A paper from the Proceedings of the
17th International Conference on Precision Agriculture and 11th Brazilian Congress on Precision and Digital Agriculture
13-15 July 2026
Porto Alegre, Brazil

3D Spatial Resolution of Nutrient and Isotopic Soil Mapping: A Baseline for Precision Soil Management

Gabriel Y. Sanchez-Vazquez[1]* and Darren R. Gröcke[1]

[1] Stable Isotope Biogeochemistry Lab, Earth Sciences, Durham University, United Kingdom

Abstract.

While there is a need to increase agricultural productivity, this process must be achieved without compromising soil health, surrounding ecosystems, or biodiversity. In Westmorland and Furness, a feasibility study is being conducted to implement a scientific, collaborative, and interdisciplinary strategy involving farmers, scientists, and environmental authorities. The aim is to optimise nutrient management and promote climate-smart agriculture through evidence-based cooperation between the agricultural sector and the scientific community.

As part of this study, high-resolution geospatial maps of nutrient distributions across a dairy farm landscape were generated, referred to as nutrient landscapes or nutriscapes. These maps characterise the spatial distribution of macro- and micronutrients, particularly nitrogen, phosphorus, and potassium, within agricultural soils. To date, 749 soil cores have been collected across the farm, with an average sampling depth of 40 cm. Isotopic ratios of $^{13}C/^{12}C$ ($\delta^{13}C$) and $^{15}N/^{14}N$ ($\delta^{15}N$), together with the weight percentages of C, N, P, and K and soil pH, were determined at depths of 2, 5, 15, 20, 30, and 40 cm. This dataset enables a detailed vertical and spatial characterisation of nutrient profiles throughout the farm.

A geospatial nutrient map of a dairy farm in Cumbria is presented as a tool to support and strengthen precision agriculture practices related to nutrient management. Although the process entails considerable labour and analytical costs, the resulting information can help reduce soil management costs, minimise nutrient runoff and leaching, improve input-use efficiency, and enhance long-term soil health. The integration of isotopic data with nutrient landscapes facilitates the identification of carbon and nitrogen pathways, as well as nutrient-use efficiency, providing a critical baseline for assessing future regenerative soil management practices.

Keywords.
Precision agriculture; soil nutrients; stable isotopes; geospatial analysis; soil carbon; soil nitrogen

The authors are solely responsible for the content of this paper, which is not a refereed publication. Citation of this work should state that it is from the Proceedings of the 17th International Conference on Precision Agriculture and 11th Brazilian Congress on Precision and Digital Agriculture. EXAMPLE: Last Name, A. B. & Coauthor, C. D. (2026). Title of paper. In Proceedings of the 17th International Conference on Precision Agriculture and 11th Brazilian Congress on Precision and Digital Agriculture (unpaginated, online). Monticello, IL: International Society of Precision Agriculture and Brazilian Congress on Precision and Digital Agriculture.

Introduction

The global demand for food is increasing forcing pressure on agricultural productivity but this should be achieved without the dentrimental decline in soil health and/or biodiversity (Da Silva et al. 2022). Climate-smart agriculture relies on strong scientific evidence to understand nutrient distribution in the soil so that more accurate management practices can be developed and applied (Sori et al. 2021). Stable isotope ratios of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) can trace nutrient cycling and processes that conventional soil analyses do not consider (Lorenz et al. 2020; Liu et al. 2023). In this study we present a 3D geospatial soil CN and isotopic assessment of a dairy farm in Grange-over-Sands, Cumbria, England.

Methodology

A total of 115 cores were sampled on a 60 m grid system to geospatially cover the entire dairy farm. Cores were taken to a depth of 40cm, described, subsampled @ 2, 5, 10, 15, 20, 30, and 40cm, dried and ground for pH and stable isotope analysis (SIA). SIA was conducted on a Thermo Scientific IsoLink Flash elemental analyser connected to a Thermo Scientific Delta V isotope ratio mass spectrometer. Measurements produced total nitrogen and carbon (wt%), $\delta^{13}C$ and $\delta^{15}N$. These data are plotted versus depth (Fig. 2-3) and using ArcGIS to generate a highresolution geospatial 3D map of nutrients and nutrient cycling on the dairy farm (Fig. 1).

Discussion and Results

pH

Soil pH is moderately acidic at the surface (5.3–6.7) to more alkaline (6.5–8.5) values towards 40cm. More acidic conditions reflect active organic matter mineralization and organic acid production. Alkaline conditions at depth reflect neutralization from the interaction of organic acidic acids with carbonate rich estuarine sands.

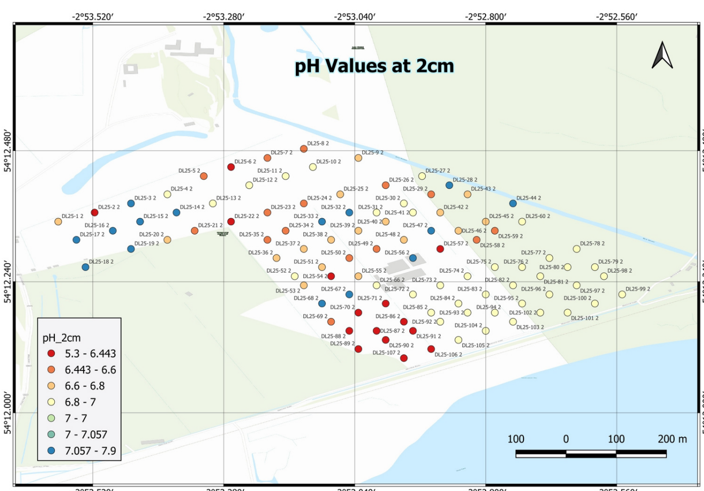

Fig 1. Spatial distribution of soil pH at 2 cm depth across the study area. Sampling points are symbolized according to their pH values, grouped into seven classes ranging from 5.3 to 7.9. Warmer colors indicate more acidic conditions, whereas green and blue tones represent neutral to slightly alkaline values.

Total Carbon (TC wt%)

Highest at the surface and decreases with depth. Indicates accumulation of fresh organic matter and humification in deeper layers.

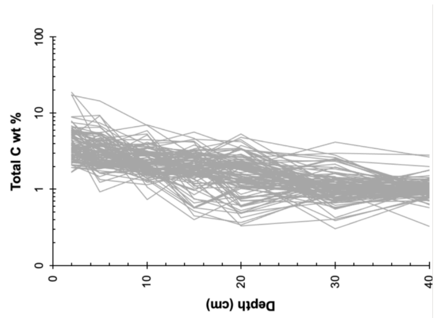

Fig 2. Profiles along the soil vertical gradient (0–40 cm). Each gray line represents an independent replicate, illustrating intra-site variability. The relatively narrow spread of the profiles indicates a consistent pattern of gradually decreasing C with depth.

Total Nitrogen (TN wt%)

Pattern parallels that of carbon. Higher concentration at the surface; reflects C–N coupling and nitrogen availability associated with organic matter.

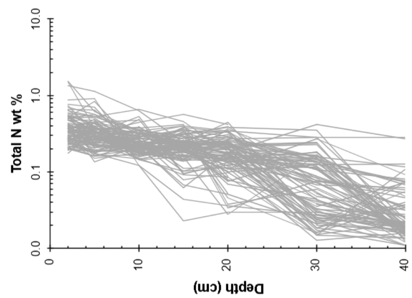

Fig 3. Profiles along the soil vertical gradient (0–40 cm). Each line represents an individual profile measured at different sampling locations. A general decrease in N with depth and greater variability in the upper 20 cm are observed, reflecting differences in organic matter accumulation and surface biogeochemical processes.

Conclusion or Summary

The analyzed soils exhibit high chemical heterogeneity, with pH ranging from moderately acidic to slightly alkaline (5.3–8.5), reflecting differences in soil composition and internal processes. Profiles with higher pH correspond to lower C/N ratios, indicating greater organic matter mineralization and potential nutrient availability, while more acidic profiles show higher C/N ratios, associated with les decomposed organic matter. Overall, these results highlight variability in organic matter quality and nutrient availability, which could influence soil fertility and biochemical dynamics.

References

Da Silva Carneiro, J. S., da Costa Leite, R., Ferreira Junior, J. M., Gomes de Faria, Á. J., Godinho Silva, S. H., Clementino dos Santos, A., & Ribeiro da Silva, R. (2022). Diagnosis of the spatial variability of soil nutrients and economics of precision management in degraded pastures grasses, 1(1), 30–43. https://doi.org/10.3390/grasses1010003.

Sori, G., Iticha, B., & Takele, C. (2021). Spatial prediction of soil acidity and nutrients for site-specific soil management in Bedele district, Southwestern Ethiopia. Agriculture & Food Security, 10, 59. https://doi.org/10.1186/s40066-021-00334-5.

Lorenz, M., Derrien, D., Zeller, B., Udelhoven, T., Werner, W., & Thiele-Bruhn, S. (2020). The linkage of ^{13}C and ^{15}N soil depth gradients with C:N and O:C stoichiometry reveals tree species effects on organic matter turnover in soil. Biogeochemistry, 151(2), 203–220. https://doi.org/10.1007/s10533-020-00721-3.

Liu, M., Zhang, X., Chen, Y., Li, H., & Wang, J. (2023). Alterations of ecosystem nitrogen status following agricultural management practices. Ecology and Evolution, 13, e9885863.