Agriculture, Ecosystems and Environment 255 (2018) 62–72

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Soil C:N ratios are unresponsive to land use change in Brazil: A comparative analysis

Yuri Lopes Zinn[a,*], Gonçalves Jotamo Marrenjo[a,b], Carlos Alberto Silva[a]

[a] *Dept. of Soil Science, Universidade Federal de Lavras, Campus, Lavras, MG 37200-000, Brazil*
[b] *Universidade Pedagógica, Delegação de Massinga, Caixa Postal 111, Maputo, Mozambique*

ARTICLE INFO

Keywords:
Soil nitrogen
Soil organic matter
Soil quality

ABSTRACT

The C:N ratio is the most widely used indicator of the quality of organic residues and soil organic matter, but little is known about how average soil C:N ratios change when pristine lands are converted to agriculture in the humid tropics. This work aimed to compile the literature on Brazilian soils and calculate percent changes in soil organic carbon (SOC), total N and C:N ratios, after conversion of native vegetation to different land use systems. The hypotheses tested were that land use change affects mean soil C:N ratios across a range of experiments, and that different land use types would affect C:N ratios differently. Overall, average changes for SOC and total N for the 0–20 cm standard depth interval were respectively −14.4 and −13.1% ($p < 0.05$, $n = 171$), whereas the average change in the C:N ratio was slightly positive (1.49%) but not significant ($p < 0.05$). For the 20–40 cm depth interval, SOC also decreased significantly (−13.2%, $p < 0.05$, $n = 72$) but not N, whereas C:N ratios increased by 0.21%, again not significantly. Linear regressions suggest that higher or lower C:N ratios upon tillage were more associated to decreased or increased N concentrations, respectively, than to respective changes in SOC. When data were treated separately by major land use systems, the results were generally similar to the overall trends. Therefore, we concluded that land use changes in Brazil, and probably in other humid tropics, have no significant effect on soil C:N ratios in average. However, when C:N effectively changes, its impact for soil fertility and quality can only be interpreted aside with respective changes in SOC and N concentrations.

1. Introduction

Increasing concern about global warming and its mitigation has strongly increased the number of studies about soils as C sinks or sources during the last two decades. More specifically, the focus has been on how soil organic carbon (SOC), a major C pool in the biosphere, is sequestered or depleted by agricultural land use systems and their changes. In consequence of this interest, a number of related meta-analyses and other comparative studies (e.g., Zinn et al., 2005; Don et al., 2011; Fialho and Zinn, 2014) have also been published. These approaches involve collecting published, high-quality data and, after proper mathematical treatment, yielding synthesized findings, currently encompassing > 5600 meta-analyses across many disciplines (Fisher, 2014). In regard to SOC dynamics and land use change, most meta-analyses concluded that SOC is depleted after clearing native vegetation, with an intensity that varies with type of land use, soil management, climate and soil texture, among other factors.

Most articles regarding SOC dynamics and nearly all meta-analyses concern quantitative measurements of SOC concentrations or stocks, and the statistical significance and direction (i.e., gain or loss) of the mean changes incurred. The qualitative or compositional aspects of SOC, although subject of a myriad of studies, have seldom been the topic of meta-analyses. This is understandable because SOC “quality” is much more difficult to define, and its measure is commonly done by labor- and time-consuming analyses of humic substances, specific compounds (e.g., carbohydrate and lignin compounds), or biological activity indicators (e.g., microbial biomass). Among the few meta-analyses available, one can cite that by Kaschuk et al. (2010), who compiled data on microbial biomass in Brazil and noted higher values in soils under no-till than under annual tillage. Also, Santos et al. (2013) collected data on the partition of total SOC into humic or fulvic acids in Brazil, reporting no consistent effects of land use changes, whereas Graaff et al. (2015) reported the negative effect of soil biodiversity loss on soil respiration. Although these few studies suggest an unexplored potential for meta-analyses on SOC quality, a much more common indicator has seldom been evaluated. Soil C:N ratios, or SOC and soil N concentrations, have been used as inputs for five out of fifteen complex soil quality indices (Bastida et al., 2008). A recent paper by Deng and Shangguan (2017) shows a data compilation and statistical analysis for SOC, N and C:N ratios as affected by afforestation in China, and can be considered a pioneer work on the use of C:N ratio meta-analysis.

For organic residues, microbial decomposition is generally expected to

---

* Corresponding author.
E-mail address: ylzinn@dcs.ufla.br (Y.L. Zinn).

https://doi.org/10.1016/j.agee.2017.12.019
Received 22 August 2017; Received in revised form 15 December 2017; Accepted 19 December 2017
0167-8809/

promote net N immobilization when initial C:N ratios are > 30, whereas values < 20 commonly result in N mineralization (Mullen, 2011), including losses via nitrification (Yoh, 2001). In soils, C:N ratios refer to the mass proportion between total SOC and total N, and are perhaps the most available indicator of soil organic matter quality and its expected decomposability. For instance, soil organic matter decomposition as measured by CO_2 and N_2O emissions was negatively correlated with soil C:N ratios (ranging from 13 to 20) under forest plantations in subtropical China (Wang et al., 2013). However, C:N ratios in pristine soils vary widely due to factors such as climate (Yoh, 2001), forest and soil type (Post and Mann, 1990; Cools et al., 2013), depth (Kirkby et al., 2016), percent of plant debris in regard to total SOC, and soil internal drainage. Across the world, mean C:N ratios typically vary between 10 and 30 across soil orders, being generally low for Mollisols and high for Ultisols (Post and Mann, 1990), and especially high in SOC-rich Histosols and Podzols (Batjes, 1996). In most soil profiles, C:N ratios are higher at the surface, due to a more advanced stage of decay in the subsurface (Batjes, 1996). Similar trends were reported for the Amazon (Batjes and Dijkshoorn, 1999), which showed lower and less variable C:N ratios than global means, which ranged from 9.8 to 12.4 in the 0–30 cm depth. For native savannas in Brazil, C:N ratios are ca. 13.4-14.5 in the 0–5 cm depth, decreasing to ca. 10.5 at the 90–100 cm depth (Zinn et al., 2011). According to Kirkby et al. (2016), variations in microbial composition along the soil profile depth may also be involved, and additionally affect C:P and C:S ratios. In the humid tropics, soil texture can also affect soil C:N ratios, as the mechanisms of organic matter retention vary among soil particle size fractions. In untilled Ferralsols of Uganda, C:N ratios ranged from 15 to 21 in clay fractions, and from 32 to 47 in sand fractions (Musinguzi et al., 2015).

Although soil C and N are mostly intertwined in soil organic matter, they follow different paths after biological decomposition. Comparing tilled and untilled paired plots, Post and Mann (1990) estimated for that global N losses are on average one-fourth of SOC losses. This results from the fact that ca. 50% of SOC is released as CO_2 after being used as an energy or C source, whereas most or all N (if C is not limiting) is used and retained by microbia, and thus tends to be conserved in soils (Kuzyakov et al., 2000; Mullen, 2011). Such N conservation can be traced to an adjustable efficiency in microbial use of C and N, which becomes higher when respectively N or C become limiting (Mooshammer et al., 2014), despite the effect of N losses via ammonia volatilization or nitrate leaching. Also, N is more mobile within the landscape and can increase downslope even when SOC is unaltered (Lozano-García and Parras-Alcántara, 2014). As rates of CO_2 release and N mineralization-immobilization-remineralization vary with a number of external and soil factors, it is not clear how the stoichiometry of SOC and N changes in agricultural soils. For instance, tillage accelerates SOC and N mineralization (Mullen, 2011), lowering C:N ratios as C losses as CO_2 are expectedly higher than those for N. This trend can be even stronger as N fertilization or biological fixation add more N to the system, which can also enhance SOC depletion by priming effects (Kuzyakov et al., 2000). On the other hand, afforestation of degraded and marginal soils with fast-growing trees can increase C:N ratios, if SOC concentrations remain unaltered but considerable N is immobilized in the forest biomass (Zinn et al., 2011).

Therefore, interpretation of the significance of soil C:N ratio changes is complex and must be done on a case basis, but a statistical perspective based on a comprehensive data base is greatly needed. This work aimed to assess how soil C:N ratios vary after conversion of native vegetation to agricultural systems in Brazil, by means of a compilation of literature data and statistical analyses of changes in C:N ratios, as well as in SOC and total N. Our rationale is to provide a better perspective on how this important indicator of soil and SOC quality can be used to assess sustainability of land use systems and their potential response to climate change. We tested the hypothesis that conversion of native vegetation to agricultural systems significantly affects mean soil C:N ratios. A secondary hypothesis tested was that such mean C:N changes vary according to land use type.

2. Material and methods

Our database was built from a literature review of dissertations, journal articles and annals of scientific meetings, consisting in synchronic, replicated studies with plots of soils under native vegetation and one or more other agricultural land use systems in Brazil. Reports chosen were those showing: a) data on total SOC and total N concentrations (mass/mass) or stocks (mass/area for a specific soil depth basis) and C:N ratios; b) both SOC and N concentrations or stocks, but not C:N ratios, which were then calculated, and c) SOC concentration or stocks and C:N ratios, from which N concentration or stocks were calculated. Ideally, organic N rather than total N would provide a better perspective, but this is not expected to be a problem since inorganic N in Brazil is typically < 1% of the total N (Ri and Prentice, 2008). Analytical methods included dry or wet (dichromate) combustion for SOC, and Dumas combustion or Kjeldahl distillation for total N. Dry methods are known to generally return higher SOC concentrations, but this is not expected to affect data comparability (Kirkby et al., 2011), since each article or study consistently used the same methods for control and treatments, and we calculated relative (percent) changes.

Soil sample preparation in all cited works involved previous removal of organic layers, air-drying and sieving < 2 mm, removing coarse roots and debris, with a minimum of three replicates. Most soils sampled in the surveyed studies were highly weathered Oxisols, Ultisols and Inceptisols rich in kaolinite and Fe/Al oxides in the clay fraction. Changes in SOC concentrations upon cultivation are strongly affected by the soil depth interval sampled (Zinn et al., 2005). Since the independent studies surveyed here sampled different depth intervals, to assure comparability we grouped data into two standardized depth intervals: 0–20 and 20–40 cm. Thus, an article showing data for a single depth (say, 0–5 or 0–15 cm) would be included in the standardized 0–20 cm grouping, if samples deeper > 20 cm were not taken. When data were provided for multiple depths (e.g., 0–5, 5–10 and 10–20 cm), a weighed average was calculated, in which more weight is given to thicker depth intervals (i.e., the data for the 10–20 cm interval has the double of weight given to the 0–5 cm interval). If the data were reported in stocks (e.g., $\mathrm{Mg\,ha^{-1}}$ or $\mathrm{kg\,m^{-2}}$), we summed up the values for each standardized depth interval, using the proportion of the sampled depth actually used. Thus, in calculating 0–20 cm stocks from data on 0–10 and 10–30 cm depths, we used half the stock reported for the 10–30 cm depth. The equal mass comparison (Garten and Wullschleger, 1999) was used to compensate for variations in soil bulk density due to land use change. Appendices 1 and 2 present the data used in the calculations for both standardized depths, whereas Fig. 1 shows the location of the cited studies in Brazil.

Since the agricultural land use systems employed in each independent study varied widely, we stratified the input data into the following groups: a) grazed pastures receiving N fertilization; b) grazed pastures without N fertilization; c) annual crops under no-till or minimal tillage; d) annual crops with annual conventional tillage, typically comprising plowing + harrowing or heavy disk harrowing, and e) perennial crops, namely coffee stands, fruit orchards and forest plantations, involving tillage only after multiple year intervals. Due to potential effects of soil texture on the SOC changes (Zinn et al., 2005), the bulk data was further stratified into the arbitrary classes clay content low (< 20%, in a mass basis), mid (20–40%) and high (> 40%), as shown in Appendix A. One study with an excessively high N gain was considered an outlier and thus removed from the database, as well as two other data showing C:N ratios < 6 not under leguminous crops, probably signaling analytical errors. To make data comparable, percent changes in SOC, total N and C:N ratios were calculated from the numerical difference among the various land use systems and the respective native vegetation control, as done in various meta-analysis studies (e.g., Don et al., 2011; Fialho and Zinn, 2014). The arithmetic mean change was then calculated for the whole dataset, or separately each land use system, provided that at least three observations were available.

Quantitative effects on SOC upon land use change can be of three types: 1) absence of change, 2) losses, and 3) gains, and thus some meta-analyses report mean changes approaching zero, as noted by Fialho and Zinn (2014) for eucalypt plantations in Brazil. The same can be expected for soil N, although much less literature is available. Thus, our approach was to perform a two-tailed *t* test in order to determine if each mean change was significantly different from zero. We used the following model: