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FELLOWSHIP FINAL REPORT

Use of soil carbon fractions for improving the diagnosis of soil C and N loss sensitivity to forest biomass harvesting in the Centre -Val de Loire region, France

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REPORT INFO

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ABSTRACT

The use of residual biomass from forest harvesting for energy production is viewed as a means to reduce fossil-fuel consumption. However, the impact of wood energy harvesting on soil and future site productivity remains a major concern. During this fellowship, we analysed why forest biomass harvesting of whole trees in Quebec reduced soil organic carbon (C) and total nitrogen (N) reserves in certain sites. We also estimated soil C and N labile and stable fractions in the Centre-Val de Loire region in France, and its relationship with current soil sensitivity indices to residual biomass harvesting. This research shed new insights on soil properties that could explain their sensitivity or resilience to forest biomass harvesting. We believe that this fellowship made a significant contribution to scientific knowledge and address pressing societal challenges.

1- Introduction

The use of forest biomass to produce energy is viewed increasingly as a means to reduce fossil fuel consumption and mitigate climate warming [1]. Still little is known on the impact of such practices on soil carbon (C) and nitrogen (N) reserves in different soils. The objective of the project was to find soil properties that can explain potential soil C and N losses at some sites subjected to whole-tree biomass harvesting compared to stem-only harvesting. The separation of soil organic matter in two fractions, a recalcitrant (e.g., mineral-associated organic matter) and a more labile one (e.g., particulate organic matter) [2] may explain the pattern of soil C and N losses by additional biomass harvesting [3-5].

To reach this objective, we, first, examined more in depth an experiment carried out in Quebec, Canada, where whole-tree biomass or stems only were harvested 30 years ago, in order to find soil or forest stand properties that could explain the C and N losses by whole-tree harvesting in the long term.

Second, we assessed the relationship between soil C fractions and their sensitivity to additional biomass harvesting for the forest region of the Centre-Val de Loire (CVL).

2- Experimental details

Using the dataset on whole-tree and stem-only harvesting from Quebec **[6]** we determined which soil properties could explain the observed lower soil C and N stocks in plots subjected to whole-tree harvesting.

We also built a database of forest soil properties for the CVL region in France using databases from RRP45 (DONESOL) [7] and (LUCAS) [8] associated with soil sensitivity index from [9] (INSENSE). This database contained data on forest stand type and soil properties. The database was cleaned and structured, currently counting 651 soil profiles (3 soil profiles were organic soils (Histosols) and were excluded from the study). We used these forest soil profiles to assess their C and N fractions in the 0-20 cm mineral soil depth using a model capable of estimating the organic C and N concentrations in mineral-associated soil organic matter (MAOM-C and MAOM-N) based on soil silt+clay content, pH, total soil organic C, total soil N, atmospheric N deposition, mean annual temperature, land cover, and extractable potassium [10]. The more labile organic C and N concentrations in particulate organic matter (POM-C and POM-N) were calculated by the difference between their total concentrations and respective MAOM concentrations. We then analysed the possible relationships between soil C fractions and sensitivity indices to whole-tree harvesting. In France, a diagnostic key at the national scale has been set up to predict soil sensitivity to nutrient fertility loss after tree biomass harvesting [11,12]. Following the regional DEFIFORBOIS project [13], criteria have been refined specifically for the CVL region. According to these keys, the majority of the CVL region is considered highly sensitive to forest biomass harvesting. We first compared these current sensitivity indices in France [11] to the calculated proportion of labile and recalcitrant soil C fractions in these soils to understand how well they fit. In addition, we determined the impact of soil type (5 broad Soil Groups, Table 1) and forest type (deciduous, coniferous, and mixed forest stands) on soil C fractions.

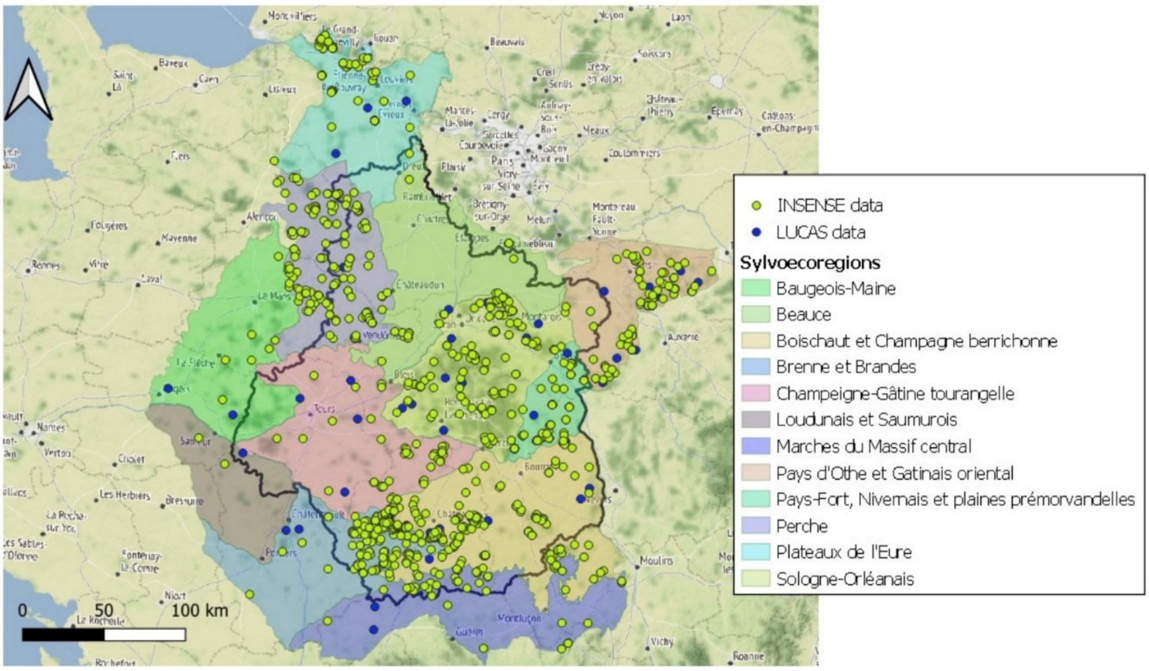

Figure 1. Location of the INSENSE and LUCAS forest soil profiles in the 12 sylvoecoregions [14] covering the Centre – Val de Loire region in France.

Table 1. Soil groups included in the CVL study.

Soil Group	World Reference Soil Group [15]	N
Podzols	Soils influenced strongly by Fe/Al chemistry: Podzols	80

Clay-enriched soils	Soils with clay-enriched subsoil: Retisols, Acrisols, Lixisols, Luvisols	104
Water-affected soils	Soils affected by a water table: Gleysols, Planosols, Stagnosols	91
Cambisols	Soils with little or no profile differentiation: Cambisols, Arenosols, Regosols	341
Shallow or gravelly soils	Soils with limitations to root growth: Leptosols	32
Total		648

3- Results and discussion

3.1- Quebec results

With the Quebec dataset, we found a good agreement between some soil characteristics and their C and N stock dynamics following whole-tree harvesting. Briefly, the relative soil C and N stocks still present after 30 years in whole-tree harvested plots down to 60 cm soil depth were related to the soil silt+clay content (Figure 2).

Boreal forest soils with silt+clay content ≥ 45% did not loose any C or N when subjected to whole-tree harvesting 30 years ago, while those with < 45 % silt+clay content were more prone to get reduced C and N stocks compared to stem-only harvesting. The detailed results can be found in the article published in 2023 [16].

These results corroborate the emerging theory regarding soil C and N stability in the presence of soil fine particles [17]. Thus, in our study, lower soil C and N stocks with whole-tree harvesting were not directly associated with corresponding initial stocks, but to the abundance of soil fine particles.

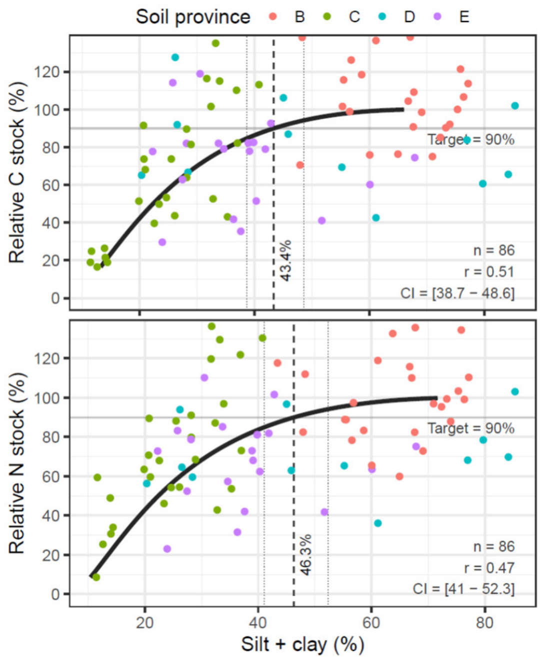

Figure 2. Relationship between the soil fine particle content (silt+clay) and the relative average soil C and N stocks (0-60 cm soil depth) after whole-tree harvesting (relative to stem-only harvesting) by soil province in Quebec. The dashed line represents the silt + clay content (and 95% confidence intervals (CI)) required to reach 90% of the soil C and N stocks after stem-only harvesting; r is the square root of the proportion of variation explained by the curve. Curves: relative soil C stocks = $100(\sin(-1.384 + 0.698 \ln(x))^2)$; relative soil N stocks = $100(\sin(-1.191 + 0.636 \ln(x))^2)$.

3.2- CVL results

In the CVL region, sensitivity of soil nutrient losses to forest residual biomass harvesting was correlated with the presence of conifers as forest cover (Figure 3). However, these sensitivity indices were negatively related to the concentrations of soil organic C and total N in the first 20 cm soil depth, except for soil C sensitivity index that was, as expected, strongly correlated to POM-C. Also, as expected, soil silt+clay content was negatively related to soil elemental sensitivity indices. But surprisingly, soil N sensitivity was negatively correlated to POM-N in these soils.

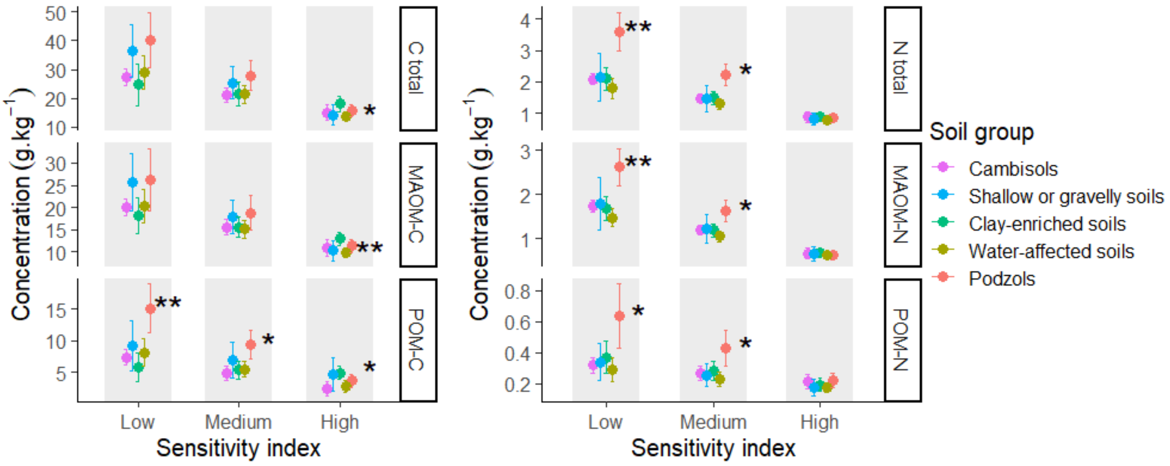

Figure 5. Concentration of organic C and total N fractions (total, MAOM, POM) in the first 20 cm soil depth according to current soil sensitivity classification (nutrients+C index) and Soil Group. At least one Soil Group differs from other Soils Groups at the probability level of * = 0.05; ** = 0.01.

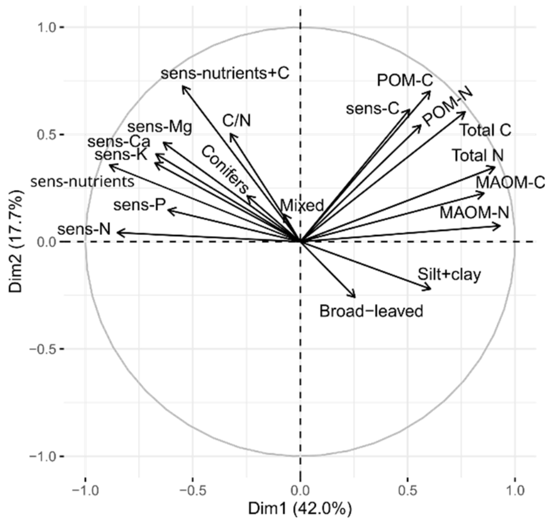

Figure 3. Principal component analysis of individual and combined soil elemental sensitivity indices ("sens-" prefix) to harvesting forest residues removal, soil C and N fractions in the first 20 cm soil depth, and forest cover. Data from the CVL forest soil profile dataset.

The soil type appears to be a major factor influencing its sensitivity to residual biomass harvesting in the CVL region (Figure 4).

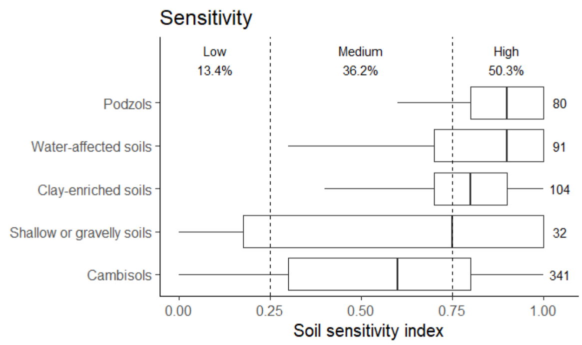

Figure 4. Distribution of the combined soil sensitivity index (nutrients+C index) according to Soil Groups in the CVL region. Numbers at the right are the number of soil profiles.

Only the majority of Cambisols in this region shows low to medium sensitivity to residual biomass harvesting. Podzols, water-affected soils, clay-enriched soils and shallow or gravelly soils were mostly in the high sensitivity range. It is somewhat surprising to find that clay-enriched soils are considered mostly sensitive. The clay enrichment must have appeared below 10 cm soil depth as the sensitivity indices are calculated based on data for this soil depth. Soil Groups differed in their total organic C and total N concentrations and fractions according to their sensitivity class (Figure 5). With respect to organic C fractions, their concentrations increased with the decrease of their classified sensitivity. This trend can be explained by the fact that soil organic matter contributes greatly to soil mineral fertility and buffering capacity which decreases soil sensitivity values. This figure indicates that Podzols have much higher POM-C than the other Soils Groups even at low and medium sensitivity. However, there were only a few observations for these low to medium sensitivity for Podzols, so the results must be interpreted with caution. Sensitivity indices based on threshold nutrient element concentration values may not be sufficient to assess soil sensitivity for loss of organic C, at least for Podzols in this region.

4- Conclusion

Soil C and N stocks are the largest in forest ecosystems. However, they can take several decades to recover following forest biomass harvesting. Therefore, it is crucial to identify soils that are sensitive to C and nutrient losses in order to prevent further unattended greenhouse gas emissions from soils subjected to residual biomass harvesting. Soil texture appears to be a major factor in the stabilization of organic C and N in boreal forest soils in Quebec. However, soil type also appears to play a major role in their sensitivity to residual biomass harvesting. Further work is needed to improve the classification methods used to determine soil sensitivity to different impacts of residual biomass harvesting (loss of nutrients affecting soil fertility and productivity and release of soil organic C accentuating greenhouse gas emissions.

5- Perspectives of future collaborations with the host laboratory

The prospect of future collaborations with the host laboratory in the field of forest soil C research is exciting and urgent in the current context of the fight against anthropogenic greenhouse gas emissions that exacerbate climate change. The laboratory's expertise in these areas provide a fertile ground for collaborative efforts that can push the boundaries of scientific knowledge and practical applications.

One potential collaboration could focus on the forest composition and soil C and N cycling. By combining our knowledge soil biogeochemistry and the laboratory's expertise in biogeochemical cycling, we can jointly explore the shorter- and longer-term effect of forest composition on soil reserves in C and N.

Furthermore, the host laboratory's strong network of industry connections presents an opportunity for impactful translational research. Through collaborative efforts, we can bridge the gap between academia and industry, ensuring that our discoveries and innovations find practical applications in forestry and ecology. This collaboration can involve joint projects, technology transfer initiatives, and the development of partnerships with the industry.

In addition to research-focused collaborations, the host laboratory can also provide valuable training and mentorship opportunities for young researchers. By fostering an environment that promotes interdisciplinary collaboration and skill development, we can jointly nurture the next generation of scientists and innovators.

Ultimately, through our future collaborations, we aim to make significant contributions to scientific knowledge, advance technological frontiers, and address pressing societal challenges. By combining our expertise, resources, and passion for scientific exploration, we can forge a partnership that not only benefits our respective institutions but also leaves a lasting impact on the scientific community and the wider world.

6- Article published in the framework of the fellowship

To this date, one article has been published in a pair-reviewed scientific journal:

Ouimet, R., N. Korboulewsky, and I. Bilger, 2023. Soil texture explains soil sensitivity to C and N losses from whole-tree harvesting in the boreal forest. Soil Systems 7(2): 39. https://doi.org/10.3390/soilsystems7020039.

A second paper on C and N fractions in forest soil of the CVL region is in preparation.

7- Acknowledgements

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