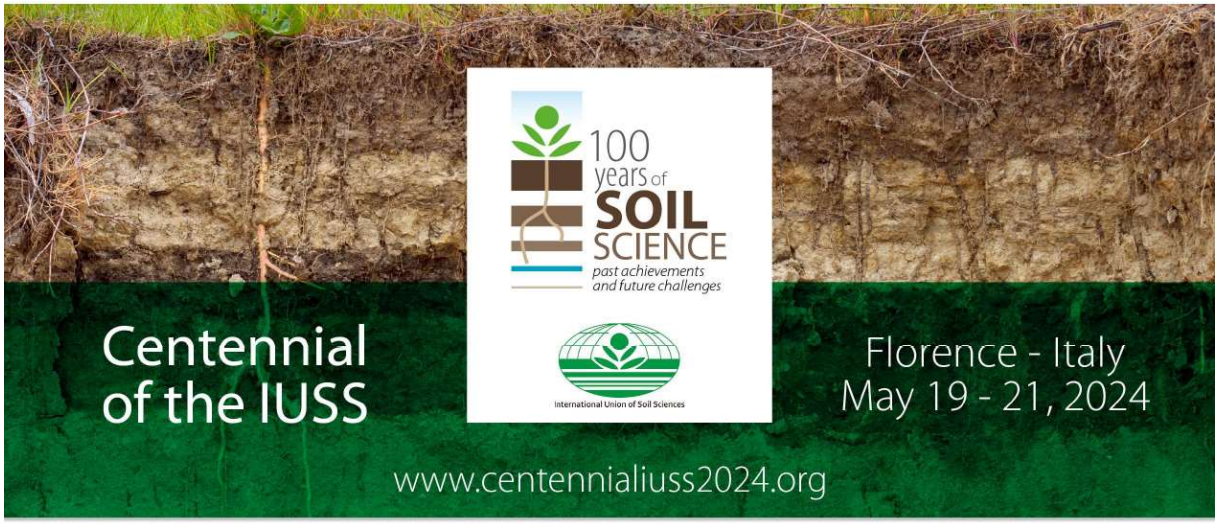

A global meta-analysis of soil organic carbon in the Anthropocene

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Abstract :

Anthropogenic activities profoundly impact soil organic carbon (SOC), affecting its contribution to ecosystem services such as climate regulation. Here, we conducted a thorough review of the impacts of land-use change, land management, and climate change on SOC. Using second-order meta-analysis, we synthesized findings from 230 first-order meta-analyses comprising over 25,000 primary studies.We show that (i) land conversion for crop production leads to high SOC loss, that can be partially restored through land management practices, particularly by introducing trees and incorporating exogenous carbon in the form of biochar or organic amendments, (ii) land management practices that are implemented in forests generally result in depletion of SOC, and (iii) indirect effects of climate change, such as through wildfires, have a greater impact on SOC than direct climate change effects (e.g., from rising temperatures). The findings of our study provide strong evidence to assist decision-makers in safeguarding SOC stocks and promoting landmanagement practices for SOC restoration. Furthermore, they serve as a crucial research roadmap, identifying areas that require attention to fill the knowledge gaps concerning the factors driving changes in SOC.

Full text :

Good morning, this is a pleasure to be with you today, even if it is remotely from France. I am Julien Demenois, from CIRAD, scientist on soil ecology and leader of the soil carbon thematic at CIRAD. Today, I will share with you, on behalf of all the colleagues mentioned on this slide, the key findings from a long term work which started before the pandemia and which were recently published in Nature Communications. The focus of my talk and of this work is to assess at the global level the impact of global changes, land use change and land management on soil carbon.

At the heart of this work there are these ideas that, political decisions should be more science-based and therefore, that, WE, as scientists, must contribute to the policy debate. This is particularly true for

soil carbon which is highly linked to the Sustainable Development Goals, especially Climate change, food security and biodiversity. However, giving straightforward key messages for policy makers is challenging when the amount of scientific papers published is increasing exponentionally each year, and soil carbon is not an exception. It is also more and more difficult for scientists to get the updated picture.

So what we did with our team is a global and comprehensive qualitiative and quantitative analysis of more than 13 000 scientific papers to date on soil carbon.

Before giving you more details on this work, what did we show :

- We showed that land management and land-use change have a much higher impact on soil C than climate change
- In particular, we showed that the conversion to cropland was detrimental for soil C
- Hopefully, we identified a large portfolio of management practices that can significantly increase soil C
- And finally, we showed that there are still efforts to study soil C in Africa and also in carbon rich areas

The method we developped is briefly summarized on this slide. We put the focus on published meta-analyses related to soil carbon, from 1900 to 2022, For that we used keywords and performed a string search in various databases : Web of Science, Ovid, Scopus, Google scholar and also retrieved some meta-analyses from other sources. We identified more than 1500 papers. Then we carried out a manual selection of the papers to avoid duplication, to check the accessibility of the papers, the scope of the papers and the fact that it was a meta-analysis. Finally, we kept 230 papers which were indeed meta-analyses related to Soil carbon.

What kind of data did we retrieve from these meta-analyses ? First, we retrieved qualitative data like the location of the studies, the type of driver of Soil carbon : global changes, land-use change, land-management practice, the type of practices…. Besides, we gathered quantitative data of the meta-analyses : the effect sizes of each meta-analysis. In this study, we performed a meta-analysis with the collected effect-sizes of the meta-analyses.

For more details on the method, I invite you to read our paper in Nature Communications which is available in Open Access.

Our results revealed that the overall effects of land-use change and land management on SOC were 7–10 times larger than the direct effects of climate change. Both negative and positive effects of land-use change and land management practices were found, thereby highlighting the opportunities of increasing SOC … but also the risks of its depletion.

Of the 60 types of land-use change analyzed, 25% presented a decrease in SOC that was greater than 24%. Among the 143 identified land management practices, 25% presented an increase that was higher than 23%. Thus, large but at the same time highly variable impacts can be expected, with some of the considered land-use changes or land management practices proving to be highly effective in increasing SOC, while others are not.

Across all studies, the conversion of forest lands, grasslands, and wetlands to croplands consistently resulted in large SOC loss, with a mean change of −25%, −16%, and −25% respectively.

The conversion of croplands to forests or grasslands resulted in significant SOC gains of +57% and +26%, respectively. This potential for SOC increase is particularly pronounced for degraded croplands (with low SOC levels), and generally in tropical regions.

The degree of SOC loss following land conversion to croplands varied depending on the type of cropping system established, with lower SOC losses observed after forest conversion to croplands cultivated under agroforestry practices or with perennial crops, compared to those cultivated with annual crops.

Similar results were found for the conversion of grasslands to croplands, where SOC losses were higher for croplands cultivated with only annual crops compared to agroforestry or the inclusion of perennial crops.

Finally, the conversion of forest lands to grasslands and the conversion of grasslands to forest lands did not lead to significant SOC changes, The effect of these two types of land-use change on SOC is indeed particularly determined by local soil and climate conditions.

In croplands, exogenous carbon inputs resulted in the largest increases in SOC. Biochar led to a mean SOC gain of +67%. Organic amendments applied in croplands resulted in a SOC gain of +29%.

However, if biochar application is regarded as having a high climate change mitigation potential, which is supported by our findings, we have also demonstrated a significant variability in the effect of biochar. This variability can likely be attributed to the diverse application rates and physicochemical properties of biochars.

Agroforestry significantly increased SOC in croplands by +20%, with mean values varying from 17 to 33 % depending of the agroforestry system.

Several other land management practices showed smaller but significant positive changes in SOC, including no-till farming, reduced tillage intensity, crop residue retention and perennial energy cropping.

For forestland, we showed that replacing a monospecific forest with a mixture of tree species resulted in a significant 9 % SOC increase. However, the number of meta-analyses investigating the effects of this management practice on SOC is still limited.

Similarly, mineral fertilization of forestland as a positive impact on SOC (~5%) but the GHG balance should be assessed.

In contrast, some other forest management practices negatively impacted SOC. For instance, converting secondary forest to plantation (−23%) or forest harvesting (−8.1%).

In grasslands, exogenous carbon inputs resulted in the largest increases in SOC. Application of organic amendments resulted in a SOC gain of +34 %, while biochar led to a mean SOC gain of +32%.

Growing trees in grasslands (i.e., silvopasture) also resulted in a significant SOC increase of +26%.

In contrast, some other land management practices had significant negative effects on SOC, such as increased intensity of grazing (−9.9%) and the presence of grazing compared to no grazing (−7.1%).

Now moving from the quantitative data to the qualitative data of this work, I would like to draw your attention on this map, showing the number of studies carried out related to SOC. We clearly see that the majority of these studies were, not surprinsingly, carried out in the USA and in China.

In contrast, a limited number of studies were carried out in Africa, with countries left blank on this map. For instance, the Congo Basin, one of the richest area in the world in terms of soil carbon has been poorly studied so far.

The stars on this map mark the soil C rich areas according to the Global Soil Partnership. We can clearly see that half of these areas where poorly studied.

Now let's make a zoom in Brazil. As I've mentioned before, Brazil is one of the most studied country in the world for SOC. However, at the states level, we showed a high variability, related in particular to the existence of long-term field trials. Thanks to this map, we can see for instance that the Caatinga biome, in the Nordeste, was less studied than the other biomes.

Before concluding my talk, I would like to highlight the fact that all these results are already displayed in an interactive website called Impact4Soil You can find maps, references and figures that can be customized.

So to conclude about the main results of this work, we can keep in mind :

- Land management and land-use change have a much higher impact on soil C than climate change
- Conversion to cropland leads to soil carbon loss
- Organic amendments and perennial plants are efficient options to increase soil carbon in cropland
- Still understudied practices: crop diversification, irrigation, perennial crops, deep-rooted annual crops
- A huge need to drive research studies in Africa and carbon rich areas

If you want to read more on this work, here are the different papers our team published. They are all freely accessible. On behalf of the team behind this work, thanks a lot for your attention!