**Introduction**

More than 70% of the Earth's land, originally covered by forests and natural ecosystems, has been converted for human use, with agriculture alone accounting for approximately 40% of the global land area. 1. However, food production results in a huge environmental footprint with one-third of soils in the world being degraded and fertile soil being lost at the rate of 24 billion tons of topsoil every year2, along with about 34% of global greenhouse gas emissions3. Meanwhile, it is projected that food production would have to increase in the future to satisfy both the need of the global growing population and the increase in per capita demand4. In this context, sustainable pathways that would contribute to land restoration, biodiversity protection and GHG mitigation are more and more emphasized.

Regenerative agriculture has emerged as an alternative farming strategy seeking to achieve global food security by reducing the use of external inputs, improving soil health and minimize environmental damage5-7. Although there is no clear consensus about a common definition for regenerative agriculture, soil conservation is considered to be the bottom-line for improving agricultural sustainability8. In this context, regenerative agriculture involves different soil conservation practices (SCPs) such as reduced or not tillage (NT), cover crop (CC), perennials and agroforestry (AF), organic farming (OF) 6,9. Existing studies report potential beneﬁts of different SCPs for increasing soil organic carbon (SOC) and soil water uptake as well as GHG mitigation climate mitigation 6,9,10. Thus, although environmental benefits seem to be considerable, yield outcomes through the implementation of different SCPs are subject to many controverses.

Some existing studies have shown that implementation of SCPs could potentially result in increasing yields11,12 while others reported a neutral or declining trends13,14. While evaluating the outcome of different crops and environmental variables on NT, as compared to conventional tillage (CT) yields, Pittelkow, et al. 15 show that NT impact on yield is dependent upon the region with increasing trend in moisture-limited arid regions while declining patterns are observed in tropical regions with maize-based systems. A global meta-analysis based on 740 paired measurements from 90 peer-reviewed articles show that NT increased barley yield by 49% especially in dry climate16. In a drought period, about 60% higher maize yields were observed under NT management compared to CT17. However, contrary trends are also reported with the application of crop rotation, residue management, and no-tillage having no effect on yield stability relative to CT18. The same study showed that OF had 15% lower yield compared to CT.

Under AF management, findings show that crop yields either increased by 7 – 16%, especially in subtropical and tropical zones19, or reduced by 2.6% in European areas depending on the density and age of the trees20. While about 14% yield increase is reported under CC especially in coarse soil texture and dryland areas along with the use of leguminous cover crops21, about 3% yield reductions were observed especially for cash crops in temperate soils22,23. About 10% decrease in wheat yields were observed following cover cropping24. In context whereby there is no significant increase or decrease, some studies reported that yields could be sustained for longtime under SCPs especially for degraded soils25. The discrepancy of yield outcomes under different SCPs have thus shown that various factors interplay to determine the magnitude and direction of crop yields for farmers.

Crop yields are influenced by a combination of soil, climate, topography and management practices. For examples, soil properties—including pH, organic carbon, nutrients, texture, and compaction—directly affect water retention, root development, and nutrient availability26. Climate variables, especially temperature and precipitation, significantly affect crop performance, with rising temperatures and droughts reducing yields in many regions27,28. Topographic factors like elevation and slope influence erosion, drainage, and microclimate conditions29. Integrating these environmental factors is crucial for developing tailored, sustainable agricultural systems that optimize crop productivity and environmental benefits. However, existing studies on soil SCPs often lack comprehensive data on key soil variables—such as bulk density, soil organic carbon, phosphorus, pH, texture, and cation exchange capacity—as well as important topographic (elevation, slope) and climatic variables (temperature, precipitation, growing degree days). Furthermore, although previous meta-analyses have examined productivity variation across management practices, they primarily focus on individual SCPs a single type12,30-32 without assessing their comparative effectiveness across diverse environmental conditions and crop types at a global scale. There remains therefore a clear need for a broader understanding of how environmental factors influence crop yield responses under different SCPs.

Although soil, climate, topography, biological activity, and management are all important drivers of crop yield, many critical variables are often missing from publicly available datasets, which limits comprehensive analyses. However, advances in remote sensing technology and digital soil mapping in recent decades have resulted in the existence of global earth data which provide valuable information on environmental conditions and variables related to soil properties (e.g. soilGrids), climate, topography etc. which in turn are potential factors affecting crop yields33-35. Leveraging these global earth data can help fill these gaps and enable more accurate, large-scale assessments of factors influencing crop production.

Our study is unique in examining multiple SCPs and their effects on relative crop yields across a range of climatic, topographic, and detailed soil variables. By leveraging both global earth observation data and field experiment results, we aim to assess how SCP-related yield responses vary under diverse environmental conditions in a wider context. However, the applicability of these global datasets hinges on their spatial resolution, accuracy, and demonstrated correlations with actual crop performance. For example, SoilGrids’ estimates of soil organic carbon and texture have been validated against in-situ measurements across multiple continents, showing root-mean-square errors of less than 10 % for SOC and strong concordance (R² > 0.7) for soil clay content in maize- and wheat-dominated regions [see Hengl et al., 2017; Tóth et al., 2018]. Similarly, remotely sensed precipitation products (e.g., CHIRPS) and temperature reanalyses (e.g., ERA5-Land) exhibit high temporal fidelity, with bias errors under 0.5 mm day⁻¹ and 1 °C, respectively, when compared to ground stations in agricultural zones [Funk et al., 2015; Muñoz-Sabater et al., 2021]. Digital elevation models (e.g., SRTM at 30 m resolution) reliably capture microtopographic gradients that drive soil moisture variability and erosion risk, factors shown to explain up to 20 % of yield variance in slope-sensitive crops such as rice and coffee [Zhang et al., 2019]. These peer-reviewed validations confirm that global earth data can meaningfully augment field-level studies, allowing us to interpolate between discrete trials and identify large-scale patterns of SCP effectiveness. By extracting global data at the precise locations of our experimental plots and then discussing the resulting trends in environmental variables and relative yields in relation to the existing literature, we situate our spatially explicit findings within the broader empirical evidence base on regenerative agriculture.