Impact of land use change on coupled cycles of carbon and metal cations in the Coastal Plain, Delaware

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Introduction

Virtually all of earth surface is now under the influence of human activities including agriculture. With ongoing climate change and due to human alteration of global carbon cycle, scientific community has become increasingly interested in the impact of land use change on soil carbon cycle. Now there is a consensus that agricultural conversion of natural forest leads to the reduction of soil carbon storage.

Though not studied in relation to the land use impacts on carbon cycle, recent investigations showed evidences that mineralogical weathering and metal cycles (eg., Fe and Al) can significantly affect the rates of carbon cycle. Additionally, it has been long known that both bioturbation and agricultural tillage vertically mix soils strongly influencing depth distribution of inorganic and organic soil materials. To our knowledge, however, the impacts of land use change on the coupled cycles among physical soil mixing, metals, and organic carbon remain virtually unexplored.

Towards this direction, we present a preliminary analysis of our ongoing data collection, which demonstrates the impacts of land use types (crop field vs. forest) on (1) soil carbon profiles and storage; (2) vertical soil mixing; (3) elemental budget; and (3) association of Fe and Al with pedogenic oxides and organic matter.

Method

Site Description and Field Sampling

The research sites are located in Coastal Plain within University of Delaware campus in Newark, Delaware. Its mean annual temperature is 13°C, and the mean annual precipitation is 1140mm. The soils are developed from stream sediments eroded from upstream Piedmont of which bedrock is largely composed of gneiss and schist. Two adjacent soil pits (~100 meter distance) represent the following land use types:

Farmland (Alfisol) is a intensive small scale crop field owned and managed by the University of Delaware. Crops in the past 4 years include soybeans, potatoes, baby lima beans, pumpkins, watermelons, cantaloupes and etc.

Woodlot (Ultisol) has not been disturbed at least for the last 60 years except by research activities. Currently, the site is covered with one of the rare remaining Piedmont Coastal Transition forest.

Except the land use difference, the two soils share almost identical climate, parent material, topography, and geomorphic surface age. Soil samples were collected by horizons.

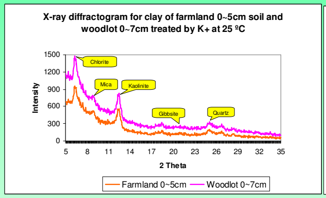
Fig. 1 Distinct soil profiles from the farmland and woodlot. Compared to the farm soil, the wood lot soil shows more clearly defined, darker, and thicker A horizon. Morphologically, the farm soil is more vertically homogenous than the woodlot soil.

Lab Analysis

- Total elemental composition (ICP-MS after lithium meta-borate fusion)
- Total carbon and total nitrogen (CN analyzer)
- Mineralogy in clay fraction (X-ray diffraction)
- Short-lived ^{137}Cs radio activity (gamma spectrometer)
- Elemental chemistry of selective dissolution (Dithionite citrate, sodium pyrophosphate, ammonium oxalate extraction)
- Geochemical mass balance model: To calculate the fractional mass losses of major oxide elements (subscript j) with Zr (subscript i) as an index immobile element

$$\tau_j = \frac{C_{jw} C_{ip}}{C_{jp} C_{iw}} - 1$$

Result and Discussion



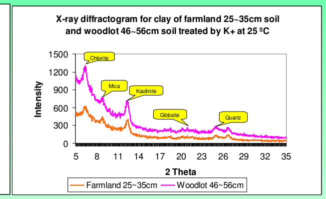
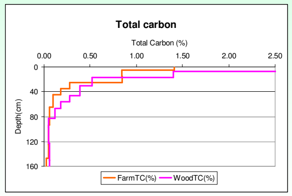


Fig.2 The two soils share almost identical mineralogy. Clay minerals are dominantly chlorite and kaolinite. Primary minerals are largely quartz and micas. Mineral species are consistent across the soils and parent material, indicating that the soils are formed from the in-situ parent material. This corroborates our use of geochemical mass balance which assumes negligible input of exogenous aeolian deposits.



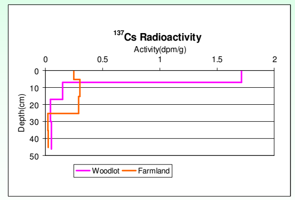
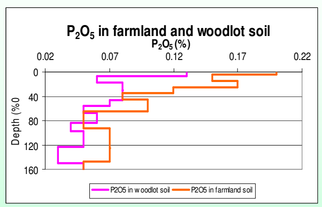


Fig.3 Throughout the entire depth, carbon contents are higher in the wood lot soil. The total soil carbon storage in woodlot is 7.7kg/m², whereas the farm soil stores 5.5kg/m². The reduction of %C with increasing depth, however, is steeper in the wood lot soil.

Fig.4 Within the upper most soil depth, ^{137}Cs activity is greater in wood lot. However, within the underlying depths of 7-25cm, ^{137}Cs activity is greater in the farm soil. Despite the higher abundance of earthworms in the wood lot, agricultural tillage created more intensively mixed soil overall.

Fig.3 & 4 show that the increased depth reach of vertical mixing by agricultural tillage created the more homogeneous carbon depth profile. More fraction of the total carbon storage is explained by deeper soil zones in the wood lot.



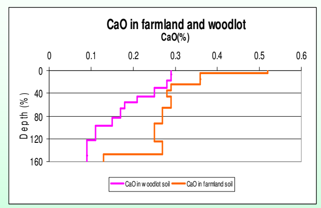
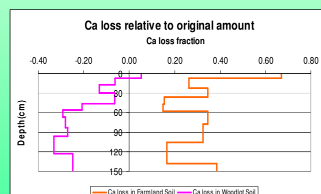


Fig.5 The concentrations of Ca and P in the farm soils are significantly higher than those in the wood lot soil, with the relative difference of Ca of 6%~66% and P of 54%~110%. The elemental storages are 4.8kg Ca/m² and 0.9kg P/m² in the farm soil and 2.7kg Ca/m² and 0.6kg P/m² in woodlot. The differences in the storages suggest that 2.1kg of Ca and 0.3kg of P have been retained per square meter of soil from the agricultural inputs of lime and fertilizer.



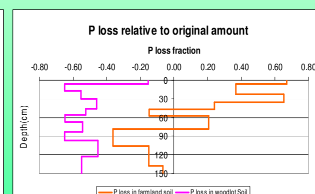
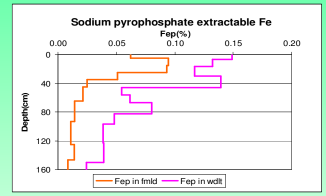


Fig.6 In the wood lot, during the soil formation from the parent material, significant fractions of original Ca (1.0kg/m²) and P (1.4kg/m²) have been lost via mineral dissolution and leaching. The slight enrichment of Ca and least fractional loss of P in the uppermost horizon in the wood lot suggests bio-recycling. In the farm soil, liming and fertilization not only completely refurbished the losses but also further added extra masses of Ca and P.

Result and Discussion (Con't)



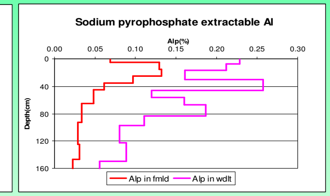
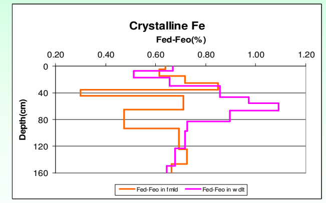


Fig.7 Sodium pyrophosphate (subscript p) extracts metals complexed with organic matters. The amounts of Fep and Alp in a given soil mass are greater in woodlot throughout the entire soil profile, indicating that organic matter stores less amount of Fe and Al in the farm soil. This can be expected from the lower C % in the farm soil.



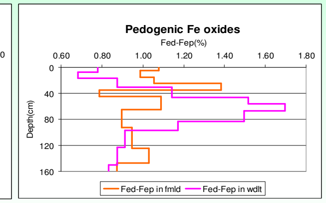
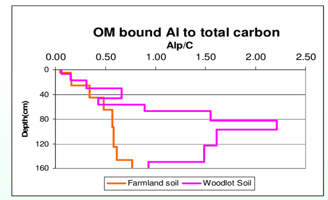


Fig.8 The amounts of crystalline and pedogenic Fe per given mass of soil are greater in the farm soil at the depth of 0-40cm probably due to (1) incorporation of B horizon material into A horizon by tillage and (2) reduced clay dispersion and eluviation because of greater amount of Ca and higher pH in the farm soil. This difference, however, is reversed in the subsoil between 40 to 120 cm depths, which may be partly due to the decreased clay eluviation from the overlying A horizon in the farm soil.



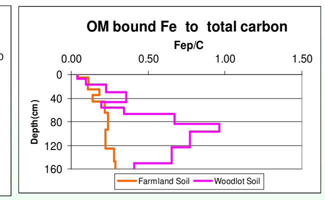


Fig.9 Organic matter complexed Al and Fe per carbon mass revealed that Al and Fe were not proportionately lost with the agriculture-associated reduction of organic matter. The organic matter in the farm soil, particularly in the B horizons, is significantly diluted in Fe and Al compared to the organic matter in the woodlot soil. This suggests the reduced translocation of Fe via organic matter chelation.

Summary

This study suggests that the crop farm soil, when compared to the adjacent forest soil, (1) has reduced C % and carbon storage; (2) has extended well-mixed A horizon; (3) has higher concentrations of Ca and P and is enriched in Ca and P relative to the parent material; (4) has greater amount of crystalline and pedogenic Fe in the top soil but less in the subsoil; and (5) has organic matter that is diluted in Al and Fe.

Reference

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