SUS-SOIL: Revitalizing Subsoil Health for Sustainable Agriculture and Ecosystem Resilience in the EU

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Abstract. About 60–70% of European Union soils are categorised as unhealthy mostly due to the erosion of the topsoil layer and subsurface depletion, meaning soil degradation being a significant danger to global sustainability. Even though it is acknowledged its ecological importance, subsoil is still understudied, which difficulties addressing its problematics. With a multidisciplinary approach, the SUS-SOIL aims at closing this gap by improving subsoil health, ecosystem services, and agroecological transitions across various land-use settings. A set of 15 Subsoil Living Labs (LLs) are being developed over eight European biogeographic areas in order to co-create and benchmark agroecological subsoil management practices (ASM). The LLs will be based in several stakeholders' categories using a participatory method to examine ASM effects on subsurface dynamics. Modern techniques include digital tools and sophisticated soil monitoring systems to support achieving project objectives. For promoting sustainable land management, key developments include interoperable soil databases, a Subsoil Decision Support Tool (S-DST), and region-specific ASM farm idiotype based on key developments.
SUS-SOIL seeks to raise awareness among stakeholders of subsoil issues, assist in policy creation for ASM techniques, and offer practical advice to improve water security and minimise climate effects. These results will improve soil management, therefore benefiting urban and rural ecosystems.
Keywords: Subsoil, agroecology, LUCAS, Sustainability, ecosystem services.

1. Introduction

EU soils face serious threats to sustainability and productivity, with 60–70% classified as unhealthy due to physical, biological, and chemical degradation, worsened by climate change (European Union, 2021). This situation jeopardizes soil productivity and the EU economy. In response, the EU has set ambitious targets for 2030: achieving land degradation neutrality, restoring degraded ecosystems, ensuring net greenhouse gas removal from the LULUCF sector, and improving water quality by 2027. Subsoils, often overlooked, play a critical role in ecosystem functioning by supplying plants with nutrients and water, storing over half of total soil carbon, and detoxifying pollutants such as heavy metals and pesticides. Subsoil health is thus vital for sustaining agronomic, forestry, and urban ecosystems. However, the intensive use of fertilizers, herbicides, and energy inputs by farmers continues to drive soil degradation. Agroecological subsoil management (ASM), promoted under EU strategies like the Green Deal and Farm to Fork, aims to reduce greenhouse gas emissions, minimize chemical inputs, and expand organic farming. The EU-funded SUS-SOIL project supports these goals by establishing 15 Living Labs across Europe. These labs will analyze different land uses under ASM practices, providing data to guide land managers and policymakers toward enhancing ecosystem services, water security, and climate resilience

2. .Materials and methods

SUS-SOIL's approach to improving subsoil health and ecosystem service provision is based on four main actions: (i) establishing a Subsoil Agroecological Management Network (ASMN) with partners from both the EU and neighboring countries (Tunisia, Egypt, and Turkey); (ii) creating a subsoil monitoring strategy to assess ecosystem functions and services across agricultural, forest, and urban land uses; (iii) developing models and tools to support farmers in adopting ASM practices, addressing sustainability and identifying barriers at multiple scales; and (iv) promoting EU-wide adoption of sustainable subsoil management through targeted tools. The monitoring methodology builds on the LUCAS soil database, with new soil samples collected down to one meter and differentiated by land use. A dedicated online application was developed to consult samples from areas with stable land use, with a special focus on forests.

3. Results and discussion

LUCAS soil sampling points are distributed across SUS-SOIL partner regions, focusing on areas with consistent land use over the past decade. Table 1 highlights the variability in soil sample coverage across regions, showing that the number of analyzed points does not correlate with region size. For example, only 12% of monitored soils were analyzed in the Netherlands compared to 50% in Germany. Broadleaved forests had the highest sample coverage (up to 74% in Galicia), whereas shrubland areas were significantly underrepresented, particularly in the Netherlands, Finland, and Brandenburg (0%). Overall, 26% of soils were sampled, with coverage rates of 29% for broadleaves, 41% for conifers, and only 9% for shrubs.

Multivariate analysis of LUCAS soil samples in Galicia (Figure 1a) revealed three principal components explaining 69.14% of the variance. The first component related to pH, the second to organic matter and nitrogen, and the third to cation exchange capacity, phosphorus, and potassium. A negative correlation was found between organic carbon, nitrogen, and pH, reflecting typical dynamics in Galicia's acidic soils, where lower pH levels promote organic matter accumulation by inhibiting microbial activity. Variance analysis (Figure 1b) showed that shrublands maintain higher organic carbon and nitrogen levels compared to permanent pastures. In contrast, pastures exhibited higher phosphorus content and water pH, likely due to common management practices such as phosphorus fertilization and liming, which are less typical in forested areas. Liming raises soil pH but also accelerates organic matter mineralization, explaining the observed patterns.

Although the LUCAS database effectively captures land use impacts on soil properties, sample size limitations remain a challenge. Nevertheless, the findings emphasize how different land uses significantly shape soil health indicators, providing valuable insights for promoting agroecological subsoil management.

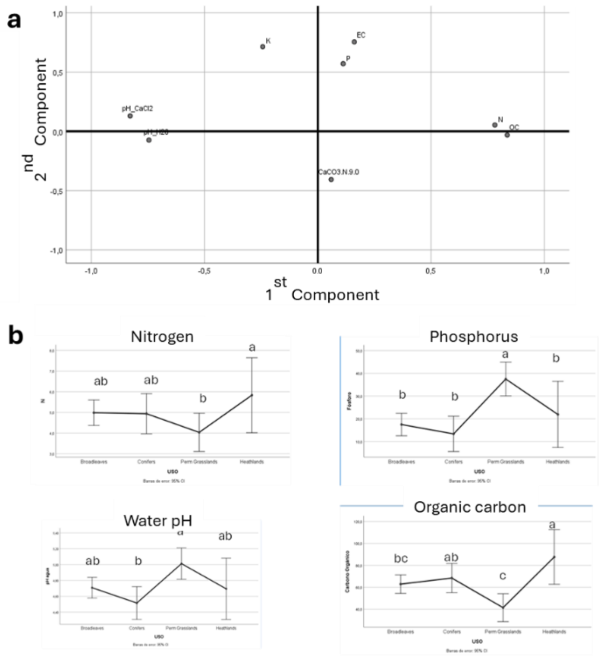

Figure 1. Component plot in rotated space of LUCAS points (a) and samples in Galicia (b).

4. Conclusion

The LUCAS database enables long-term assessment of land use impacts on soil chemical variables. In Galicia, efforts to enhance soil fertility by supplying nutrients and amendments result in decreased organic matter and nitrogen due to rising soil pH compared to forested zones.

5. Acknowledgements

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Table 1. Total number of samples.

LL		T	TopSoil	%	BroadLeaves			Conifers			Shrubs			Forestry		
					T	S	%	T	S	%	T	S	%	T	S	%
Portugal	PT16	156	71	46%	44	31	70%	24	13	54%	13	2	15%	81	46	56,79
Galicia	ES11	337	113	34%	70	52	74%	25	21	84%	56	6	11%	151	79	52,32
Madrid	ES30	114	21	18%	28	3	11%	9	5	56%	25	3	12%	62	11	17,74
Normandie	FRD	249	92	37%	40	13	33%	1	0	0%	2	1	50%	43	14	32,56
Netherlands	NL	490	57	12%	46	4	9%	16	1	6%	24	0	0%	86	5	5,81
Finland	FI	158	62	39%	11	7	64%	55	38	69%	4	0	0%	70	45	64,29
Branderbourg	DE40	126	63	50%	18	11	61%	32	27	84%	3	0	0%	53	38	71,70
Slovakia	SK	227	100	44%	66	33	50%	9	8	89%	17	1	6%	92	42	45,65
Greece	EL	1624	331	20%	355	66	19%	220	50	23%	359	31	9%	934	147	15,74
Firenze	ITI1	244	51	21%	142	16	11%	6	0	0%	10	1	10%	158	17	10,76
		3725	961	26%	820	236	29%	397	163	41%	513	45	9%	1730	444	26

References

LUCAS, European Union database

European Union, 2021. EU Soil Strategy for 2030.

https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0699

Main strategic objectives of the new CAP (Common Agricultural Policy). https://agriculture.ec.europa.eu/common-agricultural-policy/cap-overview/cap-2023-27/key-policy-objectives-cap-2023-27_en

European Union, 2020. Pact for Skills. https://pact-for-skills.ec.europa.eu/index_en?etransnolive=1