Additions of clays and clay Minerals to enhance the sequestration of carbon in soils

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Introduction

Prompted by the need to reduce atmospheric carbon dioxide concentrations for the mitigation of climate change, there is much current interest in the possibility of increasing the long-term storage, or sequestration of organic carbon (OC) in soils. In relation to the atmospheric pool of ~760 Pg soils provide a pool for carbon of ~2,500 Pg, which, although smaller than the oceanic (38,000 Pg) and geologic (~5,000 Pg) pools, but larger than the biotic pool (~560 Pg) (Lal, 2004) is labile and potentially easy to manipulate. However, while OC is naturally introduced in soils, mainly upon the death of plants, OC that is newly introduced into soils is rapidly decomposed by soil biota and oxidation unless it is made unavailable for decomposition by these means. It has long been thought that OC which is capable of long-term survival within soils is either a) converted into a recalcitrant form, b) sorbed by soil minerals, or c) becomes physically protected in pores within aggregates. However, much of the recent work, including the use of synchrotron-based techniques such as micro-small angle X-ray scattering (μSAXS) (McCarthy et al., 2008) and near-edge X-ray absorption fine structure NEXAFS (Lehmann et al., 2007; Wan et al., 2007), indicates that physical protection (c) may be the most important mechanism for the protection of OC in soils. While sorption (b) may also offer some such protection, there is little or no evidence for (a), the formation under normal soil conditions of forms of OC which are recalcitrant against decomposition (Schmidt et al., 2011), albeit that charcoal may form by burning.

The first requirement for the sequestration of organic carbon (OC) in soils is that its amount is increased by plant growth to enable its subsequent incorporation in soils. This paper reports on the enhancement of crop yields through the addition of clays to sandy soils. The results are then discussed in relation to the possible strategy of increasing the sequestration of C through the addition of clays to poor soils.

Methods

1. Field trial. The following field trials were established on 6 paired sites on a sandy soil in northeast Thailand:

(i) Control: current farmer practice of tillage and fertiliser additions

(ii) Termite mound material applied at 120 ton ha^{-1}

(iii) Leaf compost applied at 10 ton ha^{-1}

(iv) Dredged lake materials applied at 120 ton ha^{-1}

(v) Waste bentonite (from soybean processing) applied at 50 ton ha^{-1}

(vi) Waste bentonite applied at 50 ton ha^{-1} together with lime at 5 ton ha^{-1}

(vii) Local bentonite applied at 50 ton ha^{-1}.

Some combinations of these treatments, as well as treatments where application was by slotting were also used. Forage sorghum was grown on each plot and the dry matter yield was measured on harvest (see Noble et al. 2004 for details).

2. Pot trial. A commercially-available Na-saturated bentonite that had been equilibrated with chloride solutions of the appropriate cations to give an exchangeable cation suite of Ca:Mg:K in the ratio of 8:4:1 was applied at the equivalent rates of 1, 10, 20 and 40 t ha^{-1} to 500 g samples of an Ultisol from North Queensland that had become degraded by sugarcane production over 60 years and yields over forage sorghum were measured over two years and aggregated (see Noble et al. 2001 for details).

Results

The addition of several clay-based materials to light textured sandy soils in northeast Thailand increased crop productivity and associated water-use efficiency, when compared to untreated soils (Fig. 1). In North Queensland, crop yield was improved by >50% by the addition of bentonite (Fig. 2).

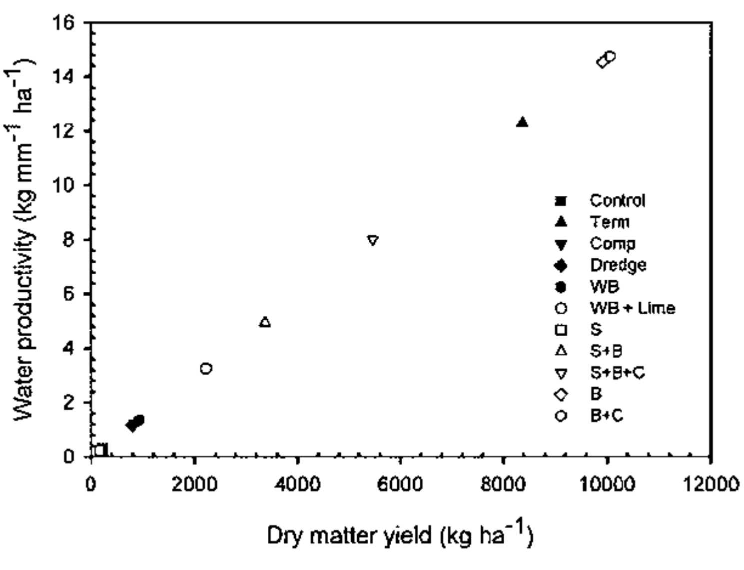

Fig. 1. Dry matter yield of sorghum in relation to water productivity for soils in NE Thailand following addition of different amendments: Compost, Dredged material, Termite mounds, Waste Bentonite, local Bentonite, S, with slotting (adapted from Noble et al., 2004).

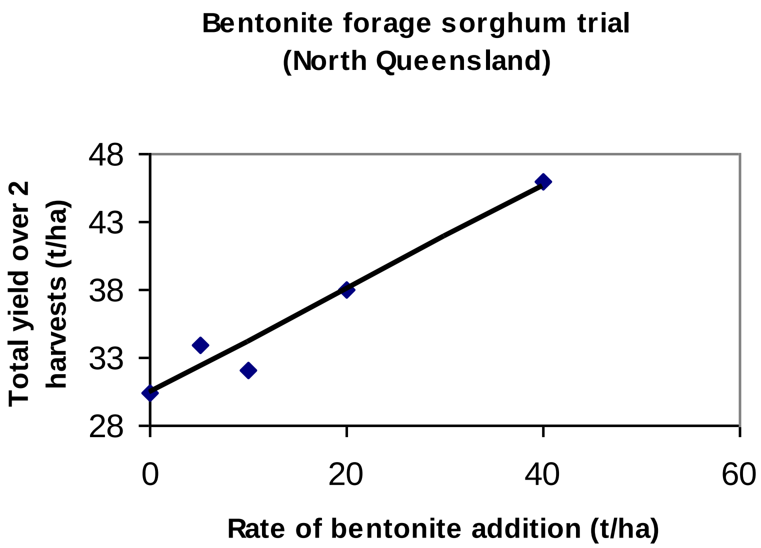

Fig. 2. Yield of sorghum in a Ultisol from north Queensland over two harvests in relation to additions of bentonite.

Discussion

Both the field and pot trials have demonstrated an increase in plant production that was brought about by the addition to soils of clay in a variety of forms, ranging from clay-rich termite mound material to both mined and waste bentonite.

In South Australia and Western Australia, subsoil clay is added to topsoils to overcome widespread non-wetting on sandy soils (Cann, 2000), and where subsoils were also sandy, addition of foundry waste bentonite overcame this problem (Churchman, unpub. results). These applications raise the prospect of increasing the organic carbon contents of soils as a by-product of the increased crop yields resulting from clay additions; data from Western Australia (Busby, 2011) confirm the effect of clay additions on enhanced OC levels in soils. However, increases in OC lead to increased sequestration of carbon only if the carbon is stabilised within the soil for ~100 years. Recent literature suggests that minerals with singly-coordinated hydroxyl groups for ligand exchange with organic functional groups are most effective for stabilizing OC in soils (Mikutta et al., 2005). It is likely that they are effective because they promote the formation of microaggregates which provide long-term protection of OC in soils. These groups are provided by poorly-crystalline minerals such as allophane and ferrihydrite. Furthermore, acid activation of bentonites enhances OC uptake for bleaching cooking oils. ~8 million tonnes of bentonite per annum are acid-activated for this use world-wide and it is possible that the excess bentonite remaining after bleaching oils could be used to enhance OC sequestration if added to soils.

Conclusions

1. Addition of clays to sandy and degraded soils enhances plant growth on these soils.
2. Enhanced plant growth leads to increases in OC in soils.
3. Clays have been, and continue to be, added to sandy soils to overcome non-wetting.
4. Minerals with reactive groups for ligand exchange with functional groups on organic matter are likely to stabilise OC in soils.
5. Highly reactive compounds of Fe and Al, as well as acid-activated clays are likely to be effective for the sequestration of C in soils.

Acknowledgment

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