Land use change and soil organic matter dynamics on two contrasting soils from Zimbabwe

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Abstract

Long-term dynamics of organic C and N in soils under smallholder maize production were studied using cultivation chronosequences in Mafungautsi and Chikwaka in order to determine the impact of land-use change on soil organic matter. The C dynamics data for sites under different soil textures and climate was used to validate the CENTURY model. The source of soil organic matter in cultivated fields, either the original forest (predominantly C3) or the subsequent maize crop (C4), was determined using the $\delta^{13}C$ signatures.

The land use change dynamics for both communal area sites from the 1960s to present day were studied using farmer surveys, ArcView GIS and aerial photographs. The consequent change in the soil organic carbon (SOC) stocks for the two sites was estimated using the CENTURY model and ArcView. Mafungautsi recorded an increase of 2 741 ha in the arable land between 1967 and 2000, whilst Chikwaka recorded a 149 ha increase in arable land between 1972 and 1996. During this period there was considerable increase in the population living in the two districts in which the sites fell. Gokwe District (Mafungautsi) recorded 408 % increase in population from 79 446 in 1962 to 403 653 in 1992. On the other hand Goromonzi District (Chikwaka) recorded a 108 % increase in population from 70 607 in 1962 to 147 149 in 1992. The increase in the forest area converted to arable land can thus be attributed to the population pressure in the two districts.

CENTURY + ArcView predicted a change in the SOC contents for Mafungautsi from 24 t C ha^{-1} to 20 t C ha^{-1} within this period of time due to the change in land use. SOC contents in Chikwaka changed from 47 t C ha^{-1} to 27 t C ha^{-1} for the 24-year period. The loss in SOC per ha was greater in the Chikwaka site although the equilibrium SOC contents were higher for this site. This was because the Chikwaka site had more clay content (48-50 % Clay + Silt) whilst the Mafungautsi site was predominantly Kalahari sand (95 % sand). Consequently, most of the SOC in the Kalahari sand soil was already stabilised since there was nothing to protect the less stable forms of SOM. On the other hand there was loss of SOM soil that is normally protected within and between soil aggregates before cultivation in the clay.

The initial measured C and N contents in the topsoil layer were higher in the Chikwaka clay soil (about 35 t ha^{-1} and 3 t ha^{-1}) than the Mafungautsi Kalahari sand (about 11 t ha^{-1} and 0.6 t ha^{-1}). This was because of the larger SOM protective capacity of the Chikwaka soil with higher clay + silt content due to physical protection. Rapid soil organic matter loss occurred within the initial 5

years of cultivation when the land-use was changed from forest to maize cultivation under smallholder management. The cultivation equilibrium organic C and N contents in topsoil were lower in the Mafungautsi Kalahari sand (about 5.7 t $ha^{-1}$and 0.28 t ha^{-1}) and higher for Chikwaka clay soil (10 t ha^{-1} and 0.76 t ha^{-1}). The C and N losses were slower, and cultivation equilibrium organic C and N contents were larger in the Chikwaka red clay soil. The differences in the equilibrium SOC were attributed to textural differences. Describing the C and N decline trends by single exponential functions accounted for a large proportion of the variance in Ap1 horizon in Mafungautsi (R^2=0.67 and 0.72) and Chikwaka smallholder farming chronosequence (R^2=0.91 and 0.70.

The changes of $\delta^{13}C$ signatures of the soil organic matter with time of cultivation at the different sites suggested different mechanisms of soil organic matter protection in soils with different textures. The changes in the $\delta^{13}C$ values of soil organic matter when the forest was cleared for maize cultivation in Mafungautsi were not detectable. This suggested little contribution of maize to soil organic matter in the sandy soil. The persistence of a fraction of the forest soil organic matter in this soil is due to chemical stabilization of the organic matter with high concentrations of lignin and polyphenols, or as charcoal. The equilibrium $\delta^{13}C$ values in cultivated fields were obtained at greater values in the Chikwaka red clays under smallholder farm management. This indicated a significant contribution of maize to soil organic matter, probably due to physical stabilization of the labile maize soil organic matter.

CENTURY model scenario analysis of management practices that may sustain soil organic matter showed low potential to build up soil organic matter in the Mafungautsi Kalahari sand. Large quantities of maize stover, exceeding 15 t ha^{-1} were predicted necessary to maintain soil organic matter at the original Mafungautsi forest equilibrium levels. Such large biomass quantities are however not achievable in this area, even under optimal management practices. Whilst zero tillage was predicted not to yield significant increases in SOC (0.3 %) for Mafungautsi, in Chikwaka it yielded a 15 % increase in SOC contents compared to the conventional tillage practice. This could also be attributed to the higher clay contents in the Chikwaka site that lead to protection of any SOC fixed by the clay soil and also due the aggregate protection of SOC which occurs in Chikwaka but lacks in the Kalahari sand in Mafungautsi.

We conclude that soil texture plays a very significant role in the fixation and loss of SOC. Whilst conversion of forest areas to arable land leads to significant losses in the SOC of both clay and sandy soils, there is more loss per ha in clay soils than in sand soils under cultivation. There also exist more options for SOC build up in the clay soil than in sandy according to the CENTURY model scenario analyses. The source of SOC in the Kalahari sandy soil is mostly charcoal from forest burning whilst in the clay soil, maize contributes significantly to the SOC.

Key words: Zimbabwe, SOC, tillage , 2 soils, texture effect, modelling