentration (i.e., g/kg) or (ii) as volumetric content (i.e., kg/ha). The data set was divided by (i) fertilizer type: unfertilized or zero N, fertilized with commercial N, fertilized with an organic source, and fertilized with combination of organic and commercial N; (ii) land use: flooded, flooded dryland, and dryland; and (iii) climate: tropical, subtropical, and temperate. The responses of fertilizer N input to SOC and SON content were calculated in two ways: (i) percentage difference in SOC and SON content following the application of fertilizer N between time (t) = 0 and t = 1, referred to as time response (TR) ratio, and (ii) percentage difference between the change in SOC and SON in N-fertilized treatments compared with the change in SOC and SON in the zero-N treatment, referred to as time by N-fertilizer response (TNR). The TR addresses the impact of the whole system (tillage, residue management, erosion, fertilizer amendment) on changes in SOC and SON, whereas the TNR specifically assesses the impact of a fertilizer N amendment. All the data were analyzed using the SAS mixed model procedure and meta-analysis.

Common notes and abbreviations: N = nitrogen; C = carbon; SOM = soil organic matter; SOC = soil organic carbon; SON = soil organic nitrogen.

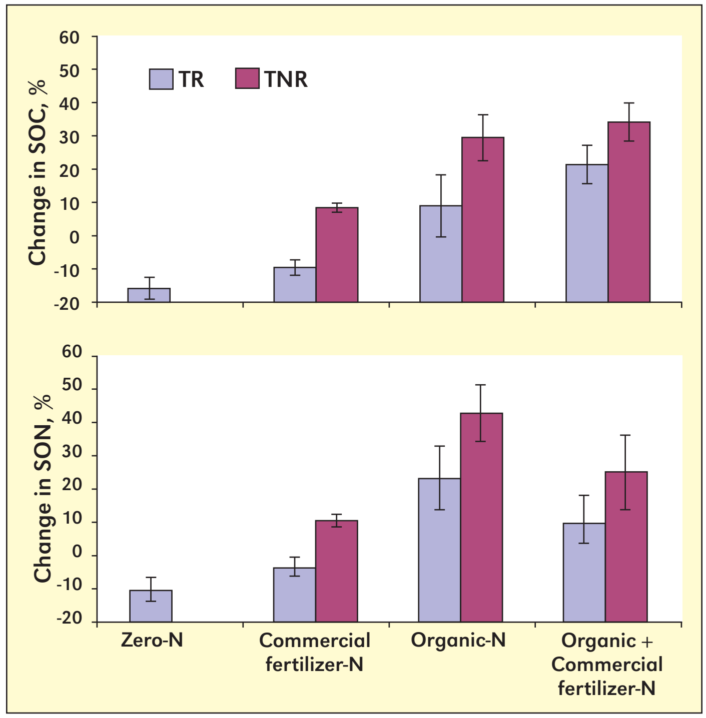

Figure 1. Percentage response in SOC and SON to fertilizer N input as calculated by time response (TR) and N-fertilizer response (TNR) ratios using meta-analysis. Vertical brackets over the data bars represent standard deviation at 95% confidence interval.

Overall, zero-N showed a larger decrease in the TR ratio of SOC and SON than when commercial N was applied (**Figure 1**). Under zero-N inputs, SOC declined by 16% and SON declined by 11%, based on meta-analysis.

When commercial N was applied, SOC decreased by only 10% and SON by 4%. It is important to consider the TNR ratio, which is based on changes in the paired comparisons. On the basis of overall averages, SOC and SON were 8 to 10% higher with commercial fertilizer N than with zero-N (**Figure 1**). These gains were statistically different from zero-N ($p < 0.05$). In general, SOC and SON declined over time from the initial to final sampling period. However, the declines in SOC and SON were lessened (or smaller) with commercial N fertilization.

Among the three subgroups of land use, flooded soils showed a marginal increase in SOC and SON, respectively, in both zero-N (3 to 9%; 1 to 4%) and commercial N treatments (9 to 15%; 8 to 12%) using the TR ratio approach. Both flooded dryland soils and dryland soils showed significant losses of SOC (4 to 19%) and SON (3 to 23%), with and without the application of commercial fertilizer N. The TNR ratios indicated that commercial N led to a relative increase in SOC. For TNR, the commercial fertilizer N response ratios more than doubled in flooded dryland (17% for SOC and 20% for SON) compared with flooded (7% for SOC and 8% for SON) and dryland (7% for SOC and 9% for SON) agro-ecosystems. This indicates that flooded soils and dryland soils are likely to respond less to commercial fertilizer N than will flooded dryland agro-ecosystems.

The general decline in SOM content across a wide range of agricultural production systems (**Figure 1**) will probably have long-term repercussions on the soil's ability to store and regulate the supply of plant-available nutrients (especially N) and ability to improve soil structure. Maintaining SOM levels will therefore remain a key component in sustainable agricultural systems (Swift and Woomer, 1993). To meet crop N demand, the decline in the N-supplying capacity of the soil will need to be compensated by an increase in commercial or organic fertilizer N use. An increase in commercial or organic fertilizer N use to sustain crop yield, however, will lead to potential increases in N losses to the environment, with reactive N becoming part of a cascade effect through the biogeochemical pathway. Therefore, new and advanced management practices should focus on maintaining or increasing SOM levels.

In conclusion, SOM content generally declined over time at virtually all of the long-term sites. However, the use of commercial fertilizer N led to a slower decrease in SOM content and not to a further additional decrease as suggested by Mulvaney et al. (2009). The primary function of commercial fertilizer N is to provide the crop with an immediately available source of N; often the nutrient most limiting plant growth. The secondary function, as shown in this analysis, is that commercial fertilizer N can reduce the decline in SOM content; or cause a small increase after a new equilibrium in SOM content has been reached following a change in management practices, such as; converting grassland to cereal cropping or the implementation of zero-tillage (no-till).

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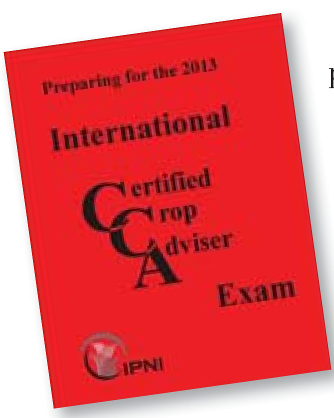

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