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SHORT COMMUNICATION

SOIL CARBON TRANSITIONS SUPPORTING CLIMATE CHANGE MITIGATION

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ABSTRACT

Maintaining and where feasible restoring soil carbon stocks is part of all sustainable development strategies that have a chance of meeting the global commitment of the Paris Agreement to contain global warming within a 1.5°C limit. Active policies to incentivize increased soil carbon storage require understanding of the drivers of soil carbon decline, as well as the conditions under which soil management leads to an increase. Soil carbon transitions -- shifts from decline to increase of soil carbon stocks -- have been recorded as part of agricultural intensification. Organic inputs supporting soil carbon may primarily depend on roots, rather than aboveground inputs, and thus on the choice of crops, trees, and grasses that make up an agricultural land use system.

Keywords: Carbon Stock, Organic Matter, Soil Management, Tropical Soil

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INTRODUCTION

Soil carbon stocks in tropical soils under natural vegetation (forest) are dependent on soil type (with volcanic and peat soils as special cases), soil texture, pH and elevation (as a proxy for temperature) (Noordwijk et al., 1997). Conversion of forest soils to agricultural use leads to a loss of soil carbon, with a meta-analysis of published data (excluding peat soils) averaging a 25% loss (Don et al., 2011) Thus, “Agricultural soils, having been depleted of much of their native carbon stocks, have a significant CO_2 sink capacity” (Paustian et al., 1997). Soil carbon increases for rice fields have been described for Java and other parts of Asia, reversing a long-term trend of soil degradation (Minasny et al., 2012) (Fig. 1). A generic pattern of ‘soil carbon transition’ was discussed as part of a global soil C assessment (van Noordwijk et al., 2014).

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Soil is globally the largest terrestrial carbon pool (Scharlemann et al., 2014) and increases could help in climate change mitigation. As part of global warming, however, soil carbon is at risk of increased decomposition, reducing stocks (Crowther et al., 2016; Melillo et al., 2017).

Soil carbon samples have been analyzed with consistent methods since the 1930s, but averaging over all Java-based samples of the Bogor soil research institute showed a consistent decline till around 1975, with highest loss rates in the 1950s and 1960s (Fig. 1). After 1975 the rate of change became positive and part of the past losses could be recovered. In the period of 1930-1940 soil C in the 0-10 cm depth layer was around 2% (w/w); it declined to 0.8% in 1960-1970 but increased again to 1.1% around the year 2000. Soil C increases were mainly related to changing agricultural practices: effective soil conservation and increased cropping intensity, increasing the root residue input per year.

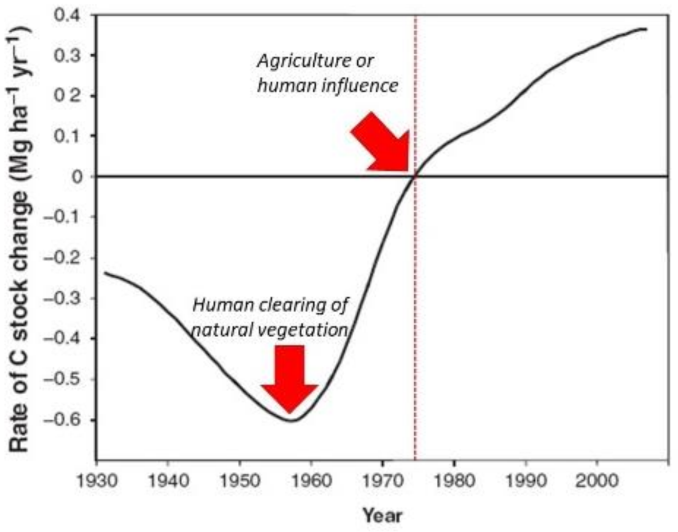

Figure 1. The rate of change soil organic carbon stock (Mg ha^{-1} yr^{-1}) in the 0-10 cm depth layer in 2002 soil samples from Java, analyzed per decade (Minasny et al., 2012)

The Paris Agreement to contain global warming at a 1.5° C increase triggered global interest in the 'four per mille' concept, suggesting that if all soils could increase their carbon content by 4‰ yr−1 this would make a substantial contribution to the global climate change mitigation goals (Minasny et al., 2017; Soussana et al., 2017). The concept has, however, been criticized as challenging the credibility of soil science (Baveye et al., 2017) and as an issue of view of managing expectations (de Vries, 2017; Poulton et al., 2018). For specific agroforestry practices, such as fallows and multistrata agroforestry, there is evidence that the goal can be achieved (Corbeels et al., 2018), but not in practices with lower tree densities such as alley cropping and parklands systems (Bayala et al., 2015). To better understand the debate, we need to appreciate recent progress in the underlying processes and spatial patterns, as well as benefits, increased soil C storage provides (Banwart et al., 2014).

HOW DOES SOIL C CONTENT RELATE TO INPUTS, DECOMPOSERS, AND ENGINEERS?

In a recent overview of current understanding of the processes that in interaction determine soil carbon stocks (Dignac et al., 2017) soil C stabilisation mechanisms were discussed as interacting biotic and abiotic processes: organic inputs from plant litter and root turnover, microorganisms (fungi and bacteria), belowground food-webs and 'ecosystem engineers' (earthworms, termites, ants), interacting with soil particle aggregation, soil physical structure and porosity (Fig. 2). Agriculture acts on these processes through, among others, choice of plant species and density, plant residue retains and exports, amendments, fertilization, irrigation, liming and tillage. A recent analysis (Jackson et al., 2017) suggests that root inputs are approximately five times more likely than an equivalent mass of aboveground litter to be stabilized as SOM. Full understanding at process level is yet to be included in integrated global frameworks to assess the impacts of land use and management change on soil carbon (Smith et al., 2012).

Soil carbon concentrations in the top layers have often been measured, but for conversion to carbon stock estimates the soil bulk density (dry weight per unit soil volume) needs to be known as well, and data on this parameter are not routinely collected. A further issue is the sampling depth, with soil tillage mixing soil layers and leading to decreases in some, and increases in other layers. The international accounting standard has settled on estimates for the 0-30 cm depth layer, noting that on average half of the soil carbon in the 0-100 cm depth layer can be found in the 0-30 cm depth layer, while it is likely to respond more rapidly to changes in land use than that in deeper layers. From a research perspective, however, interest in deeper soil carbon continues.

The C-organic content in the deeper soil layers depends on the development and decomposition of plant roots as well as leaching of organic molecules from top soil layers. In many tropical soils acidity (low pH) and Aluminium toxicity constrain subsoil root development, and hence subsoil C inputs. Hairiah et al., (1996) reported a comparison of tree species on an acid soil (pH 4.5) in North Lampung, showing that a local tree species *Peltohorum pterocarpum* (Leguminosae) had the deepest root system, being tolerant to Al toxicity and allowing the tree to stay green during long droughts. Selection of such trees adapted to acid soils can contribute to both adaptation and mitigation strategies to climate change. Another example (Fig. 3) of grass root systems in Brazil related the tolerance to Al toxicity (about 0.77 $cmol_c$ dm^{-3}) of Signal grass, compared to Elephant grass with the development of deep roots and a total soil C stock of 358 and 214 t C ha^{-1}, respectively (Saraiva et al., 2014).

A recent analysis of global soil C data (Huang et al., 2018) showed that the correlation between SOC and soil temperature was negative between 52° N and 40° S parallels (covering tropics, subtropics and Mediterranean part of temperate zones) and positive beyond this region, as it integrates over increased decomposition and modified organic inputs (dominating in cooler temperate, sub-boreal and boreal zones). Time-averaged assessment of soil C in relation to perennial crops, suggests that an initial decline after land conversion and crop establishment can be compensated in later stages of the crop's life cycle (Khasanah et al., 2015).

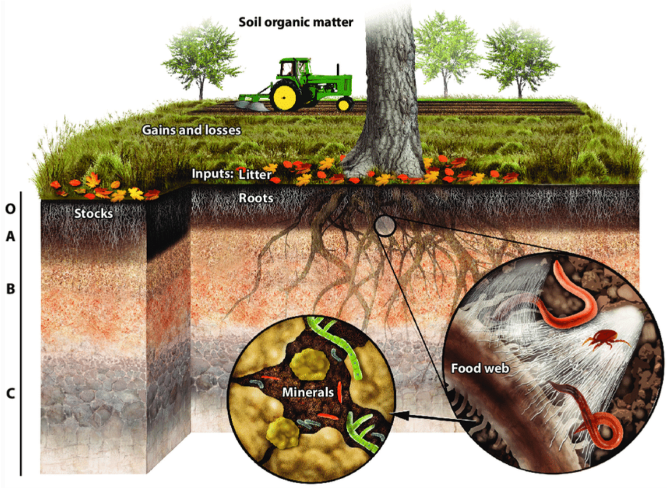

Figure 2. Abiotic and biotic factors important for soil organic matter (SOM) formation. (O= topsoil organic horizon, A=the topmost mineral horizon that contains a high concentration of partially decomposed OM), B=subsoil, a zone of weathering products and material leached from top layers, C=primarily weathered bedrock (Jackson et al., 2017)

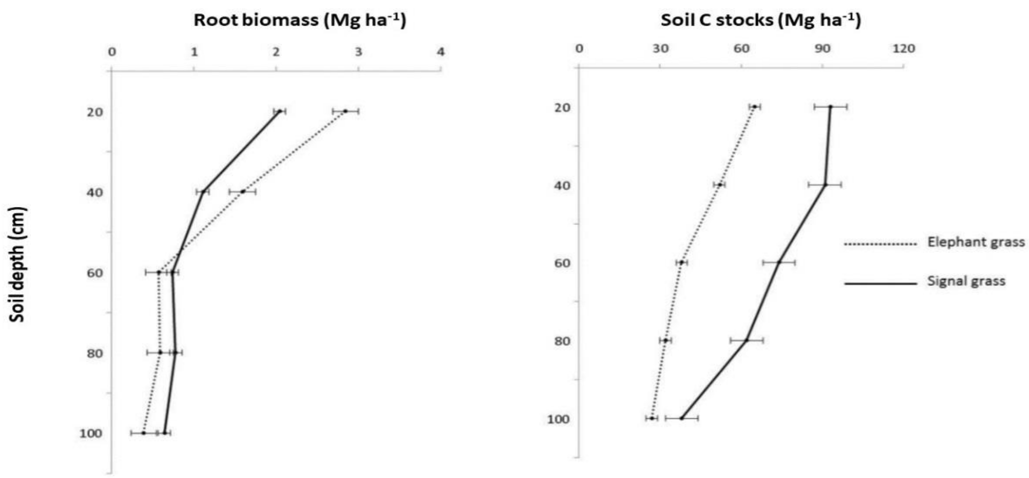

Figure 3. Root biomass of Al-tolerant Elephant grass (IRI 381) and Signal grass that grew on an ultisol in Brazil (Left) and their soil C stock of different soil layer (Right); horizontal bars indicate the standard error of the mean (Jackson et al., 2017)

Biogeochemical models rely almost exclusively on clay content to modify rates of SOM turnover, but more precise predictors are emerging from current research (Rasmussen et al., 2018). exchangeable calcium strongly predicted SOM content in water-limited, alkaline soils, whereas with increasing moisture availability and acidity, iron- and aluminum-oxyhydroxides emerged as better predictors, demonstrating that the relative importance of SOM stabilization mechanisms scales with climate and acidity. This matches the analysis of Indonesian soils in the 1930's when a curvilinear relationship between soil pH and soil C content was described by Hardon and re-established on soil C data for Sumatra in the 1970's: the agronomically optimum soil pH implies the lowest soil C storage, suggesting that some of the crop responses to liming on acid soils may be due to increased nitrogen mineralization followed by increased N availability for the crops. Selection of acid soil tolerant crops, and reducing lime requirements can contribute to increased soil C storage.

PEAT SOILS

Process-level understanding of the changes in tropical peat in response to drainage, forest conversion and fire have increased substantially in the past decade, as has the 'willingness to act' or policy commitment to reverse the trend (van Noordwijk et al., 2014). The 'ability to act' and make the plans for peatland rewetting operational, however, has become a bottleneck, as is the lack of 'paludiculture' options that thrive under wet conditions. Continued research at process level has shown that measurement of subsidence rates provides an integration over short-term variation in emissions, but needs to account for spatial variation in the dynamics of microtopography (Khasanah & Noordwijk, 2018).

DISCUSSION: INCENTIVES FOR FARMERS TO INCREASE SOIL C CONTENT OF THEIR SOILS?

Although there still are expectations that evidence-based incentives at farmer level could become operational, the high transaction costs and the relatively small increases in a stock of considerable spatial variability make it an unattractive option (van Noordwijk, 2014). The main incentive for farmers to increase soil C content is formed by the increased buffering function for water and nutrients that such soils have.

From the 'soil carbon transition' examples we can learn that no specific 'soil carbon incentives' may be needed if a sustainable intensification pathway is selected that combines higher land productivity and increased soil C inputs, with the increased soil buffering helping to reduce vulnerability to more extreme weather events. The appropriate scale for monitoring such changes are the mandated periodical national greenhouse gas inventories.

CONCLUSION

Soil C stabilization mechanisms were interacting biotic and abiotic processes. The agriculture acts on these processes through choosing the plant species and density, plant residue retains and exports, amendments, fertilization, irrigation, liming and tillage. The main incentive for farmers to increase soil C content is formed by the increased buffering function for water and nutrients that such soils have, and the mandated periodical national greenhouse gas inventories was needed to monitoring the fluctuation of soil C.

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