ABSTRACT

Soil sensing and mapping have the potential to provide quick and affordable options for soil testing. This research utilized 1,778 surface soil samples collected from four agro-climatic regions of the Indo-Gangetic Plain in India to create digital soil maps for available Zn, Cu, Fe, and Mn. Initially, 52 environmental covariates were considered, and the top 20 were selected using the Boruta feature ranking and selection algorithm. These covariates, originally extracted at a 30 m spatial resolution, were rescaled and resampled to 150 m × 150 m using bilinear interpolation. The selected covariates were then used in a comprehensive comparison of 14 machine learning (ML) models, including ensemble models, to predict spatial variability. The best-fitting model, an ensemble model, was ultimately chosen for the final mapping process. The study also explored the interrelationship between soil and rice grain micronutrient concentrations to assess the biofortification potential of Zn and Fe. Linear regression models indicated moderate agreement, with R^2 values ranging from 0.52 to 0.63, highlighting the potential to use soil data to predict and enhance grain micronutrient content in specific agricultural pockets. Additionally, Portable X-ray fluorescence (PXRF) spectrometry was applied alongside various auxiliary properties, such as physiographic and agro-climatic data, to predict available K, Ca, Mg, and B through four ML algorithms by using representative soil samples from diverse soil types. The integration of auxiliary soil parameters with PXRF data generally improved prediction accuracy compared to using PXRF alone and presented a cost-effective and accessible nutrient management strategy for resource-poor settings. The study also examined the combined use of PXRF spectrometry and soil image features to assess soil fertility quickly. By analyzing 1,133 soil samples from various zones and integrating color and texture features from microscopic soil images with PXRF data, the research demonstrated significant enhancements in prediction accuracies for critical parameters like available B (R^2 = 0.80) and organic carbon (R^2 = 0.88). This data fusion approach also improved predictions for available Mn and the sulfur availability index (SAI), with R^2 values of 0.72 and 0.70, respectively. The integration of these technologies offers a fast and affordable method for soil testing, which could be expanded upon with the application of deep learning models to a broader dataset of soil images in diverse agro-climatic conditions.

Keywords: DSM; PXRF; soil image; machine learning; biofortification; soil fertility