Soil Fertility, Plant Nutrition and Soil Health
How producers will make decisions in the future and what we can learn from other countries.

by Victor Monseff de Almeida Campos (NuffieldBR Scholar, July 2023).

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About the Author

Victor Monseff de Almeida Campos is a Brazilian agronomic engineer, coffee and cattle producer, and CEO of 3R Ribersolo, a leading agricultural diagnostics company formed from the merger of Ribersolo and 3RLab. He has built his career at the intersection of farm production, soil analysis, and agribusiness consulting, with a focus on sustainable practices and high-precision diagnostics. Academically, he holds degrees in agronomy (UNESP), an MBA in Agribusiness (USP), a specialization in Soil Management (ESALQ/USP), and a master's in Coffee Economics and Science (University of Trieste, Italy). As a 2018 Nuffield Scholar, he researched global innovations in soil fertility, plant nutrition, and soil health to inform Brazilian agriculture.

Executive Summary

CONTEXT

This report, produced under the Nuffield International Farming Scholarships program by Victor Monseff de Almeida Campos (2023), investigates how farmers in different countries will make decisions about soil fertility, plant nutrition, and soil health in the future. The study explores the state of emerging soil sensor technologies, compares international approaches to soil analysis and management, and assesses how these tools might influence practical farm decision-making. The research was based on study travel across multiple countries and engagement with laboratories, researchers, farmers, and agribusiness professionals.

KEY FINDINGS / CONCLUSIONS

1. **Growing availability of soil data, but limited usability for farmers**
   Technologies (especially sensors) and approaches (soil health metrics, remote/proximal sensing) are expanding rapidly around the world. However, there is a lag in converting sensor data into information that is simple, accurate and actionable for farmers.

2. **High interest but insufficient maturity of sensor applications**
   Agricultural labs and consultancies globally are keen to adopt sensor-based methods for soil fertility analysis. Nonetheless, sensor applications are not yet mature enough for consensus on best practices—some companies aggressively market before the technologies are fully validated.

3. **Diversity of promising sensors with specific strengths and limitations**

   - Vis-NIR/MIR diffuse reflectance sensors show promise for predicting soil texture, organic matter, and some chemical properties, though extraction of nutrients with biological relevance remains challenging.

- Techniques like XRF and LIBS (laser-based, optical) offer potential especially for total element content, but issues such as sample preparation (e.g. pelletizing) or transferring models across different soil types remain barriers.

- Sensors measuring electrical/electromagnetic properties (e.g. apparent electrical conductivity, resistivity) can be useful for physical soil attributes (texture, moisture etc.), though chemical/ nutrient estimation via these is less reliable.

- Ion-selective electrochemical sensors have had mixed results; good for pH (and some ions) under controlled conditions, poorer consistency in field or more variable soil types.

4. **Local calibration, quality of reference (lab) data, and contextual factors are critical**
Successful sensor-based predictions tend to use locally calibrated models and high quality, standardized laboratory reference data. When these are lacking, sensor results are inconsistent.
Temporal stability (across cropping seasons, fertilization regimes, management styles) is also less understood.

5. **Soil health concept, and soil fertility decisions, vary by region**
Soil health and fertility challenges differ: in temperate, intensive systems (e.g. Europe) the issues include nutrient excess, regulation and environmental protection; in tropical systems like Brazil, the concerns are often low natural fertility, organic matter depletion, and access to accurate diagnostics. This affects what sensor systems and priorities make sense in each context.

RECOMMENDATIONS

Based on the findings, the report offers the following recommendations aimed at laboratories, consultancies, the public sector, and the broader agricultural community:

1. **Increase cooperation among labs and research institutions in Brazil**
Brazilian agricultural analysis labs should collaborate to share knowledge, coordinate reference data quality, and jointly develop spectral libraries for soils. This would reduce duplication, improve calibration robustness, and facilitate adoption of sensor-based methods.

2. **Develop spectral libraries / databases of sensor data tied to high-quality lab reference data**
Establishing well-curated, local spectral libraries (for vis-NIR, MIR, XRF, LIBS, etc.) is crucial. These enable better model calibration, transferability, and more accurate predictions suited to local soil types, climate, and management.

3. **Pursue hybrid laboratory models**
Adopt “hybrid labs” where some samples are analyzed by traditional wet chemistry to serve as ground truth, and many others are analyzed by sensor methods calibrated against that ground truth. This mix can reduce costs, environmental impact (less use of reagents), and time, while maintaining accuracy.

4. **Field experimentation (on-farm trials) linked with precision agriculture tools**
Increase on-farm trials where sensors are used under real farm conditions, integrated with other data sources (yield maps, remote sensing, management history), to test stability, practicality, and economic benefits.

5. **Ensure quality control in reference laboratory analyses**
Laboratories must maintain rigorous standards in sampling, sample preparation, analysis, and reporting. Errors or variability in reference data undermine the value of sensor calibration.

6. **Prioritize sensor technologies according to local needs and soil constraints**
   Choose sensor types that align with the key limiting factors for fertility in the region (e.g. organic matter content, pH, nutrient deficiencies) rather than a "one size fits all" approach. For tropical soils, sensors helping improve organic matter and nutrient availability might give higher returns.

7. **Promote public and private investment in sensor R&D and dissemination**
   Support from government, agricultural agencies, and private firms is needed to fund research, development of user-friendly devices, and infrastructure (e.g., data platforms). This includes policy support, grants, and possibly regulation to ensure accuracy and reliability.

8. **Improve communication and education with producers**
   Simplify the science into digestible information; train producers (farmers) in interpreting sensor outputs; develop tools/interfaces that allow ease of use; and ensure that decision support based on sensor data is reliable and economically justified.