AgriScope
Monthly e-Magazine on Agriculture and Interdisciplinary Sciences
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Email at us: agri4scope@gmail.com
ISSN: 3139-6488

Overcoming Hidden Hunger in Horticultural Soils: Optimizing Secondary and Micronutrient Management for Crop Quality and Sustainability

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Article ID: 29007

ABSTRACT

Hidden hunger in horticultural soils, resulting from deficiencies of secondary nutrients (calcium, magnesium and sulphur) and micronutrients (iron, zinc, boron, manganese, copper and molybdenum) has become a significant challenge to sustainable horticultural production. Although required in small quantities, these nutrients are essential for plant growth, enzyme activation, chlorophyll synthesis, flowering, fruit development and stress tolerance. Continuous cropping, excessive dependence on NPK fertilizers, low organic matter and soil degradation have accelerated nutrient depletion, leading to reduced yield, poor crop quality and lower nutritional value of horticultural produce. Optimizing secondary and micronutrient management through integrated nutrient management practices is crucial for improving soil fertility, crop productivity and produce quality. Soil and plant tissue testing, balanced fertilization, organic amendments, biofertilizers, foliar application and fertigation enhance nutrient availability and use efficiency while reducing environmental losses. Emerging technologies such as precision nutrient management, nano-fertilizers and digital soil mapping further improve the timely and site-specific supply of nutrients. Adequate nutrition with secondary and micronutrients enhances the quality of fruits and vegetables by increasing vitamin and mineral content, improving colour, flavour, shelf life and marketability and also strengthening crop resilience to biotic and abiotic stresses. A holistic nutrient management strategy integrating conventional and advanced approaches is essential to overcome hidden hunger, maintain long-term soil health and ensure sustainable horticultural production. Such strategies will play a vital role in achieving food and nutritional security while promoting environmentally sustainable agriculture.

Keywords: Hidden hunger, Secondary nutrients, Soil fertility, Precision agriculture, Sustainable horticulture.

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INTRODUCTION

Horticulture plays a crucial role in food and nutritional security because fruits and vegetables supply vitamins, minerals, antioxidants, dietary fibre and a range of bioactive compounds. However, the nutritional quality of horticultural produce is closely associated with the availability and balance of nutrients in the soil. Soil fertility is not simply the ability of soil to support plant growth; it involves the capacity of soil to provide essential nutrients along with suitable chemical, physical and biological conditions for plant development.

The concept of **hidden hunger** traditionally refers to deficiencies of essential vitamins and minerals in the human diet, but its roots may extend into the soil–plant system. When soils contain inadequate amounts of available micronutrients, crops may exhibit reduced growth and may accumulate insufficient concentrations of essential minerals in their edible portions. FAO emphasizes the close relationship between soil health, crop quality and nutritional value, highlighting the importance of balanced soil nutrition in addressing micronutrient deficiencies.

Horticultural crops are generally high-value and nutrient-responsive crops and their quality is determined not only by yield but also by nutritional composition, appearance, taste, texture, storage ability and bioactive compounds. Therefore, management of secondary and micronutrients should receive greater attention alongside conventional NPK fertilization.

Secondary and Micronutrients: An Often-Overlooked Component of Plant Nutrition

The essential nutrients required by plants include primary nutrients such as nitrogen, phosphorus and potassium; secondary nutrients such as calcium, magnesium and sulphur; and micronutrients required in smaller quantities. Micronutrients include iron, zinc, manganese, copper, boron, molybdenum and chlorine and nickel. Despite their relatively small quantitative requirements, micronutrients have specific roles in enzyme activity, photosynthesis, metabolism and other essential plant processes. Calcium contributes to cell wall development, membrane stability and cell signalling. Magnesium is the central element of the chlorophyll molecule and is involved in photosynthesis and enzyme activation. Sulphur is essential for protein synthesis and contributes to the formation of important sulphur-containing compounds.

Among micronutrients, iron is essential for chlorophyll formation and electron transport, while zinc contributes to enzyme activity and plant growth regulation. Boron plays important roles in

cell wall formation, reproductive development and pollen viability. Manganese is involved in photosynthesis and enzyme activation, while copper participates in several enzymatic processes. Molybdenum is particularly important in nitrogen metabolism. Thus, the deficiency of even a single nutrient can interfere with plant physiological processes and ultimately affect yield and quality.

Causes of Hidden Hunger in Horticultural Soils

The increasing occurrence of secondary and micronutrient deficiencies is closely associated with intensive cropping and imbalanced nutrient management**.** Continuous removal of nutrients through repeated harvests can gradually deplete soil nutrient reserves. FAO reports that intensive cropping systems can extract substantial quantities of nutrients from soils and that deficiencies may emerge unless adequate nutrient restoration measures are implemented.

The exclusive or excessive emphasis on NPK fertilizers is another important factor. Although NPK fertilizers are essential for achieving high yields, they do not necessarily replenish all nutrients removed by crops. Long-term nutrient imbalance can therefore lead to depletion of secondary and micronutrients.

Low soil organic matter can further reduce nutrient availability and biological activity. Soil pH, texture, moisture, organic matter, redox conditions and interactions among nutrients influence the availability of micronutrients to plants. The availability of micronutrients depends on soil chemical, physical and biological characteristics as well as plant factors. Nutrient antagonism is also important. For example, excessive phosphorus application can induce zinc or iron deficiency under certain soil conditions. Similarly, interactions between calcium, magnesium and other nutrients may affect the availability of micronutrients.

Importance of Secondary and Micronutrients in Horticultural Crop Quality

Secondary and micronutrients influence horticultural crops beyond simple biomass production. Adequate nutrient availability can enhance photosynthesis, root development, flowering, fruit set, cell division and carbohydrate accumulation thereby improving yield and marketable quality. Micronutrients also contribute directly to quality characteristics and improve fruit size, colour, flavour, nutritional value and bioactive compounds while potentially reducing postharvest losses

ISSN: 3139-6488

and extending shelf life. Thus, secondary and micronutrient management provides a link between soil fertility, crop productivity, nutritional quality and human health.

Strategies for Optimizing Secondary and Micronutrient Management

1 Soil and Plant Testing: should form the basis of nutrient management. Determination of available nutrient concentrations helps identify deficiencies and prevents unnecessary fertilizer application. Plant tissue analysis can complement soil testing by indicating the actual nutrient status of the crop.

2 Balanced Fertilization: involves supplying nutrients according to crop demand and soil nutrient status rather than concentrating only on NPK. Secondary nutrients such as Ca, Mg and S should be incorporated wherever deficiencies occur along with required micronutrients such as Zn, Fe, B, Mn, Cu and Mo. The objective of balanced fertilization is to maintain nutrient balance rather than simply increasing fertilizer rates. Excessive application of one nutrient may reduce the availability or uptake of another, making balanced fertilization essential for efficient nutrient use.

3 Integration of Organic and Inorganic Sources: Farmyard manure, compost, vermicompost, green manure and crop residues can improve soil organic matter, microbial activity, nutrient cycling, soil structure and water-holding capacity. Combining organic nutrient sources with mineral fertilizers provides a more comprehensive nutrient supply and can improve long-term soil fertility.

4 Biofertilizers and Beneficial Microorganisms: Biofertilizers are defined as the preparations containing live microbes that help in enhancing soil fertility by fixing atmospheric nitrogen, solubilizing phosphorus and decomposing organic wastes and help in plant growth through production of growth promoting hormones. The beneficial microorganisms can improve nutrient availability and facilitate nutrient cycling. The integration of microbial inoculants with organic and mineral nutrient sources can contribute to improved nutrient use efficiency and soil biological health.

5 Soil Application and Foliar Nutrition: Micronutrients may be supplied through soil application or foliar sprays depending on the crop, nutrient and severity of deficiency. Soil application provides nutrients to the root zone whereas foliar nutrition can provide a rapid correction of certain

deficiencies, particularly when soil conditions restrict nutrient availability. For horticultural crops, foliar application can be useful during critical stages such as flowering, fruit development and rapid vegetative growth. However, application rates and concentrations should be based on crop requirements to avoid toxicity.

6 Fertigation: allows nutrients to be delivered through irrigation water, particularly through drip systems. It can improve the synchronization between nutrient supply and crop demand, increase nutrient-use efficiency and reduce losses. This approach is particularly suitable for intensive horticultural production where precise management of water and nutrients is important.

7 Precision Nutrient Management: provides opportunities for site-specific management of nutrient deficiencies. Soil nutrient mapping, GPS, GIS, remote sensing, variable-rate application and decision-support tools can help identify nutrient-deficient areas and optimize fertilizer use. These approaches are important because nutrient availability varies spatially within fields. Site-specific application can therefore reduce unnecessary fertilizer use while improving nutrient recovery by crops.

Sustainability and Environmental Considerations

Efficient secondary and micronutrient management is not simply a strategy for increasing crop yield. It is also important for reducing nutrient losses and improving resource-use efficiency. Excessive or inappropriate fertilizer application can result in nutrient accumulation, leaching, runoff and environmental contamination.

Sustainable nutrient management therefore requires the **right source, right rate, right time and right method** of nutrient application. The judicious fertilizer management, nutrient measurement and mapping, crop diversification, long-term soil management and appropriate micronutrient use are key approaches to correcting nutrient imbalances.

Conclusion

Hidden hunger in horticultural soils represents an important challenge for sustainable crop production because deficiencies of secondary and micronutrients can simultaneously affect soil fertility, plant growth, crop yield and nutritional quality. Continuous cropping, imbalanced

ISSN: 3139-6488

fertilization, declining soil organic matter and adverse soil conditions can increase the risk of nutrient deficiencies.

A holistic approach based on soil and plant testing, balanced fertilization, integrated use of organic and inorganic nutrient sources, biofertilizers, foliar nutrition, fertigation and precision nutrient management can help overcome these limitations. Appropriate management of secondary and micronutrients can improve not only productivity but also nutritional quality, marketability and postharvest performance of horticultural crops. Therefore, the future of sustainable horticulture lies in shifting from **"more fertilizer" to "better-balanced nutrition."** Optimizing nutrient supply according to soil status, crop demand and environmental conditions can help produce healthier crops, restore soil fertility and contribute to improved nutritional security which offers a promising pathway towards resilient, resource-efficient and nutritionally sensitive horticultural production.