Opinion

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Precision agriculture should monitor alkaline soils as closely as medicine monitors patients

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Global population growth, climate change and environmental degradation are accelerating the expansion of alkaline and saline soils worldwide, jeopardizing global productivity and food security. According to the FAO,[1] more than 1,381 million hectares (10.7% of the Earth's land area) are already affected by salts, while an additional 1,000 million hectares are at risk of salinization.

Among the most promising strategies is phytoremediation, a nature-based solution that enables agricultural production while restoring degraded soils. Through the establishment of plant species capable of extracting, stabilizing, metabolizing and degrading contaminants, phytoremediation improves both the physicochemical properties of soils and their biological functioning. Equally important, plants stimulate nutrient cycling and rebuild soil microbial communities, gradually converting degraded soils into productive ecosystems with improved pH balance and nutrient availability.[2]

Soil alkalinization is one of the most severe forms of land degradation because it is closely linked to erosion, desertification and declining agricultural productivity. Approximately half of the world's agricultural land is affected to some degree by salinity or alkalinity, with substantial reductions in crop yields. Wheat grown under alkaline conditions may lose nearly 30% of its productivity, whereas maize and cotton can experience yield reductions of 55% and 15%, respectively.[3,4] Although saline and alkaline soils are frequently considered together because they impose osmotic stress on plants, alkaline soils generate an additional and often more damaging chemical stress. High pH conditions impair nutrient availability, disrupt cellular metabolism and may compromise DNA integrity, making alkalinity particularly detrimental to plant development and soil ecosystem functioning.[5,6]

Precision agriculture has emerged as a powerful framework for addressing this challenge. Its central principle is straightforward: no two soils should be managed identically. Instead, agronomic decisions should be guided by site-specific assessments integrating the physical, chemical and biological characteristics of each field. Yet the implementation of precision agriculture remains uneven. While technologically advanced agricultural systems, including those in the United States and parts of China,[7] increasingly rely on sophisticated analytical platforms to optimize crop performance under adverse soil conditions, many regions continue to respond to alkaline soils with a single, conventional solution—increasing chemical fertilizer inputs. Such an approach rarely addresses the underlying causes of soil degradation.

Recent advances suggest a more comprehensive path forward. Monitoring soil microbiota has become one of the most informative components of precision agriculture.[8] High-throughput omics technologies now provide unprecedented insights into plant–soil–microbe interactions, revealing microbial functions that enhance crop resilience under alkaline conditions. Likewise, degraded and contaminated soils consistently exhibit simplified microbial communities dominated by relatively few taxa, including members of the *phylum Proteobacteria*, reflecting profound losses of ecological complexity.[9]

The next generation of precision agriculture should integrate satellite remote sensing with molecular and microbiological diagnostics to generate dynamic, high-resolution assessments of soil health.[10] However, technology alone is not sufficient. Agricultural soils should be monitored following a paradigm long adopted in medicine: every soil deserves its own longitudinal record. Just as physicians monitor patients throughout their lives, soils should be continuously evaluated to document their responses to climatic variability and management practices, while tracking changes in physical properties such as texture and water-holding capacity, chemical parameters including pH and salinity, and biological indicators such as microbial diversity and functional activity.

Viewing soils as living systems rather than static substrates fundamentally changes how they should be managed. Precision agriculture therefore represents more than a technological innovation; it offers a conceptual framework for preventive soil stewardship. As medicine has demonstrated that continuous monitoring improves patient outcomes, agriculture must recognize that long-term monitoring of soil health is essential for sustaining productivity, restoring degraded ecosystems and safeguarding global food security. Ultimately, healthy soils are inseparable from healthy crops, healthy ecosystems and healthy societies.

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Conflicts of interest

All authors declare that there is no conflicts of interest.

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