Biogeosciences Discussions

Interactive comment on "Aggregate structure and stability linked to carbon dynamics in a south Chilean Andisol" *by* D. Huygens et al.

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Thank you for the interesting comments and constructive suggestions for further improvement of the paper. The cited papers in press were very useful to add further information to the manuscript, and partly confirm our hypothesis. In this "comment on a comment", we will briefly go into detail about some aspects of your comments. We hope that we can provide a contribution to the discussion, and give referees as such the possibility to consider our new annotations. Other comments, which mainly deal with elaborating a different structure and adding some more subchapters, will be modified after the finalization of the open discussion and receipt of more comments.

Specific comments

It is true that the used method for testing the aggregate stability is not a standard one. It is a modified version of the method described by De Leenheer and De Boodt (1959). This method has also been cited in the "Encyclopedia of Soil Science" (Diaz-Zorita

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et al., 2002). The reference method consists in performing a wet sieving procedure to divide the whole soil into different size fractions. This was done twice: at first, starting from air-dry soil, and secondly, starting from field-moist soil. The difference in weighted average diameter of both size distributions is an index for the aggregate stability. However, we were obliged to slightly alter the method:

- As drying of the soil might have an irreversible effect on the aggregates of volcanic ash soils, we chose to dry the soil to a gravimetric water content of approximately 30%, and refer to this as "air dry soil".

- As well, we used less sieves (and thus obtained less size aggregate fractions) because we sieved the soil to 2 mm after sampling. In the revised version of the manuscript, we will mention the reference of the method described by De Leenheer and De Boodt (1959).

The encyclopedia of soil science indicates different methods for the stability index. From our analysis, we were as well able to calculate the stability index according to Kemper and Rosenau (1986). Performing the same statistical analysis on this index of stability, a comparable statistical correlation between "aggregate stability index" and Al-ox content was obtained ($r = 0.48$, $p = 0.01$). However, we are completely aware of the fact that this statistical relationship should be handled with care. It was not our intention to prove a theory or to deduce conclusions based only on this statistical information. We believe that statistics can only serve to support a conclusion, not to make one. A graph indicating the relation between the extractable Alox content and the aggregate stability index will be included in the revised manuscript version.

Question: Why not combine the C pool in the heavy fraction of the MOM and the C pool in the large mineral fraction (>150 μm)? We as well considered this option, but finally we decided not to do it because of the following reasons:

- By clearly observing the different fractions, we noticed a clear difference in structure and properties of both fractions. The HF-MOM fractions consisted out of a fine struc-

ture, derived from plant material, but in a later stage of decomposition compared to the LF-MOM. The mineral fraction ($>150~\mu$m), on the other hand, consisted out of soil aggregates, in which no recognizable plant material was found.

- By analyzing the carbon concentration of both fractions, we observed as well a significant difference. The HF-MOM had a carbon concentration of about 250 g C kg-1 fraction, while the TC concentration of the mineral fraction varied from about 50-130 g C kg-1 fraction.

Because of the absence of applying ultrasonic energy to the soil aggregates, microaggregates might still contain some occluded POM. That's right, with the applied fractionation scheme, we were not able to isolate the POM occluded in some microaggregates. Before applying extra dispersive energy to the soil ("supplementary disruption processes", i.e. drying and rewetting of the soil), the soil aggregates were only to a limited extent degraded as a result of the wet sieving procedure. Macro-aggregates (and micro-aggregates) were apparently relative water-stable before the "drying-rewetting" procedure. The fact that before the release of organic material occluded in soil (macro and micro) aggregates, we did not observed differences in d13C values, only confirms our hypothesis that the aggregate hierarchy principle is not valid in this soil type. No extra young organic material was found in the larger aggregate classes before destruction of the aggregate.

Question: work out a stronger separation between the function of Al-humus complexes/allophane as stabilizing agent and their role in aggregate formation. This will be elaborated in the revised version of the manuscript. We agree that their possibly might be a direct effect of the chemical binding or physico-chemical processes, but keeping in mind the applied methodology we were not able to distinguish differences in SOM stabilization between the different studied land use treatments by these processes. Methods such as 13C NMR spectra and metal amendments to synthetic organics might be more useful to distinguish and quantify the importance of physico chemical processes per se. For this reason, we mainly emphasized physical protection

in this paper. However, a short literature review with respect to physico chemical processes will be given in the revised version of the manuscript. We will briefly quote stabilizing mechanisms such as ligand exchange, metal-humus complexes and sorption to clay minerals, and try to asses its importance for this specific soil type. As indicated in the manuscript, Al extractants are not completely selective for a specific phase (Bertsch and Bloom, 1996), in particular when Al, SOM and soil minerals are tightly associated as in the proposed SOM stabilization mechanism. For this reason, we do not believe that pyrophosphate extractable Al enabled us to isolate only Al associated with SOM. We believe that also Al bounded to soil mineral (in the so called "Al-mineral humus complexes") might be isolated. As well, we believe that aggregate formation and SOM stabilization are closely related, and the stabilization might be mainly a consequence of the physical protection in soil aggregates. Sollins et al. (1996) indicated the difficulty to separate physico-chemical processes and physical protection as factors influencing SOM stabilization. Physico-chemical associations namely tend to promote aggregation. Boudot et al. (1989) observed that the chemical binding between metals (such as Al and Fe) per se could not be regarded as responsible for any significant protective effect, and that complexation and adsorption processes does not necessarily mean protection against biodegradation. The formation of an insoluble metallic hydroxide trapping and wrapping the organic molecules, and therefore either preserving it from access by soluble soil enzymes or preventing their movement to immobile enzymatic constituents associated with microbial cells (=inaccessibility or physical protection), would better account for the observed protective effect than the chemical binding per se. In the short literature review of the revised concerning this theme, we will go further into detail with respect to the stabilizing role of the chemical binding per se.

The issue of difference in SOM input between the different land use treatments will as well be worked out in the revised version of the manuscript. Following paragraph will be added to the text:

Guo and Gifford (2002) found in their review average differences from +8% for the con-

version of native forest to pasture and -10% for pasture to plantations. Pasture grasses maintain a continuous vegetation cover on the soil and have high turnover rates and productivity, particularly belowground. As a result more intense humus formation would take place (Brown and Lugo, 1990; Yakimenko, 1998). In forested ecosystems, the SOM inputs originate partly from aboveground and accumulate more in and on the surface soil due to non-mixing of the litter (Paul et al., 2002). In forests, SOM tends to decompose partly before it is incorporated into the soil as recognizable plant material. Thus, under grassland a thicker A horizon is formed compared with forests (e.g. Birkland, 1984). According to Guo and Gifford (2002), the lower C content in plantations may partly be attributed to soil disturbances and consequent loss in physical protection of the SOM involved in the establishment of plantations. Also, during the first years after the establishment of a plantation, reduced C sequestration takes place as a result of low C input (due to a small forest biomass and low litter fall rate) (Wilde, 1964) and a continued decomposition of the C present in the soil profile.

Comment with respect to Fe stabilization. In the discussion before the sep-up of the experimental work, we discussed as well the fact of incorporating Fe-oxides into this study. Finally, we decided not to add information with respect to Fe to this paper because of following reasons:

- We determined as well the pyrophosphate extractable Fe concentration for the different soils. However, we found that these values were on average four times smaller than the pyrophosphate extractable Al concentrations. In acidic soil pedogenesis, mineral weathering gives rise to aluminous ions prior to ferric ones. Thus, aluminous complexes predominate, and organic matter stabilization should be more to Al than to Fe.

- As this paper mainly emphasizes on aggregate formation and aggregate stability, we revised literature to reveal to importance of iron on this subject. We encountered contrasting information in literature with respect to this issue. Desphande et al. (1964) and (1968), Greenland et al. (1968), Borggaard (1983) found that soil aggregates were not stabilized by Fe. However, other studies (such as; Colombo and Torrent,

1991; Oades and Waters, 1991; Ferreira Fontes, 1992; Igwe et al., 1995, Duiker et al., 2003) did found an effect of Fe on aggregate stabilization.

However, many of these studies did not differentiate between Al and Fe oxides, only focused only on Fe, or deduced conclusions after applying treatments that removed both Al and Fe oxides (unspecific Fe removal) (e.g. Colombo and Torrent, 1991; Ferreira Fontes, 1992, Igwe et al., 1995, Oades and Waters, 1991). Looking at the extractable Al and Fe contents of these studies, we encountered that in some studies, the ratio of extractable Fe/Al was significantly higher compared to our values (e.g. Duiker et al., 2003, Colombo and Torrent, 1991). Studies who did compare the relative importance of both Al and Fe indicated that Al is more important for aggregate stabilization than Fe. Desphande et al. (1964) concluded that iron oxides are present in the soil as discrete crystals and do not cement the soil particles, while Al oxides would be responsible for the complexation of soil particles. Keeping in mind these considerations, we concluded that in this particular soil type, Al stabilization of the SOM was more important compared to Fe stabilization.

Comment on AEC and CEC: We agree, it will be changed in the revised version.

Comment referring to page 205, second paragraph: we will change it as well in the revised manuscript version

Information on sampling pits: Sampling pits were located on average 20 meters from each other within one land use treatments. However, this might be slightly different for the three land use treatments as the total area of the grassland was larger compared to the forests. Homogeneity and representativity of the sampling sites was ensured by previous analyses. The Nothofagus obliqua forest was considered to be representative for a "Chilean Central-South Nothofagus obliqua forest" according to our own characterization of the forest, including vegetation analysis, soil analysis and flora composition. Forest characteristics for this forest type are described by Donoso (1993). As other sites (GRASS and PINUS) were considered as homogeneous in vegetation, vegeta-

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tion representativity was not checked. Earlier, sampling was performed in the study areas to characterize the homogeneity of the sites. Different sampling pits of a 130 cm depth were made to perform a physico-chemical characterization of the soil profiles. Our sampling pits were located near three representative sampling pits and allowed us to consider our samples as representative for the area.

According to the theory described by Meijboom et al. (1995), macroaggregates would be destroyed by the wet sieving procedure. However, in our study, the macroaggregates appeared to be quite water-stable and were not entirely destroyed by the applied dispersive energy of the water. A water jet was the only attempt to destroy macroaggregates.

References with respect to the determination of bulk density and soil texture will be included in the revised manuscript version. Bulk density was determined by hammering steel cylinders with a known volume into the undisturbed soil (Klute, 1986). After transport to the laboratory, the cylinders were dried at 105°C during 24 hours, after which its weight was determined. Three replicates per land use treatment were performed. Texture was determined in the field by a method described by Milford (1997). It is a method based on the adhesive characteristics of the soil. The soil sample is manually processed and based on some prescribed properties, a manual determines the soil texture according to the USDA texture triangle. Known the texture, the contents of clay, silt and sand can be estimated within a certain range. Performing this procedure, it is thus not possible to determine the exact percentages of clay, silt and sand. For all soils, the texture was classified as sandy-loam by this procedure.

Comment to page 216-217. Interesting suggestion. This theory will surely have some influence on the aggregate distribution in the grassland. It will be referred in the revised manuscript as a possible mechanism influencing the aggregate distribution. Together with other mechanisms (see above), it might lead to a coarser aggregate distribution in the grassland compared to the other land use treatments.

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Technical corrections: These corrections will be implemented in the revised manuscript version. Thank you very much.

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