

***Interactive comment on* “Conversion of tropical forests to smallholder rubber and oil palm plantations impacts nutrient leaching losses and nutrient retention efficiency in highly weathered soils” by Syahrul Kurniawan et al.**

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Author's response:

First, we extend our sincere thanks to Dr. Fujii for his insightful suggestions and comments that help improve our manuscript greatly. We describe how we have addressed his comments in our answers below.

1. One of major issues is soil classification (Acrisols). Sumatra soils are more or less affected by volcanic ash deposition. Soils are relatively young among Indonesian soils.

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I am afraid whether the soils studied satisfy Acrisols' low clay activity. Please confirm the soil profile data especially in the Bt horizon. Low CEC/clay is required. In addition, both loam and clay Acrisols contain high contents of clays. Please clarify how two types were separated.

Author's response:

Soil particle size distribution was determined from the three sites (or replicate plots) of each land use within each landscape (which was subsequently classified according to the major soil texture group). In each site, soil samples for particle size analysis was taken from 6 depth intervals within 2-m depth. For the general soil texture classification, we took the values of depth-weighted average for each site, and then the averaged for the 12 sites (4 land uses x 3 sites) for each landscape. Similarly, cation exchange capacity (CEC) was determined from 2 to 5 samples per depth for each site. We also did an oxalate-extraction for Fe and Al, and these characteristics did not satisfy for an Andic property.

Our soil texture classification is based on the averages of the plots in order to come up with a general category of soil texture. The clay area had an average across sites of 48% clay, 27% silt and 25% sand. The loam area had particle size fractions that bordered between loam and (sandy) clay loam, and for ease in writing the classification in the manuscript, we generally termed this as loam (22-32% clay, 25-30% silt and 45-50% sand).

In the clay soils (with more than 40% clay), >8% increase in clay was observed in the subsoil. In the loam soils, the ratio of subsoil % clay to overlying layer was >1.2. Both of these metrics satisfied the criterion for an Argic horizon. These Argic horizons of our sites has CEC of < 24 cmolc kg⁻¹ clay and base saturation of <10% (all reported in our earlier publication, Allen et al. 2016).

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As these characteristics were already reported in our earlier publication (Allen et al. 2016), we did not elaborate these in the present manuscript. However, in order to address this concern of Dr. Fujii, we inserted in section 2.1, after a short description of the loam and clay Acrisol soils, the following:

Detailed soil characteristics of these classifications are reported by Allen et al. (2016).

2. L447 The authors link between N leaching and the acid-buffering capacity of the soils, but link between N leaching and clay contents will be precise. Exchangeable Al as well as pH is a record of soil acidification, but quantitative link between N loss and soil ANC cannot be supported by calculating proton budgets in soil.

Author's response:

We agree with the reviewer's comments. As stated in the Results (L366-376), N leaching fluxes (and N and base cation retention efficiency) were significantly correlated with soil base saturation, ECEC and organic C which were, in turn, correlated with clay content. Thus, this L447 is a leap in our interpretation, and we changed this L447 (as a topic sentence for this Discussion on correlations of nutrient leaching fluxes with soil biochemical characteristics) to refer only to what were clearly reflected by the correlation tests.

Author's changes in the manuscript: We changed L447 to:

The influenced of soil texture on soil biochemical characteristics also linked to the leaching losses or, conversely, nutrient retention efficiency.

3. There were some droughts or dry-wet cycles in Indonesia. This has strong impacts on solute concentration and leaching flux. I recommend to add correlation analyses between water flux (or soil water content) and solute concentration to check dilution or condensation effects by dry-wet cycles. This effect can affect annual nutrient loss as well. At least, adding discussion will improve manuscript.

Author's response:

From the start of our data analyses, we have explored all correlation tests, including correlations of element concentrations with the modelled soil moisture content at 1.5-m depth (lysimeter sampling) in order to check for dilution or condensation; the correlation tests with soil moisture contents were conducted in a similar manner as those synthesized in Appendix Tables 3 and 4. The only significant correlation coefficients with soil moisture contents were found for the fertilized area of the oil palm plantations in the loam Acrisol soil for K, Ca, Mg and total S concentrations ($r = -0.59 - -0.72$, $P \leq 0.05$, $n = 12$ monthly measurements for one year). However, the influence of soil water content on nutrient concentrations were anyway incorporated in the calculation of leaching fluxes (nutrient concentration \times drainage flux), as stated in L244-249. Also, all the correlations that used the nutrient concentrations (Appendix Tables 3 and 4) were interpreted only to assess which cations were correlated with which anions (i.e., L334-337, L344-347, L358-361) in order to support the partial ionic charge balance of solutes, as depicted in Fig. 1.

Author's changes in the manuscript:

Considering that (1) these above correlation tests were only significant in four elements at one spatial category (fertilized area of oil palm in the loam soils) and (2) the influence of soil water on element concentrations were incorporated in the calculation of leaching fluxes, we will not add this in the Discussion. This is so that the main highlights of our findings will not be buried, as suggested by Dr. Teh's (reviewer 1) first major suggestion.

4. Throughout the paper, the authors use the ambiguous term "soil fertility". The definition of soil fertility is not same among the readers. Please define it in the beginning of the paper. Most of soil scientists avoid to use the term "soil fertility" in scientific paper.

Author's response:

We agree and take this suggestion. When we used the word soil fertility, we specified in brackets the soil biochemical characteristics that we used as basis. These were already done in the original manuscript version of the Introduction and M&M.

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Introduction L61-62 - Soil texture affects nutrient leaching through its control on soil fertility (e.g., cation exchange capacity, decomposition, and nutrient cycling) and soil water-holding capacity.

M & M L126-128 - In summary, the soil textural difference leads to inherent differences in soil fertility (e.g., higher effective cation exchange capacity, base saturation, Bray-extractable P and lower Al saturation) in the clay than the loam Acrisols under forest and jungle rubber (Appendix Table A1).

Author's changes in the manuscript:

We specified the soil biochemical properties when we used the word soil fertility. Namely: Discussion, section 4.2, the last 2 sentences of 1st paragraph:

The lower annual nutrient leaching fluxes in clay as compared to loam Acrisols (i.e., TDN, Na, Ca, Mg; Table 4) were paralleled by higher gross rates of NH₄⁺ production and immobilization (Allen et al., 2015), soil N stocks, ECEC, base saturation (Appendix Table A1) and water-holding capacity (Hassler et al., 2015). Our findings showed that soil texture regulated nutrient leaching losses and soil fertility (e.g., nutrient stocks and N-cycling rates) in these highly weathered Acrisol soils.

In the Abstract and Discussion, section 4.3 last sentence of 1st paragraph – we replaced 'soil fertility' with 'nutrient availability':

Our results showed that disruption of nutrient cycling between the soil and vegetation brought about by land-use conversion to rubber plantations, combined with the absence of soil amendments, had decreased nutrient leaching (Tables 3 and 4) as well soil nutrient availability (i.e., P stocks, microbial N, gross N mineralization rates; Allen et al., 2015; Allen et al., 2016).

In the Conclusion, we replaced soil fertility with soil nutrients or nutrient levels.

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1. The authors regarded jungle rubber as original vegetation, but it is introduced from Brazil some hundreds of years ago. It is not native vegetation.

Author's response:

We replaced the word 'original' with 'previous' (in the Introduction) or 'reference land use' (in the Discussion), which was what we actually meant. We use 'previous' or 'reference land use' to denote the land use immediately before the conversion to rubber and oil palm.

2. The authors ascribed the greater nutrient losses from loam Acrisols than those from clay Acrisols. However, tree composition is not same between two sites. The authors need to add careful discussion on this topic.

Author's response:

This is a very good point and we take this into consideration. Our interpretation that soil texture was the main factor influencing leaching losses is based on the following: a) total net primary production (aboveground + belowground), as an indicator of plant usage of soil nutrients, of the forest and jungle rubber did not differ between the loam and clay Acrisol soils (Kotowska et al., 2015). b) despite higher tree stem density, basal area and root mass (all together maybe indicative of potential differences in nutrient demands of vegetation between these soils) in the loam than in the clay Acrisol soils (Appendix Table A2), the loam Acrisols still showed generally larger leaching fluxes than the clay Acrisols. c) based from the rubber plantations' (which all have the same low degree of management, e.g. unfertilized, in both soil types) Na leaching fluxes (the element more prone to leaching because of its monovalence and large hydration radius), the loam Acrisol soil was also higher ($P = 0.06$) than the clay Acrisols.

Previously we did not include these above points in the Discussion to keep the information more focused, especially that we have a data-rich paper. However, in the revised version we will include point (a) to address the reviewer's suggestion. We will

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not point this additional discussion on the tree species composition but on the net primary production and vegetation structure, as these parameters are commonly used as indicators of vegetation's nutrient demand.

Author's changes in the manuscript: In the Discussion section 4.2, 2nd to the last sentence of the first paragraph, we added this:

Nutrient demand of vegetation may not be the dominant control on leaching fluxes, as the net primary production of these reference land uses did not differ between the loam and clay Acrisol soils (Kotowska et al., 2015). Similarly, the vegetation structure of the reference land uses (tree density, basal area, root biomass; Appendix Table A2) even seemed larger in the loam than the clay Acrisols.

3. L525-527 erosion and enhanced microbial mineralization of the native SOM can also contribute to low SOC stocks in oil palm plantation.

Author's response:

Yes, and we did not include in our discussion the erosion effect. Soil respiration in our oil palm plantations has significantly decreased compared to the reference land uses (Hassler et al., 2015). Based on correlations analysis with other soil biochemical parameters (15N signatures, SOC, P and base cation stocks), we attributed the reduced soil CO₂ fluxes from the oil palm plantations as the result of the strongly decomposed soil organic matter and reduced soil C stocks, which in turn are due to reduced litter input as well as to a possible reduction in C allocation to roots because of addition of nutrients from liming and P fertilization (Hassler et al., 2015).

Author's changes in the manuscript: Considering that erosion is an important process contributing to a decrease in SOC, we replaced the word 'strong' with 'additional' in this L525-527:

Moreover, the increased annual DOC fluxes in fertilized areas of oil palm plantations (Table 4) suggests a reduction in the retention of DOC in the soil. This, combined with

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the decreases in litterfall and root production, harvest export (Kotowska et al., 2015), and decreases in soil CO₂ emissions (Hassler et al., 2015) from the same oil palm plantations, provided additional support for the decreases in soil organic C stocks in smallholder oil palm plantations in the same study region (van Straaten et al., 2015).

4. L505-506 What data can support this statement?

Author's response: This statement (i.e., increases in dissolved Al and acidity of soil solution; Table 3) was based on the Results section where dissolved Al and soil water pH were presented (L348-349).

Author's changes in the manuscript: In this sentence, we now inserted Table 3 as the data source.

5. Table A2 sp. or spp. should not be written in italic. Dipterocarpaceae spp. include Shorea spp. The tree composition should be re-checked.

Author's response:

We agree with the reviewer. This Appendix Table A1 was based on information we had in 2015, when another group working on species diversity in our plots were yet continuing to identify the species, and we had by mistake doubly listed the families Dipterocarpaceae and Shorea. We will check the most common tree families (>20 individuals per plot) with the recent data of identified trees.

Author's changes in the manuscript:

We now not write sp. or spp. in normal font, deleted Shorea, will recheck these most common families of trees with the data of Rembold et al. (2017), and update this reference in the Table A1 instead of the previous unpublished data.

Rembold, K., Mangopo, H., Tjitrosoedirdjo, S.S., and Kreft, H.: Plant diversity, forest dependency, and alien plant invasions in tropical agricultural landscapes, *Biodivers. Conserv.*, 213, 234-242, <https://doi.org/10.1016/j.biocon.2017.07.020>, 2017.

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6. Throughout the paper, “l-1” and “L-1” are used inconsistently. Please use terms consistently.

Author’s response: We appreciate very much for this very thorough read, and we indeed overlooked l-1.

Author’s changes in the manuscript: We corrected the entire text to have uniformed unit abbreviation, L-1.

Interactive comment on Biogeosciences Discuss., <https://doi.org/10.5194/bg-2018-221>, 2018.

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