Nutrient use efficiency in agricultural systems:

A Brazilian perspective

Written by

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Most Brazilian soils are deep, highly weathered, acidic, and of low natural fertility. Many strategies have been developed for building soil fertility using lime and mineral fertilizers, particularly phosphorus (P), potassium (K), and micronutrients to attain higher yields. Brazil currently uses 8% of all the fertilizer produced in the world. The country is fourth among the largest consumers, behind only China, India and the United States. However, there is a big problem: national production is minimal. More than 85% of nutrient sources are imported to meet agricultural demand.

Furthermore, the efficiency of fertilizer use is often low and nutrient inputs can represent more than 40% of the production costs of some crops.

The tremendous external dependence on the supply of nutrients makes the country's position quite fragile and heavily dependent on the national variation in input prices. Variations in prices and the uncertainty in supply have been the primary concern for Brazilian producers. Currently, Brazil finds itself in a highly complex situation where costly inputs are imported and often underutilized. Nevertheless, it's crucial to acknowledge the various methods available to enhance nutrient utilization efficiency in the agricultural field. Numerous technologies exist for producers, offering avenues to improve this aspect.

Technological innovation stands as a cornerstone for the success of Brazilian agribusiness, given that its growth has historically relied on the creation and adoption of innovative technologies. The advancements in agricultural productivity have been deeply rooted in technological innovation. Consequently, a consistent influx of technical knowledge becomes imperative for the sector's sustainability.

Below, several technological solutions are outlined, aimed at enhancing the implementation of optimal agricultural practices. These solutions can significantly contribute to achieving high yields within the framework of rational and sustainable Brazilian agriculture.

Soil analysis

Soil chemical analysis is essential to assess soil fertility. By interpreting the results, it is possible to carry out chemical soil management efficiently and economically. By integrating physical analyses such as density and soil texture with more accessible biological analyses such as enzyme activities, it becomes possible to conduct a comprehensive and highly informative assessment of soil conditions. The results of chemical analyses determine the nutrient stock and levels of growth-limiting chemical elements before planting. This enables precise recommendations for liming and fertilization, as well as ongoing monitoring and evaluation of nutrient balance in the soil.

Moreover, maintaining a balanced nutrient profile within the soil-plant system can be viewed as an indicator of the sustainability of agricultural land use. For optimal results, all recommendations regarding liming and fertilization should stem from chemical analyses performed on samples representing various production systems. This approach avoids the use of fixed amounts of limestone and fertilizer formulations, which, when applied indiscriminately, can result in imbalances, either through underdosing or excessive application.

Enhanced efficiency fertilizers (EEF)

One of the options for reducing the environmental impacts and increasing nutrient availability to crops is using nutrient sources with increased efficiency, such as enhanced efficiency fertilizers (EEFs). Examples of this include slow release and controlled release fertilizers. Both feature technologies that alter release patterns and delay the solubilization of nutrients.

Various fertilizer technologies exist to enhance efficiency, such as coatings (which involve applying a material to serve as a physical barrier around the fertilizer), composite fertilizers (fertilizers processed with particles within their structure), chemical surface modification (involving the mixture or deposition of molecular compounds), or interaction with biological agents. These innovative methods aim to improve nutrient utilization efficiency by minimizing losses caused by leaching (N and K), volatilization (N), denitrification (N), and fixation (P), thereby enhancing plant uptake through a gradual supply aligned with crop demand.

Ideally, the release of nutrients should be controlled and synchronized with the plant's growth rate to adequately address its changing nutritional requirements throughout the growth and production cycle.

(left) Soil liming in a crop-livestock-forest integrated system in São Carlos-SP, Brazil; *(right)* No-till corn sowing in a crop-livestock-forest integrated system in São Carlos-SP, Brazil

Precision Agriculture (PA)

Research results and the practical experience of farmers have indicated that combining agronomic knowledge with digital technologies, such as precision agriculture (PA), can also help improve fertilizer use efficiency. Neglecting spatial variation within production areas can significantly impact both yield and environmental quality when managing soil fertility. Hence, understanding the spatial variability of soil chemical and physical properties becomes crucial for establishing uniform management zones. This knowledge facilitates the application of lime and fertilizers at varying rates and locations, promoting the judicious utilization of resources.

Precision agriculture (PA) begins with data collection, analysis, and interpretation to generate recommendations for field interventions and harvesting. It involves an integrated knowledge chain, combining machinery, equipment, and sensors with information technologies to support agricultural management. Thus, creating thematic maps becomes pivotal in defining highly effective management strategies, particularly in optimizing input usage.

The utilization of georeferenced soil sampling and variable-rate input applications has been prevalent in expansive production areas, notably in soybean, corn, sugar cane, and cotton crops. Results are evident across various perennial crops and pastures, showcasing the potential to map and assess the spatial variability of soil properties, subsequently recommending lime and fertilizer application based on these maps.

PA technologies play a vital role in enhancing resource efficiency by precisely applying the appropriate dosage at the right location and time.

However, for further advancements in PA, there is a need to reduce mapping costs while enhancing robustness and accuracy. Ongoing developments involve testing and employing new methods, sensors, and equipment in the field to achieve this objective. PA is increasingly driven by the rapid evolution of the Internet of Things (IoT), big data, cloud computing, and artificial intelligence (AI). These technologies, when integrated with interfaces, are expected to converge, encompassing PA within agriculture's management information systems.

Integrated systems

Conservation agriculture includes a set of management practices based on no-tillage, which means direct planting without soil harrowing or ploughing, maintaining permanent soil covered with inter-season crops, and crop diversification. Adopting these conservation practices increases the input of organic matter into the soil and changes its decomposition rates, favouring the aggregation of particles and promoting soil structure. Crop rotation and soil cover play a pivotal role in enhancing soil quality, affecting various aspects such as water infiltration and retention, temperature regulation, stimulation of biological activity, and reduction of pressure from weeds and diseases. By minimizing soil disturbance and preserving its structure, there's a notable increase in water-conducting pores. Consequently, this reversal of the erosion process leads to heightened water retention capacity and improved nutrient availability for plants. The increase in the amount of soil organic matter (SOM) also leads to higher nutrient retention, lower emissions of greenhouse gases (mainly CO_2, CH_4, and N_2O) into the atmosphere, and a reduction in global warming.

Crop-livestock and forest integrated systems (ICLF) are options for conservation agriculture, which enable the recovery of degraded pasture areas, lead to improvements in the physical, chemical, and biological properties of the soil, increase the competitiveness of rural enterprises and diversify and stabilize income on rural property. Furthermore, crop rotation with legumes contributes to biological N fixation. ■