Combined Proceedings IPPS 74:391-398. 2024.

Leaf Sap Analysis for Plant Resilience

David Knaus

Apical Crop Science LLC, 1382 SE 3rd Ave, Suite 4, Canby, Oregon 97013 USA

david@apical-ag.com

Keywords: plant sap analysis, nutrient management, abiotic and biotic stress, disease and insect resistance, diagnostics, data science, precision agriculture

Summary

Leaf sap analysis, also known as plant sap analysis, is a diagnostic tool that assesses plant health by measuring mineral levels and other analytes in plant sap. This method provides an immediate snapshot of micro- and macro-elements (e.g., nitrogen, phosphorus, potassium) being transported within the plant, as well as additional compounds such as total proteins, phenolic compounds, ethanol, and carbohydrates (measured via Brix analysis). These metrics help evaluate plant stress and susceptibility to pests and diseases before visible symptoms emerge. By integrating diagnostics, data science, and crop biofeedback, growers gain real-time insights into nutritional imbalances, enabling informed adjustments to fertilization and management practices. This approach enhances plant resilience, optimizes resource use (e.g., fertilizers, water), and reduces reliance on pesticides and fungicides, supporting sustainable agriculture.

INTRODUCTION

Leaf sap analysis, a subset of plant sap analysis, has emerged as a cornerstone of precision nutrient management, offering applications in foliar spray design, fertilizer efficiency evaluation, biostimulant testing, nutrient stress diagnostics, and systemic issue identification (**Fig. 1**).

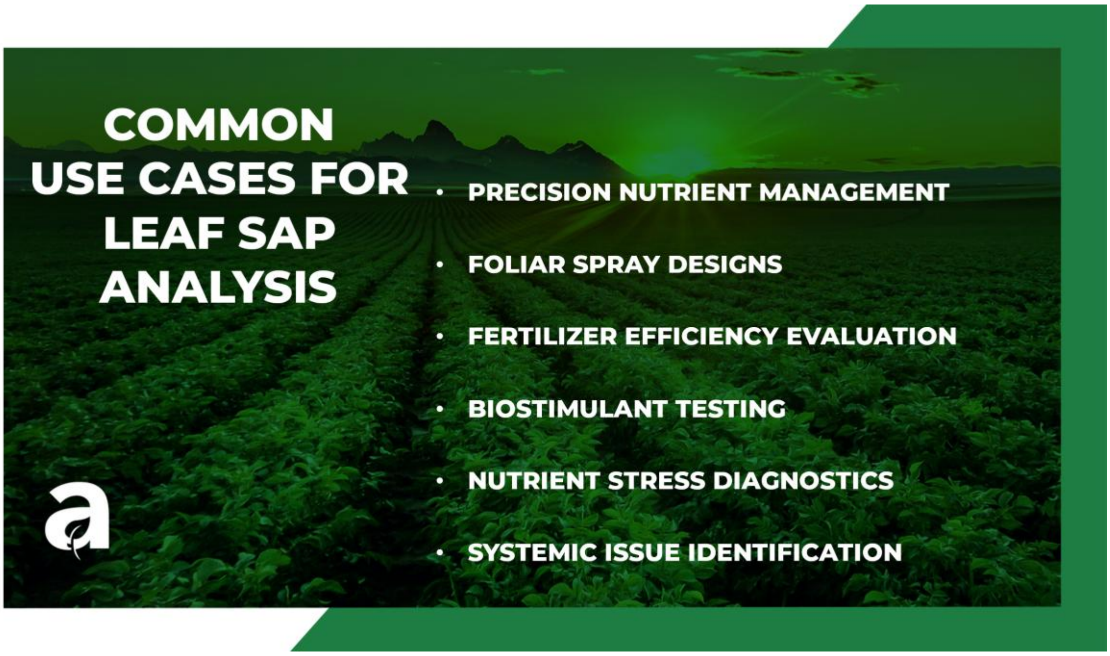

Figure 1. Common Uses for Leaf Sap Analysis. This figure illustrates key applications of leaf sap analysis, including precision nutrient management, foliar spray optimization, fertilizer efficiency assessment, biostimulant evaluation, nutrient stress diagnostics, and systemic issue detection. Visual elements include icons representing plants, nutrient charts, and analytical tools (e.g., spectrometers), emphasizing its multifaceted role in crop care.

Unlike traditional soil or tissue analysis, which provide static snapshots, leaf sap analysis captures the dynamic translocation of nutrients and metabolites within the plant, offering a real-time assessment of physiological status. This enables growers to detect deficiencies or excesses (e.g., nitrogen, phosphorus, zinc) before physical symptoms manifest, facilitating proactive management decisions that bolster crop health and resilience against abiotic (e.g., drought, salinity) and biotic (e.g., pathogens, insects) stresses.

The scientific foundation for leaf sap analysis is well-established, with studies demonstrating its efficacy in monitoring macro- and micro-element levels in plant tissue (Esteves et al., 2021). Recent research by Fan et al. (2021) highlights the biochemical and physiological cross-talk between macro- (e.g., N, P, K) and micro-nutrients (e.g., Zn, Fe), emphasizing molecular mechanisms such as nutrient stress signaling and phytohormone interactions. This understanding is critical for sustainable intensification, a strategy that optimizes fertilizer and input efficiency while minimizing environmental impact (Tilman et al., 2011). Additionally, advancements in analytical techniques—such as inductively coupled plasma mass spectrometry (ICP-MS) and high-performance liquid chromatography (HPLC)—have enhanced the precision of sap analysis, making it a valuable tool for modern agriculture (Reuter & Robinson, 1997).

SOIL, LEAF TISSUE AND SAP ANALYSIS

The practice of analyzing soil, leaf tissue, and plant sap for mineral determination dates back to the 1920s, pioneered by agricultural chemists like Treub (1923), who correlated sap nutrient levels with plant growth **(Fig. 2)**. However, it was not until the 2010s that leaf sap analysis gained prominence with the integration of advanced technologies, such as RGB imaging, SPAD chlorophyll meters, and near-infrared spectroscopy (NIRS). These tools enable detailed assessments of plant biomass, chlorophyll content, nitrogen status, and pest/disease indicators (Gitelson et al., 2003). Today, specialized laboratories equipped with ICP-MS, gas chromatography-mass spectrometry (GC-MS), and automated sap extraction systems provide comprehensive insights into plant-sap correlations with soil health and crop quality (Jones, 2012).

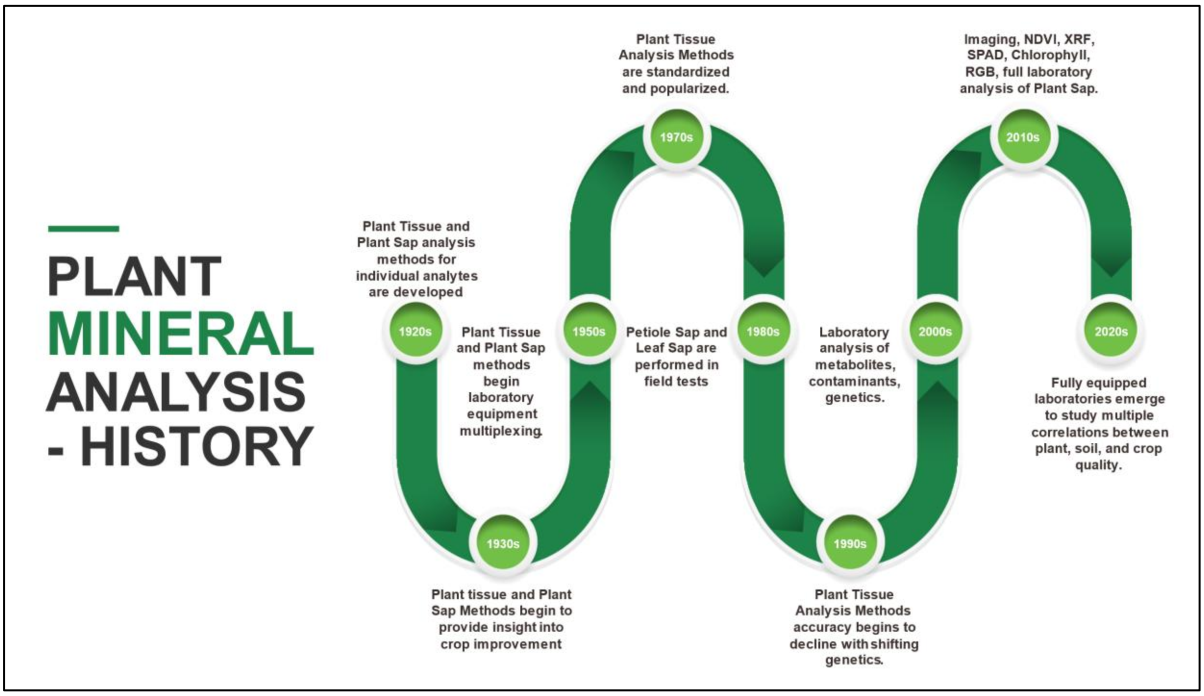

Figure 2. A History of Plant Mineral Analysis Using Plant Tissue and Plant Sap Methods. This timeline chart traces the evolution of plant mineral analysis from the 1920s (initial soil and tissue studies) to the 2010s (integration of RGB imaging, SPAD meters, and NIRS). Key milestones include Treub's early sap analysis (1923), the advent of tissue testing in the 1940s, and modern precision tools, highlighting technological advancements.

A COMPARISON OF PLANT ANALYSIS METHODS

Plant analysis methods—utilizing satellites (RGB imaging), drones (Normalized Difference Vegetation Index, NDVI), tissue analysis, handheld spectral instruments, and leaf sap analysis—offer distinct benefits and limitations (**Fig. 3).** Leaf sap analysis stands out for its immediate snapshot of nutrient translocation, cellular precision, and precise sampling, making it ideal for real-time decision-making. Satellite and drone methods provide broad spatial coverage but lack cellular resolution, while tissue analysis, though detailed, is retrospective and labor-intensive (Marschner, 2012). Handheld spectral tools offer portability but are less specific than sap analysis. The integration of these methods with data science enhances diagnostic accuracy, as demonstrated by machine learning models predicting nutrient deficiencies (Singh et al., 2020).

SOME COMMON TOOLS FOR ASSESSING MINERAL IMBALANCE

Some common tools for assessing mineral imbalance (deficiency and excess) in plants include identifying plant macro- and micro-elements based on leaf maturity (older vs. newer leaves) and visual observations (**Figs. 4 and 5**). Mulder's Chart is based on the interaction of plant macro- and micro-elements in plant nutrition and fertility programs (Mulder, 1953).

apical
Know more.

MATCHING GROWER GOALS TO PLANT ANALYSIS METHODS

SOIL FERTILITY LEVEL	LOW	MID-LOW	MID	MID-HIGH	HIGH
Crop Value	Low	Mid-Low	Mid	Mid-High	High
METHOD	RGB (Satellite)	NDVI (Drone)	Tissue	Handheld Spectral (XRF, NIR)	Plant Sap
BENEFITS	Weak/Moderate /Strong	Qualitative (Stress indicicators)	Annual Assesment of Mineral Inputs	Micro Snapshot or many micro snapshots	Nutrient Translocation within a Plant
STRENGTHS	Low Cost/Ac	Versatile Data Set	Accurate on a General Scale	Rapid for large number of subsamples	Cellular Precision
WEAKNESSES	Clouds, Source of underlying problems unclear	Weather, Limited Quantitative Data	Annual Assessment	Small Sample Size	Precise Sampling

Figure 3. A Comparison of plant analysis methods utilizing satellites (RGB), drones (NDVI), tissue analysis, Handheld Spectral Instruments, and Plant Sap Analysis. The table compares methods based on coverage (e.g., field-wide vs. cellular), timeliness (real-time vs. retrospective), precision (high vs. moderate), and cost (low vs. high). Leaf sap analysis is highlighted for its real-time nutrient translocation data, while drones excel in spatial mapping, and tissue analysis provides historical insights.

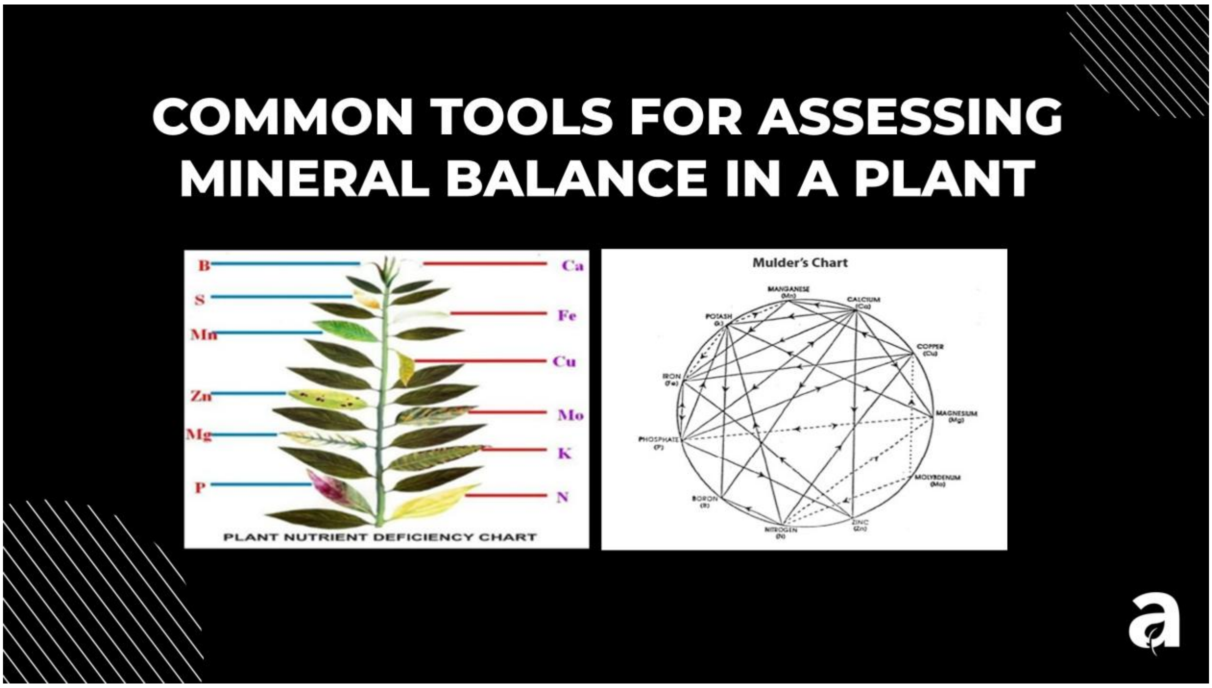

Figure. 4. Common tools for assessing mineral imbalance (deficiency and excess) in plants. This figure shows (left) a diagram of leaf maturity analysis (older vs. newer leaves) with color-coded deficiency symptoms (e.g., yellowing for N deficiency), and (right) Mulder's Chart illustrating nutrient interactions (e.g., P-Zn antagonism).

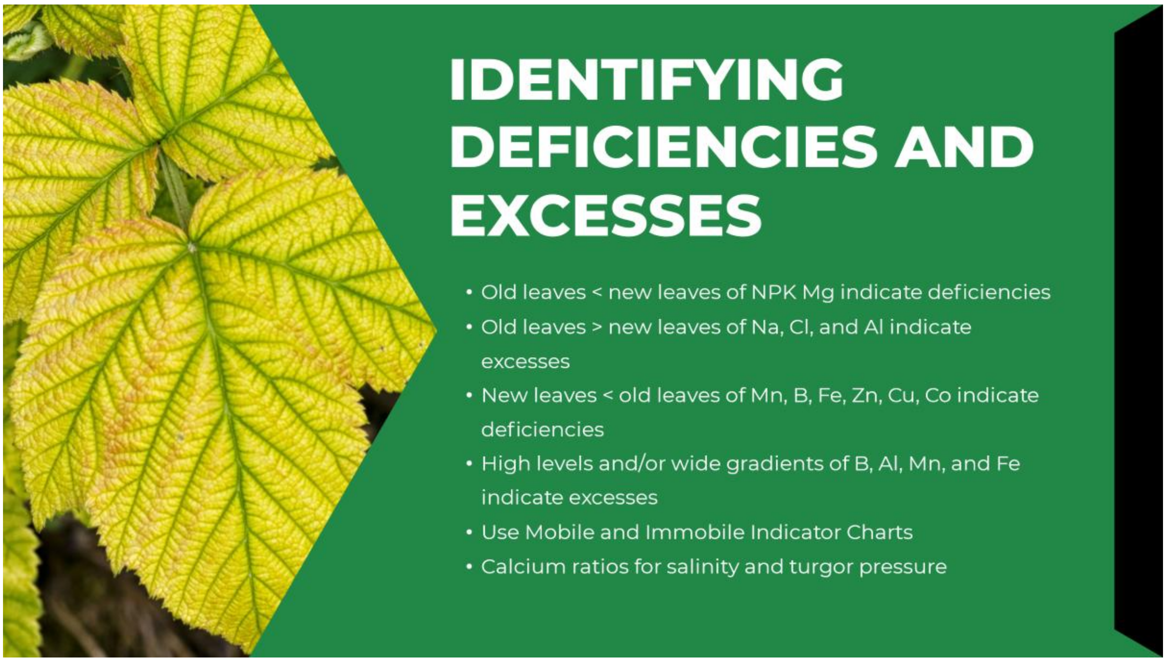

Figure 5. Identifying plant mineral deficiencies and excesses in older and new leaves. This image depicts leaf samples with labeled deficiencies (e.g., N in older leaves, Zn in new leaves) and excesses (e.g., K-induced Mg deficiency), providing a visual guide for field diagnosis.

UTILIZING LEAF SAP ANALYSIS TO MANAGE FERTILIZATION AND PLANT EFFICACY

Leaf sap analysis eliminates guesswork in fertilization by detecting imbalances that cause stress, such as macro- and micro-element deficiencies or over-fertilization leading to defoliation or stunted growth (**Fig. 6**). Mineral imbalances weaken plant immunity, increasing susceptibility to biotic (e.g., aphids, fungi) and abiotic (e.g., heat, drought) stresses, often linked to carbon deficiency from disrupted photosynthesis (**Fig. 7**). By monitoring sap nutrient levels (e.g., P at 0.2–0.5% dry weight, Zn at 20–50 ppm), growers can adjust fertilization to optimize photosynthetic efficiency and immune response (Reuter & Robinson, 1997).

This approach, part of comprehensive nutrient management, integrates diagnostics, data science, and crop biofeedback to recommend tailored interventions (**Fig. 8).** For instance, machine learning algorithms analyzing sap data with soil and weather inputs can predict stress thresholds, reducing input waste by 10–15% (Kamilaris and Prenafeta-Boldú, 2018). Leaf sap analysis thus supports sustainable intensification, aligning with global goals to enhance food security while minimizing environmental footprints (Godfray et al., 2010).

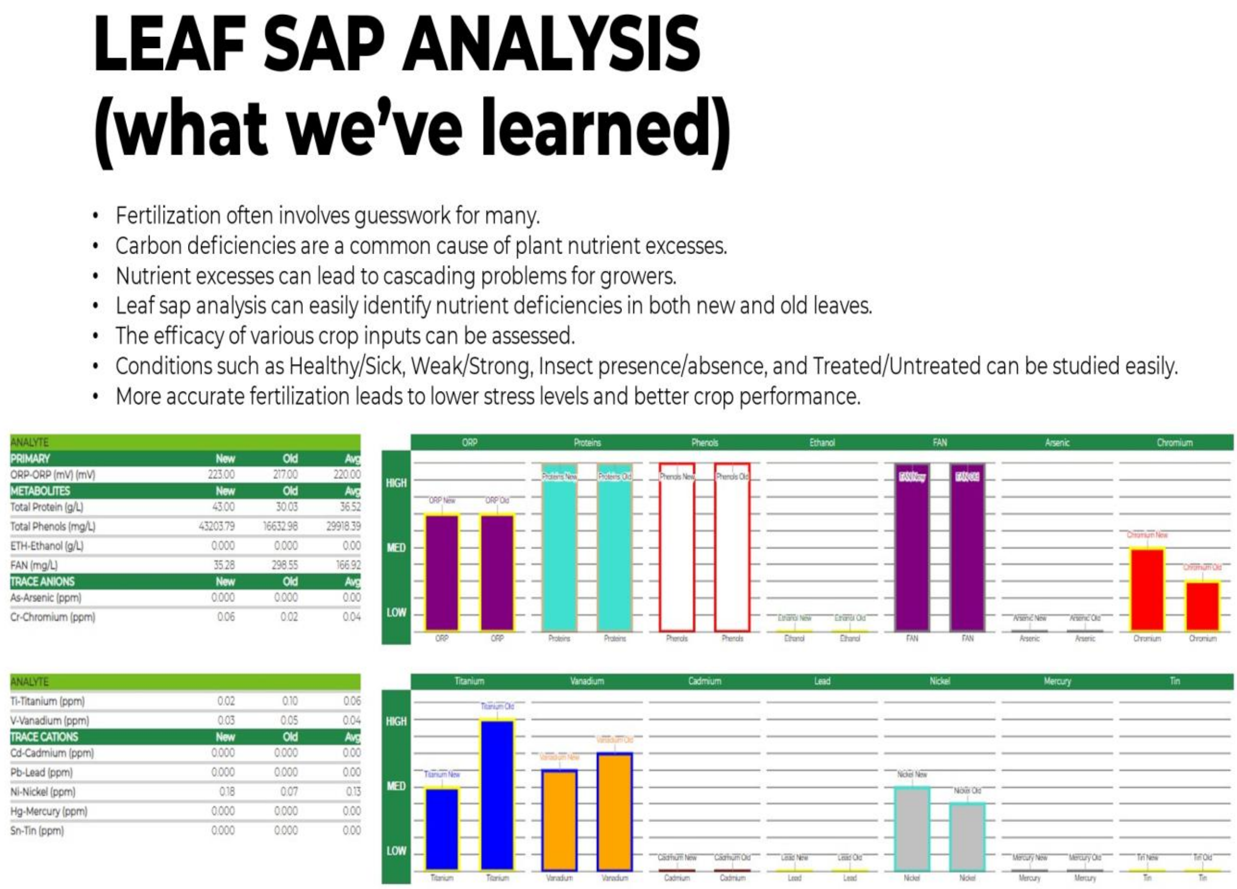

Figure 6. Utilizing leaf sap analysis to manage fertilization and plant efficacy. This flowchart shows sap analysis detecting imbalances (e.g., low P), triggering fertilizer adjustments, and improving resistance to pests, with icons for sap extraction tools and healthy plants.

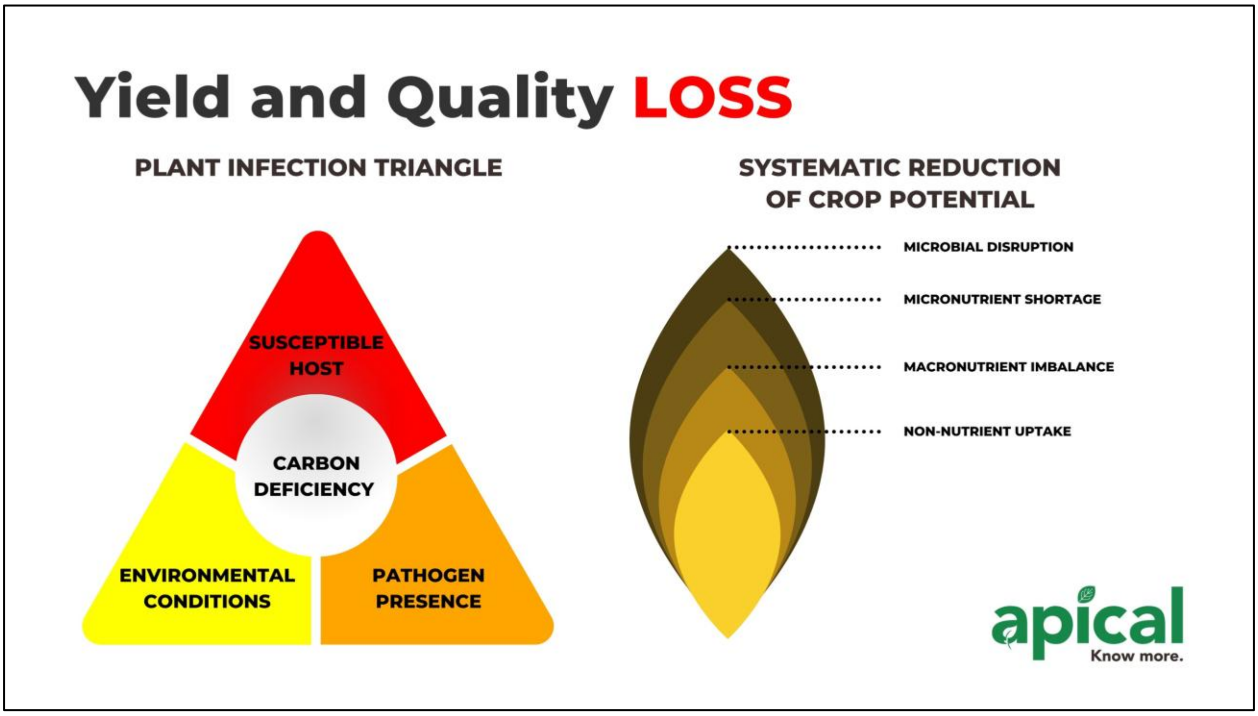

Figure 7. Carbon deficiency (reduced photosynthesis and subsequent carbon production) due to mineral imbalance. This diagram illustrates how mineral shortages (e.g., Mg for chlorophyll) reduce photosynthesis, weakening pest resistance, with arrows linking nutrient uptake to carbon metabolism.

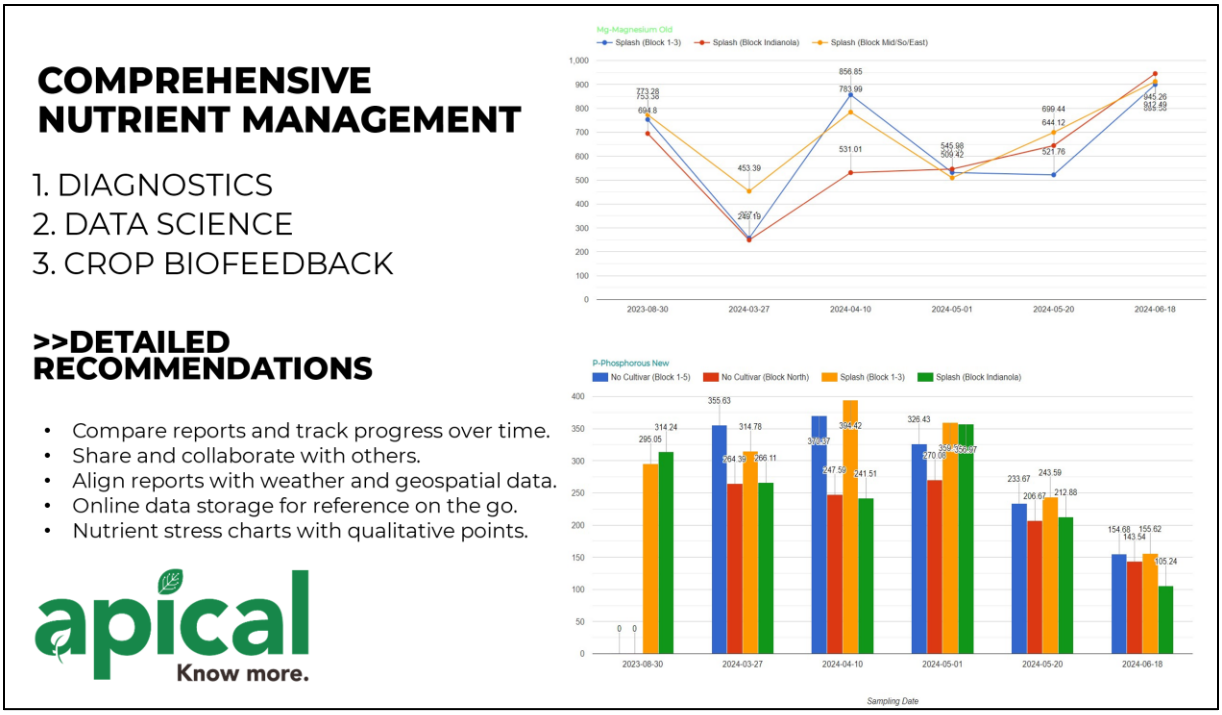

Figure 8. Comprehensive nutrient management includes diagnostics, data science, crop biofeedback, and subsequent crop recommendations. This cycle diagram depicts sap analysis feeding into data models, generating biofeedback, and providing fertilizer recommendations, with feedback loops to refine management practices.

LITERATURE CITED

Esteves, E., Locatelli, G., Alcon Bou, N., and Soranz, R. (2021). Sap analysis: A powerful tool for monitoring plant nutrition. Horticulture 2021, *7*(11): *26* https://doi.org/10.3390/horticulturae7110426

Fan, X., Zhou, X., Chen, H., Tang, M., and Xie. X. (2021). Cross-talk between macro- and micronutrient uptake and signaling in plants. Front. Plant Sci. *12*:663477. doi: 10.3389/fpls.2021.663477

Gitelson, A. A., Gritz, Y., and Merzlyak, M. N. (2003). Relationships between leaf chlorophyll content and spectral reflectance across a wide range of species. Remote Sensing of Environment 87: 337–352. https://doi.org/10.1016/j.rse.2003.06.003

Godfray, H. C. J., Beddington, J. R., Crute, I. R., et al. (2010). Food security: The challenge of feeding 9 billion people. Science *327*: 812–818. https://doi.org/10.1126/science.1185383

Jones, J. B. Jr. (2012). Plant Nutrition and Soil Fertility Manual. CRC Press.

Kamilaris, A., and Prenafeta-Boldú, F. X. (2018). Deep learning in agriculture: A survey. *C*omputers and Electronics in Agriculture *147*:70–90. https://doi.org/10.1016/j.compag.2018.02.016

Marschner, P. (2012). Marschner's Mineral Nutrition of Higher Plants. Academic Press.

Mulder, D. (1953). Les elements mineurs en culture fruitiere. Convegno Nazionale Frutticoltura *118*:98.

Pohl, P., Dzimitrowicz, A., and Lesniewicz, A. (2019). Advances in elemental analysis of plant sap using portable XRF spectrometry. *Talanta*, *195*:–317. https://doi.org/10.1016/j.talanta.2018.11.051

Reuter, D. J., and Robinson, J. B. (1997). Plant Analysis: An Interpretation Manual. CSIRO Publishing.

Singh, A., Ganapathysubramanian, B., Singh, A. K., and Sarkar, S. (2020). Machine learning for high-throughput plant phenotyping. Plant Methods *16*:87. https://doi.org/10.1186/s13007-020-00620-2

Tilman, D., Balzer, C., Hill, J., and Befort, B. L. (2011). Global food demand and the sustainable intensification of agriculture. Proceedings of the National Academy of Sciences *108*: 20260–20264. https://doi.org/10.1073/pnas.1116437108

Treub, M. (1923). On the mineral composition of plant sap and its relation to growth. Annals of Botany *37*: 123–135.