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Sequestering soil carbon in the low input farming systems of the semi-arid tropics – does litter quality matter?

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Abstract
Maintaining soil organic matter (SOM) in low input smallholder rice cropping systems worldwide is of paramount importance to maintaining livelihoods and food security. A long term rainfed lowland rice experiment tested the hypothesis that applying small (1.5 t/ha dry matter) annual additions of slowly decomposable plant materials which were grown offsite and applied prior to land preparation, could result in increased soil organic carbon, crop yield and improve the recovery of nutrients compared with plant materials of higher quality or straw retention alone. Annual leaf litter applications over 9 seasons resulted in significant increases in SOC of 39% (from 3.5 to 4.9 mg/g) in the leaf litter treatments compared to only 13 % in the no-leaf litter control. In terms of rice grain production and nutrient use efficiency, leaf litter quality was an important driver. Apparent nutrient recovery of nitrogen and sulfur reflected the decomposition rate of the added residues. Sustainable farming systems will require that crop yields are stable through the maintenance of soil fertility and the balanced use of nutrients in the system. The results of this study are therefore highly significant and provide evidence that low rate, long term residue management can have profound effects.

Keywords: Soil carbon, labile carbon, residue management, rice cropping systems, soil organic matter, apparent nutrient recovery, long-term trial.

Introduction, scope and main objectives

The SOM content of agricultural soils plays an important role in many aspects of chemical, biological and structural fertility. In annual-based rainfed cropping systems of the semi-arid tropics, there have been few studies providing evidence that soil SOM can be increased without substantial off-site additions of organic residues, or long periods under pasture or forestry. So one can conclude that under most rainfed arable systems, with crop residue retention, the best that can be achieved is the maintenance of soil organic carbon (SOC), and under some management such as conservation agriculture, small increases in SOC in the topsoil layer. But focusing only on SOC content misses an important part of the story. In low input systems, productivity is closely connected to soil organic matter status, which can be very low in subtropical climates (<1% in many soils). Organic inputs such as leaf litters, crop residues or farm yard manure, in such systems provide both a short-term supply of nutrients through decomposition and substrate for the synthesis of SOM. An understanding of the litter decomposition processes is therefore central to developing improved management practices for plant residues which may maintain long-term soil organic carbon content and soil nutrient supply rate.

Methodology

A long term (12 year) rainfed lowland rice experiment tested the hypothesis that applying small (1.5 t/ha dry matter) annual additions of slowly decomposable plant materials which were grown offsite and applied prior to land preparation, could result in increased soil organic carbon, crop yield and improve the recovery of nutrients compared with plant materials of higher quality or straw retention alone. This experiment was commenced in 1992 at the Ubon Rice Research Center (15o12`N; 104o41`E, 123 masl) on an infertile acid sandy soil (Aeric Paleaquult). The site of the experiment had been cleared in 1971 and farmed to rice for at least 20 years prior to the experiment. Pre-trial soil samples showed high bulk density (mean=1.47 g/cm3), low water holding capacity, low cation exchange capacity (sum of Ca^{2+}, Mg^{2+}, Na^{2+}, K^{+}) = 5.9 cmol/kg, low concentration of total organic C of 3.5 mg/g, moderate available P (Bray II) of 19 mg/kg; low exchangeable K of 0.04 cmol kg-1.

The experiment consisted of a complete factorial design with five leaf litter treatments (No leaf litter, *Cajanus cajan, Acacia auriculiformis, Samanea saman* and *Phyllanthus taxodifolius* applied at 1500 kg dry weight/ha and incorporated 1 week before transplanting, two inorganic fertiliser rates (Low 25:7:7 and High 50:14:14 kg/ha of N, P and K, respectively) and two after-harvest rice stubble treatments (stubble removed and returned), with 3 replications. Plot size was 3 x 5 m. The experiment was repeated over 12 years (first rice crop in 1992 and final crop in 2003) in the same plots and using the same management in all years. Details of field management and analytics can be found in Blair et al. 1996, Naklang et al. (1999) and Whitbread et al. (1999).

Results

This experiment, first reported by Naklang et al. (1999) and Whitbread et al. (1999), showed that annual leaf litter applications over 9 seasons resulted in significant increases in SOC of 39% (from 3.5 to 4.9 mg/g) in the leaf litter treatments compared to only 13 % in the no-leaf litter control. While decomposition rate of the 5 leaf litters varied widely, there was no significant difference in their effect on SOC sequestration. There was also no significant increase observed in soil C as a result of the return of straw to the system.

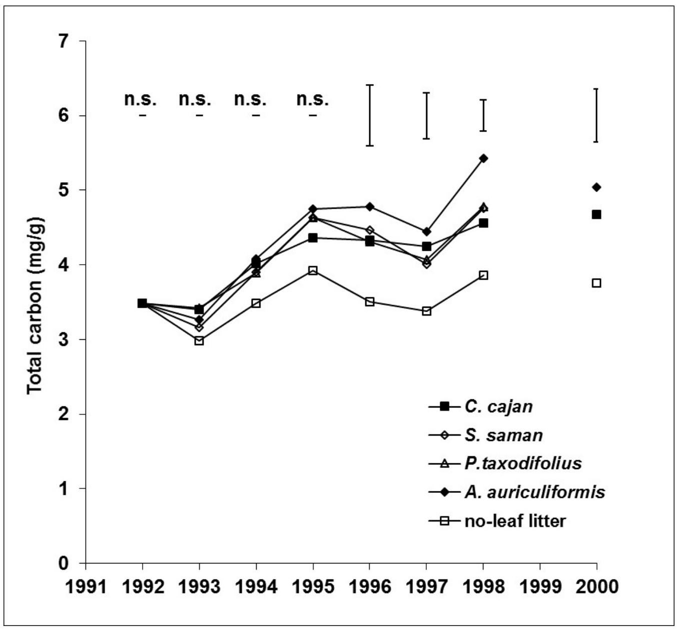

Fig. 1: Total carbon (mg/g) of the leaf litter and the no leaf litter control treatments in 1992-1998 and 2000 (Note. Data presented in averaged across fertiliser + after harvest stubble treatments).

In terms of rice grain production and nutrient use efficiency, leaf litter quality was an important driver. In the initial years of the trial, grain yield was increased in the range of 364 - 670 kg/ha relative to the no leaf litter control in treatments with higher quality leaf litters however this effect decreased with each successive season until the 6th season where all leaf litter treatments yielded similarly and significantly more than the no leaf litter control. Apparent recovery of plant available nitrogen and sulfur, both highly mobile nutrients, increased in each season in all leaf litter treatments with highest apparent recoveries associated with the applications of the lowest quality leaf litter. The benefits of organic resources in improving the efficiency with which mineral fertilisers are utilized may be small in the short-term but higher in the longer-term because of this link to maintenance of SOM content.

Discussion

The generally poor soil fertility status in northeast Thailand, resulting from low inherent nutrient content, low fertiliser use and the dominance of sandy soils, has been reported frequently (Haefele et al. 2006;

Boling et al. 2008). In these fine-textured soils, nutrients and soluble carbon compounds may move down the profile, thus resulting in little, or no, long term increase in soil fertility when residues are added.
The relatively small increases in SOC (1.2 - 1.6 mg/g) associated with this residue management system demonstrate how difficult it is to increase soil organic matter content in such annual cropping systems in the semi-arid tropics. Many studies have shown that the quality of plant residues has a profound effect on decomposition pattern and in effect on the mineralisation-immobilisation dynamics of soil nutrients (Vanlauwe et al. 2004). In most cases, the availability of soil inorganic N will, at least in the short term, control the kinetics of C decomposition (Corbeels et al. 2000). While C:N ratio of plant material is normally closely correlated to potential decomposition rate, some residues, for example *Mucuna pruriens* or *Flemingia macrophyla* both tropical legumes, display decomposition patterns that are modified by high polyphenol content despite high leaf N concentration and a low C:N ratio (Vanlawue et al. 1996). Although the decomposition process results in the transformation of organic matter into more stable forms (Jenkinson 1981), whether more slowly decomposable organic materials can be used in agricultural systems to raise SOM content is still not clear (Palm et al. 2001).

Conclusions

Studies that report on the positive effects of organic residues or FYM application on crop yield, nutrient uptake or increased SOC are not new, but in most cases use unrealistically high application rates from off-site sources. This study is unique in its long term application of leaf litters with varying qualities to a rice system. While the effect of residue application on increasing SOC are modest, the impacts on rice grain yield and the efficiency of nutrient recovery are significant and provide the basis for a sustainable rice system.

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