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Harmonizing Agriculture: Nurturing Soil through Micronutrients Management and Texture Dynamics

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

The present review delves into the essential aspect of micronutrient management and soil texture dynamics in agriculture thus emphasizing their pivotal roles in sustaining soil health and optimizing crop productivity. Micronutrients, though required in trace amounts are critical for various physiological and biochemical processes in plants. Micronutrient deficiencies can profoundly impact plant growth and yield, necessitating effective management strategies such as soil amendments, foliar applications, and balanced fertilization practices. Additionally, the paper explores the potential of soil microbes to enhance micronutrient availability. Soil testing emerges as a crucial tool for monitoring nutrient levels and guiding nutrient application decisions. Furthermore, soil texture dynamics significantly influence nutrient availability, highlighting the importance of soil composition and structure. Conservation tillage practices, crop rotation, and the use of micronutrient fertilizers are discussed as means to promote soil health and optimize nutrient profiles. Overall, the paper underscores the importance of integrating micronutrient management and texture dynamics for harmonizing agriculture, ensuring sustainable soil health, and fostering increased crop yields.

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1. INTRODUCTION

Micronutrients are essential components of agriculture contributing significantly to plant growth and development. These crucial elements which include iron, manganese, copper, zinc, boron, and molybdenum are required in modest amounts but are critical for a variety of physiological and biochemical activities in plants. Micronutrient deficiencies can be detrimental to plant growth, resulting in stunted development, lower yields, and poor crop quality [1]. Most micronutrients are connected with plant enzymatic systems. Thus, micronutrient insufficiency and toxicity can decrease the overall agricultural output [2]. Changes in soil environmental parameters such as organic matter, pH, lime concentration, and soil texture have an enormous effect on the availability of micronutrients for plant growth, emphasizing the need to monitor and regulate micronutrient levels in agricultural soils [3,4]. There have been reports countrywide of micronutrient deficiencies in soil, including 40 percent of zinc (Zn), 12.6 percent of iron (Fe), 4.5 percent of copper (Cu), 6.0 percent of manganese (Mn), and 22.8 percent of boron (B) [5]. According to a study, 49 percent of Indian soils may be lacking in zinc, 12 percent in iron, 5 percent in manganese, 3 percent in copper, and 33 percent in Boron [6]. Farmers can address the micronutrient deficiencies in agriculture through a variety of strategies, including soil amendments [7], foliar applications [8], and balanced fertilization practices.

Utilizing the potential of soil microbes such as micronutrient solubilizers and arbuscular mycorrhizal fungi can improve the micronutrient availability in the soil, leading to improved plant health and productivity. Farmers can ensure sustainable agriculture, optimal soil nutrient levels, and increased crop production by recognizing the importance of micronutrients and implementing effective management practices [1]. Soil possesses numerous basic properties that include texture, sand, silt, clay, inorganic constituents, particle density, organic composition, bulk density, pore space, temperature, moisture constant, resistivity, surface roughness, soil air, humus, penetration depth, emissivity, and microwave brightness. Sand, silt, and clay all contribute to soil texture. Soil texture analysis helps to determine the physico-chemical characteristics and nutrient concentration [9]. These particles vary in size with sand being the largest (0.05 to 2 mm), followed by silt (0.002 to 0.05mm) and clay being the smallest (0.002 mm). The combination of these particles in different ratios determines the texture of the soil. Different soil textures have distinct characteristics that influence plant growth, root development, and overall agricultural productivity that have been observed. In the study of microwave dielectric characteristics of soil, it is observed that physical and chemical qualities show significant variation in dielectric properties and that these dielectric properties can be used to forecast soil fertility and health [10]. Soil texture also corresponds with soil porosity, which determines water-holding capacity, gaseous diffusion, and water flow, all of which influence soil health. Thus, gaseous diffusion and water infiltration trigger the survival of microbial propagules and supply moisture and air for microbial growth. This diversity affects soil CO_2 production in clay loam soil, which is approximately 50 percent higher than sandy soil [11]. Soil texture also influences the root system, consequently controlling soil CO_2 outflow [12].

2. MICRONUTRIENTS IN SOIL HEALTH

A micronutrient is an elemental substance crucial for the growth of higher plants, characterized by its minimal requirement and accumulation, typically measured in milligrams per kilogram of soil or biomass, or in grams per hectare. Trace elements encompass these micronutrients comprising elements found in minute quantities within the soil, water, air, or living organisms, including microorganisms, plants, animals, and humans [13]. Micronutrients constitute a minor portion of the total plant composition yet play a vital role in its development. Primarily, they are utilized in enzymes rather than serving as structural constituents of the plant [14].

3. ROLE OF MICRONUTRIENTS

These micronutrients play crucial roles in plants' various physiological and metabolic processes, despite being needed in trace amounts. Eight micronutrients are necessary for optimal plant growth: boron, zinc, manganese, molybdenum, iron, copper, chlorine, and nickel. These elements are vital for plant development, but excessive amounts in soil can lead to toxicity due to their requirement in minute quantities [13,15].

Table 1. Range of nutritional element concentrations and sufficient values in plants [22]

Element	Range of concentration (ppm)	AdequateConcentration (ppm)
Iron (Fe)	20-600	100
Boron (B)	0.20-800	20
Manganese (Mn)	10-600	50
Zinc (Zn)	10-250	20
Copper (Cu)	2-50	6
Molybdenum (Mo)	0.10-10	0.10
Chlorine (Cl)	10-80,000	100
Nickel (Ni)	0.05-5	0.05

Boron is essential for pollen germination and cell wall formation [16], while iron acts as an oxygen carrier and promotes chlorophyll formation [17]. Copper plays a significant role in enhancing crop growth by promoting tillering and improving the viability of pollen in the crop [18], zinc aids in plant growth hormones and enzyme systems [19], and manganese enhances phosphorous availability and activates enzymes [20]. Additionally, magnesium is crucial for chlorophyll synthesis and enzyme activation [21], while molybdenum is required for nitrogen fixation and enzyme activities in plants. These micronutrients are vital for the overall health and productivity of the plant and their deficiency or imbalance in the soil can lead to nutrient deficiencies in plants, impacting growth, yield, and quality. Therefore, maintaining adequate levels of these micronutrients in the soil is essential for optimal plant growth and development.

Micronutrients are required in trace levels, and plants typically require sufficient concentrations of them below 100 parts per million (Table 1).

Micronutrients work as cofactors in enzymes involved in metabolic processes, resulting in higher quality and production. Plant activities include protein and carbohydrate metabolism, as well as photosynthetic rates. Increased protein content, TSS, and other quality indicators lead to improved yield and micronutrients like iron, which aids in chlorophyll production and photosynthesis. It impacts N_2-fixation in legumes because micronutrients such as Fe and Mo are essential components of nitrogenous enzymes that aid in the production of leghaemoglobin (an oxygen scavenger) [23]. Micronutrient concentrations are often greater on the surface soil and decrease with depth. Despite the high concentration of most micronutrients in soils, only a tiny portion is accessible to plants [24,25]. Soil, plant, microbial, and environmental variables all influence micronutrient uptake in plants. pH, redox potential, biological activity, SOM, cation exchange capacity, and clay content all impact micronutrient availability in soils [28]. Plants ability to absorb and utilize micronutrients from soil is influenced by a variety of factors, including HCO3-, root exudation of organic acids (citric, malic, tartaric, oxalic, phenolic), sugars, and non-proteinogenic amino acids (phytosiderophores), enzyme secretion (phosphatases), plant demand, plant species/cultivars, and microbial associations (enhanced CO_2 production, rhizobia, mycorrhizae, rhizobacteria) [26,27]. These studies state that utilizing nutrients like Zn, Fe, and Mn through foliar spraying significantly boosts crop yield [28].

4. MICRONUTRIENTS DEFICIENCY

Micronutrient deficits can be observed through crop symptoms, soil testing, and plant tissue analysis. Disease/pest infestations, pesticide damage, nutrient inadequacies or harsh environmental circumstances can all induce plant symptoms like stunted growth and leaf chlorosis [29,30,31]). Any one of the 17 vital plant nutrients might be insufficient which can reduce the overall productivity. Deficiency symptoms are implied by a nutrient concentration below the critical value or sufficiency range, and deficient plants react to nutrient delivery [32,25].

Iron deficiency, commonly seen in alkaline or calcareous soils creates considerable obstacles for horticultural crops. The predominant symptom is interveinal chlorosis, which generates yellow leaf tissue with green veins. This visual clue highlights the crucial role of Fe in chlorophyll synthesis [33]. Over 0.4 million fatalities occur globally each year as a result of zinc deficiency, underscoring the element's critical role in maintaining human health. Deformities in the leaves, stunted development, and chlorosis are frequent symptoms of zinc deficits. Furthermore, zinc is essential for the creation and metabolism of DNA, meaning that its absence can have significant effects on cell function [34]. Mn is vital

Table 2. Micronutrient deficiency and visual indicators in common horticultural crops

Micronutrient	Deficiency symptoms	Visual Indicators	Common crops	References
Iron	Chlorosis in young leaves, interveinal yellowing, reduced root growth.	White or yellowish leaf veins contrasting with green leaf tissue, reduced root shoot.	Strawberry, Tomato, Areca palm citrus, beans	[38]
Zinc	Stunted growth, shortened internodes, and malformed leaves.	Rosette formation, small leaf size, bronze or chlorotic foliage.	Peppers, Maize, Sweet orange, Pecan	[39]
Copper	Lea tip necrosis, wilting, reduced root growth.	Brown or withered leaf tip, twisted young leaves.	Tomato, grape, chilies, melon	[40]
Manganese	Reduced root shoot growth, decline in photosynthesis, susceptibility to marsh spot disease.	Light green or yellowish leaf tissue, damage to cellular structures.	Pinus, Liverwort, Tomato, Grape wine	[41]
Boron	Brittle and distorted leaves, necrotic growing points.	Thickened curled or wrinkled leaves, hollow stem.	Citrus, Satureja, Hazelnut, Pea.	[39]
Molybdenum	Stunted growth, and reduced nodulation in legumes.	Leaf margins become chlorotic and necrotic	Pea, Soybean, Clover, Alfalfa	[39]

for activities like photosynthesis and enzyme activation, however, it is mostly low in alkaline or high-pH soils [35,36]. Deficits in Cu, which occur mostly in sandy or severely weathered soils and impact lignin synthesis and pigment production, are detrimental to a variety of enzymatic processes. The appearance of twisted leaves, leaf withering, and stunted development are some of the symptoms. Cu is necessary for the synthesis of chlorophyll, and its absence interferes with photosynthesis and energy generation [37] (Table 2) gives a quick review of various micronutrient deficits and associated symptoms.

5. SOIL TEXTURE DYNAMICS

Soil texture has an enormous impact on nutrient availability. Sandy clay loam and sandy loam textures respond strongly to nitrogen, phosphorus, potassium, and manure application, whereas zinc and NPK nutrients limit crop performance and uptake in sandy clay and clay loam soils [42]. Macronutrient availability is also influenced by crop residue type, soil texture, and incubation time.

6. EFFECT OF SOIL TEXTURE ON NUTRIENT AVAILABILITY

Soil composition plays a crucial role in nutrient retention and availability, with clay-rich soils having a higher cation exchange (CEC) and nutrient holding capacity compared to sandy soils, which have larger pore spaces leading to increased leaching of nutrients [43]. Soil structure, defined as the arrangement of soil particles into aggregates, is vital for water and nutrient movement. Well-structured soil with adequate pore spaces facilitates water infiltration and nutrient retention, whereas, compact soil hinders water movement and promotes runoff [44,45]. Drainage and aeration also impact nutrient loss and solubility. Poorly drained soils promote nitrogen loss through denitrification, while, excessively drained sandy soils lead to leaching losses [46,47]. Flooded soil increases the solubility of minerals like iron, and manganese. Moisture is essential for root growth and nutrient uptake, with adequate moisture enhancing nutrient diffusion and organic matter decomposition [48]. pH influences nutrient availability by altering nutrient forms, affecting leaching capabilities and nutrient adsorption. Certain nutrients are more available at specific pH ranges with phosphorus being most available at neutral pH. Additionally, pH affects nitrogen transformations such as mineralization and nitrification, as pH-sensitive bacteria are involved. Temperature influences nutrient intake by affecting the plant's capacity to grow. Plant species and cultivars have different ideal temperatures [49,50,51]. An essential component of the breakdown of organic materials, microbial activity, is likewise influenced by soil temperature [52,53].

7. WATER AND ROOT DISTRIBUTION

There is a study that examines the important relationships that exist between soil and roots in terms of the ways that they affect root development as well as the way they affect the availability of nutrients [54,55]. The most evident impacts on roots are changes in the rates of root extension, root diameter, and root branching; however, when a root penetrates the soil, it can also affect the formation of root hairs and the degree of wall thickening in the endodermis at a distance below the root apex [56,57]. The availability of nutrients near the root might vary depending on nutrient intake and mobility, as well as imbalances in cation and anion uptake. As roots penetrate the earth, the release of organic molecules- especially organic acids by them varies. Acidic compounds can function as chelating agents in the soil, increasing the availability of nutrients like phosphorus and iron [56]. Nutrients like phosphorus and potassium, which are strongly absorbed by soils but are only found in trace amounts in the soil solution, diffuse to the root [58]. The concentration of these nutrients in the soil solution around the root falls when absorption takes place. By doing this, a gradient is created that allows nutrients to pass from a zone of high concentration into the depleted solution next to the root in the soil solution [59].

8. EFFICACY OF SOIL TESTING FOR MICRONUTRIENT MANAGEMENT

Soil testing serves multiple purposes, including monitoring nutrient levels for record-keeping as well as guiding decisions regarding nutrient application. One of the objectives of a soil testing program is to prevent excessive application of nutrients or salts. Since different organic materials such as manure, biosolids, and compost contain varying nutrient compositions, analyzing these materials for nutrients can aid in determining which soil tests are suitable. However, certain tests commonly offered by agricultural laboratories, such as organic matter, ammonium-N (NH4-N), and sulfur (S) tests, are less effective in evaluating management impacts on soil fertility. Soil organic matter testing is often included in routine soil tests but offers limited value for nutrient management decisions. When assessing sulfur (S) levels, plant-tissue testing is preferred over soil testing, as soil test results for sulfur (sulphate-S or total S) are not consistently reliable indicators of crop yield response to sulfur fertilizer application in many cases [60]. Some studies state that selecting the appropriate method for micronutrient application hinges on several factors including the specific element and its formulation (liquid or dry), the severity of the deficiency, and the growth stage of the plant when addressing deficiency symptoms. The two primary routes of micronutrient application are soil and foliar. Soil application is generally favored for most nutrients, especially when deficiencies are identified before or at the start of the growing season. Micronutrients integrated with other fertilizers and applied directly to the soil during planting tend to be more effective over an extended period compared to foliar application. Moreover, soil application ensures that the nutrients are readily available to the plant at the earliest opportunity [31]. Foliar application of micronutrients, such as Foliar Application of micronutrients such as iron, is particularly beneficial for elements that are not efficiently utilized when applied to the soil. This method allows for quick uptake in emergencies when deficiencies are identified or when other materials are being sprayed. Unlike soil application, foliar application generally requires lower use rates, but multiple applications may be necessary to ensure adequate nutrient uptake by the plants [23].

9. MICRONUTRIENT FERTILIZATION

Micronutrient fertilization comes in various forms, each offering unique benefits and applications. These options encompass chelated micronutrients, micronutrient granules, and liquid micronutrient solutions. Chelated micronutrient refers to compounds where micronutrients are bound to organic molecules, enhancing the stability and accessibility to plants. Typically, they are applied to soil or used as foliar sprays [61]. Conversely, micronutrient granules are solid formulations suitable for direct incorporation into the soil or application as top dressing. Liquid micronutrient solutions, being easily soluble, are applied through fertigation systems, ensuring efficient nutrient absorption by plants [62]. Effective application of micronutrient fertilizers is essential for maximizing nutrient uptake by plants. Various application methods include broadcasting, banding, and foliar spraying. Broadcasting entails even spreading of fertilizer across the field, suitable for crops with extensive root systems to ensure uniform nutrient distribution in the soil. In contrast, banding involves concentrated application near plant roots, beneficial for targeting specific areas or addressing nutrient mobility limitations in soil. Foliar application, where the fertilizer is sprayed directly onto leaves, quickly rectifies deficiencies and facilitates immediate nutrient absorption. However, it's crucial to dilute properly and avoid excessive application to prevent adverse effects [63].

10. SOIL TEXTURE OPTIMIZATION TECHNIQUES

10.1 Soil Amendment

Soil amendments are any materials that when added to soil will improve its properties and processes. The primary advantage of soil amendments is that they enhance soil health and make it easier for oilseed crops to get nutrients. Most readily accessible supplements that may be added directly to soil following treatments include soil organic (such as animal manure, compost, vermicompost, biosolids/sewage sludge, biochar, etc.) and inorganic (such as gypsum, zeolite, pyrite, etc) [64]. The utilization of organic manures offers multiple benefits, not only because they naturally contain micronutrients but also due to their capacity to enhance the availability of natural micronutrients in the soil, thereby aiding plant uptake [65]. Incorporating organic materials such as compost, farmyard manure (FYM), green manures, and plant residues into the soil has been recognized as advantageous. These organic amendments not only provide micronutrients but also facilitate the formation of soluble complexes, thereby making micronutrients more accessible to plants [66]. The two inorganic additions that are most frequently employed to condition soil are gypsum and lime. Other inorganic sources of amendments include basic slag, sulfur, perlite, bentonite clays, Epsom salt, sodium chloride, and so on. Salt stress can be reduced and saline-sodic soil supply S nutrients can be restored with the application of amendments like gypsum. The oldest soil supplement, gypsum is a significant source of calcium and sulfur that is frequently applied to crops. In addition to natural mining gypsum, saline-sodic soils can be treated with flue gas desulfurization (FGD) gypsum, which is a by-product of coal-fired power plants [67].

10.2 Conservation Tillage

There were studies agreed on the considerable benefits of conservation tillage practices, such as minimal tillage and residue mulching, for soil health. For instance, minimal tillage enhances soil water and carbon retention, boosts aggregate stability, and improves saturated hydraulic conductivity, all while reducing bulk density when compared to traditional tillage methods [68]. Additionally, preserving crop residues in the field directly or indirectly enhances soil quality by mitigating erosion, preserving soil moisture, regulating hydrothermal conditions, and augmenting soil porosity and infiltration. These residues also serve as a vital energy source for microbial growth and activity, thereby increasing soil microbial biomass and carbon substrate availability [69]. Consequently, integrating conservation tillage with both inorganic and organic plant nutrients holds promise for enhancing soil fertility and crop productivity [70,71].

10.3 Crop Rotation

Crop rotation serves as a vital strategy for managing the differing nutrient requirements of various crops, thereby preventing soil nutrient depletion and promoting a more balanced nutrient profile. By alternating between crops with distinct nutrient needs, farmers can effectively maintain soil fertility and productivity [72]. During non-cropping periods, the introduction of cover crops further enhances soil health and productivity. These cover crops, strategically planted when primary crops are not cultivated, offer numerous benefits to the agroecosystem. Acting as green manure, they contribute organic matter to the soil upon decomposition, enriching soil structure and stimulating microbial activity. Additionally, the root systems of cover crops play a crucial role in preventing soil erosion [73], stabilizing slopes [74], and improving water retention. Moreover, cover crops act as dynamic nutrient managers by extracting excess nitrogen and other nutrients from the soil, mitigating nutrient leaching, and enhancing overall nutrient availability [75].

11. CONCLUSION

Micronutrients are integral to agriculture, playing a vital role in plant growth and development. Addressing micronutrient deficiencies through effective management strategies such as soil amendments, foliar applications, and balanced fertilization practices is essential for ensuring sustainable agriculture and optimizing crop production. Harnessing the potential of soil microbes further enhances micronutrient availability in the soil, contributing to improved plant health and productivity. Soil testing serves as a crucial tool for monitoring nutrient levels and guiding nutrient application decisions. Additionally, soil texture dynamics significantly impact nutrient availability, emphasizing the importance of soil composition and structure in agricultural productivity. By implementing conservation tillage practices, crop rotation, and utilizing various forms of micronutrient fertilizers, farmers can enhance soil health, minimize nutrient depletion, and promote a balanced nutrient profile. Overall, recognizing the significance of micronutrients and implementing comprehensive management practices is essential for achieving sustainable agriculture, optimal soil health, and increased crop yields to meet the growing demands of a global population.

REFERENCES

1. Syed S, Kumar P, Hashmi MS, Singh H, Yadav A. Dynamics importance of micronutrients in agricultural soil. Just Agriculture. 2023;3(8):157.
2. Abu ST, Malgwi WB. Spatial variability of soil physico-chemical properties in kadawa irrigation project in Sudan savanna Agroecology of Nigeria. International Journal of Agricultural; 2011.
3. Nazif W, Perveen S, Saleem I. Status of micronutrients in soils of district bhimber (Azad Jammu and kashmir); 2006.
4. Shubham, Sharma U, Kaushal R, Sharma YP. Effect of forest fires on soil carbon dynamics in different land uses under NW Himalayas. Indian Journal of Ecology. 2022;49(6):2322-2329. DOI:https://doi.org/10.55362/IJE/2022/3828
5. Kumar D, Patel KP, Ramani VP, Shukla AK, Meena RS. Management of micronutrients in soil for the nutritional security. in: Meena, r. (EDS) nutrient dynamics for sustainable crop production. Springer, Singapore; 2020. Available:https://doi.org/10.1007/978-981-13-8660-2_4

6. Sharma J, Kumar P, Dua VK, Sharma V, Kumar D, Kumar S, Rawal S, Khan MA. Status of micronutrients in intensively cultivated potato growing soils of Punjab. Potato Journal. 2017;44(1):58-64.
7. Araya-Alman M, Olivares B, Acevedo-Opazo C, et al. Relationship between soil properties and banana productivity in the two main cultivation areas in venezuela. J Soil Sci Plant Nutr. 2020;20(3):2512-2524. Available:https://doi.org/10.1007/s42729-020-00317-8
8. Campos BO. Banana production in Venezuela: Novel solutions to productivity and plant health. Springer Nature; 2023. Available:https://doi.org/10.1007/978-3-031-34475-6
9. Deshmukh Sushant, Dhiware MD, Nahire SB. Physio-chemical and dielectric properties of soil samples At X -Band Microwave Frequency of Nasik Region, Bionard Frontier. 2015;8(3):279- 282.
10. Sahu JP, Shrivastava AK. Soil texture: Panacea for agriculture. European Chemical Bulletin. 2023;12(1):956-976.
11. Kowalenko CG, Ivarson KC, Cameron DR. Effect of moisture content, temperature and nitrogen fertilization on carbon dioxide evolution from field soils. Soil Biology and Biochemistry. 1978;10(5):417-423.
12. Upadhyay S, Raghubanshi AS. Determinants of soil carbon dynamics in urban ecosystems. In: Urban Ecology, Elsevier, Amsterdam. 2020;299-314. Available:https://doi.org/10.1016/B978-0-12-820730-7.00016-1
13. IsrealZewide, Abde Sherefu. Review paper on effect of micronutrients for crop production. J. Nutrition and Food Processing. 2021;4(7). DOI:10.31579/2637-8914/063
14. Blauwet M.. Micronutrients. Introduction to Soil Science; 2023. Available:https://iastate.pressbooks.pub/introsoilscience/chapter/micronutrients/
15. Shubham, Sharma U, Kaushal R Effect of nitrification inhibitors on quality, yield and economics of cauliflower cv. PSB K1 in Typic Eutrochrept under mid hills of North Western Himalayas, Journal of Plant Nutrition. 2023;46:17:4096-4109. DOI: 10.1080/01904167.2023.2220741
16. Parr AJ, Loughman BC. Boron and Membrane Function in Plants. In: Robb, D.A. and Pierpoint, W.S., Eds., Metals and Micronutrients, Uptake and Utilization by Plants, Academic Press, New York. 1983;87-107.
17. Eskandari H. The importance of iron (Fe) in plant Products and Mechanism of Its uptake by plants. J. Appl. Environ. Biol. Sci. 2011;1(10):448-452.
18. Arnon DI, Stout PR. The essentiality of certain elements in minute quantity for plants with special reference to copper. Plant Physiology. 1939;14(2):371–375. Available:https://doi.org/10.1104/pp.14.2.371
19. Alloway BJ. Zinc in soils and crop nutrition. 2nd Edition, IZA and IFA, Brussels, Belgium and Paris, France; 2008.
20. Millaleo R, Reyes DM, Ivanov AG, Mora ML, Alberdi M. Manganese as essential and toxic element for plants transport, accumulation and resistance mechanisms. Journal of Soil Science and Plant Nutrition. 2010;10:470-481.
21. Ram RA, Bose TK. Effect of foliar application of magnesium and micronutrients on growth, yield and fruit quality of mandarin orange (Citrus reticulata Blanco). Indian Journal of Horticulture. 2000;57(3):215-220.
22. Lohry R. Micronutrients: Functions, sources and application methods. In Proceedings of the Indiana CCA Conference, Indianapolis, IN, USA. 2007;18–19.
23. Rahman R, Sofi JA, Javeed I, Malik TH, Nisar S. Role of micronutrients in crop production. Int. J. Curr. Microbiol. App. Sci. 2020(1):2265-2287.
24. Gupta UC, Wu K, Liang S. Micronutrients in soils, crops, and livestock. Earth Science Frontiers. 2008;15(5):110–125. Available:https://doi.org/10.1016/S1872-5791(09)60003-8
25. Shubham, Sharma U, Kaushal R. Effect of soil applied natural and synthetic nitrification inhibitors on nitrogen transformations and nitrification inhibition in NW Himalayan region of Himachal Pradesh. Indian Journal of Soil Conservation. 2023;51(2):95-101.
26. Fageria NK, Baligar VC, Clark RB. Micronutrients in crop production. Advances in Agronomy. 2002;77:185-268. Available:https://doi.org/10.1016/S0065-2113(02)77015-6
27. Clark RB, Zeto SK. Mineral acquisition by arbuscular mycorrhizal plants. Journal of Plant Nutrition. 2000;23(7):867-902.

Available:https://doi.org/10.1080/01904160009382068

28. Sarkar D, Mandal B, Kundu MC. Increasing use efficiency of boron fertilisers by rescheduling the time and methods of application for crops in India. Plant and Soil. 2007;301(1):77-85.
Available:https://doi.org/10.1007/s11104-007-9423-1
29. Olivares B, Rey JC, Lobo D, Navas-Cortés JA, Gómez JA, Landa BB. Fusarium wilt of bananas: A review of agro-environmental factors in the venezuelan production system affecting its development. Agronomy. 2021a;11(5):986.
Available:https://doi.org/10.3390/agronomy11050986
30. Olivares B, Paredes F, Rey J, Lobo D, Galvis-Causil S. The relationship between the normalized difference vegetation index, rainfall, and potential evapotranspiration in a banana plantation of Venezuela. SAINS TANAH - Journal of Soil Science and Agroclimatology. 2021b;18(1):58-64.
Available:http://dx.doi.org/10.20961/stjssa.v18i1.50379
31. Butzen S. Micronutrients for crop production. Pioneer Crop Insights. 2020;20:1–4.
32. Mundorf T, Wortmann C, Shapiro C, Paparozzi E. Time of day effect on foliar nutrient concentrations in corn and soybean. Journal of Plant Nutrition. 2015;38(14):2312-2325.
DOI: 10.1080/01904167.2014.939760
33. Nugent PE, Bhella HS. A new chlorotic mutant of muskmelon. HortScience N. 2022;23.
Available:https://doi.org/10.21273/hortsci.23.2.379
34. Stanton C, Sanders D, Kr¨ amer U, Podar D. Zinc in plants: Integrating homeostasis and biofortification. Mol. Plant; 2022.
Available:https://doi.org/10.1016/j.molp.2021.12.008
35. Alejandro S, oller HS, Meier B, Peiter E. Manganese in plants: From acquisition to subcellular allocation. Front. Plant Sci; 2020.
Available:https://doi.org/10.3389/fpls.2020.00300.
36. Shubham, Sharma U, Chahal A. Effect of forest fire on ammonification and nitrification: A study under chir pine *(Pinus roxburghii*) forest areas of Himachal Pradesh. Indian Journal of Ecology. 2021;48(2):376-380.
37. Sun Q, Li T, Alva AK, Li YC. Mobility and fractionation of copper in sandy soils. Enviro. Pollut. Bioavailab. 2019;31.
Available:https://doi.org/10.1080/09542299.2018.1558114
38. Zaiter HZ, Coyne DP, Clark RB. Genetic variation and inheritance of resistance of leaf iron-deficiency chlorosis in dry beans. J. Am. Soc. Hortic. Sci. 2022;112.
Available:https://doi.org/10.21273/jashs.112.6.1019.
39. Wall S, Hafiz IA, Khan RI, Bashir MA, Uddin S, Khan SU, Ajmal U, Hussain S, Khalid MF.. Zinc and boron application at different phenological stages alleviates tree growth, fruit yield and quality of sweet orange Cv. ‘Blood Red. Gesunde Pflanzen. 2022;74.
Available:https://doi.org/10.1007/s10343-021-00616-9
40. Fortis-Hern´andez M, Ortiz-Lopez J, Preciado-Rangel P, Trejo-Valencia R, Lagunes- Fortiz E, Andrade-Sifuentes A, Rueda-Puente EO. Biofortification with copper nanoparticles (Nps Cu) and its effect on the physical and nutraceutical quality of hydroponic melon fruits. Not. Bot. Horti. Agrobot. Cluj Napoca. 2022;50.
Available:https://doi.org/10.15835/nbha50112568
41. Messant M, Hani U, Hennebelle T, Gu´ erard F, Gaki` ere B, Gall A, Thomine S, Krieger-Liszkay A. Manganese concentration affects chloroplast structure and the photosynthetic apparatus in Marchantia polymorpha. Plant Physiol. 2023;192.
Available:https://doi.org/10.1093/plphys/kiad052
42. Huanlun, Cheng, Min, Ji, Che, Wangyang Hu, Yilun Cheng, Xu Hu, Shichen Xiong, Jiangkun Zheng, Yuanbo Gong. Soil-available nutrients associated with soil chemical and aggregate properties following vegetation restoration in western Sichuan, China. Forests. 2023;14:259-259.
DOI: 10.3390/f14020259
43. Lobo D, Olivares B, Rey JC, Vega A, Rueda-Calderón A. Relationships between the Visual Evaluation of Soil Structure (VESS) and soil properties in agriculture: A

meta-analysis. Scientia agropecuaria. 2023;14 – 1:67 - 78.

Available:https://doi.org/10.17268/sci.agropecu.2023.007

44. Calero J, Olivares BO, Rey JC, Lobo D, Landa BB, Gómez JA. Correlation of banana productivity levels and soil morphological properties using regularized optimal scaling regression. Catena. 2022;208:105718.

    Available:https://doi.org/10.1016/j.catena.2021.105718

45. Hernandez R, Olivares B, Arias A, Molina JC, Pereira Y. Eco-territorial adaptability of tomato crops for sustainable agricultural production in Carabobo, Venezuela. Idesia. 2020;38(2):95-102.

    Available:http://dx.doi.org/10.4067/S0718342920200002000095

46. Hernández R, Olivares B, Arias A, Molina JC, Pereira Y. Agroclimatic zoning of corn crop for sustainable agricultural production in Carabobo, Venezuela. Revista Universitaria de Geografía. 2018;27(2):139-159.

    Available:https://n9.cl/l2m83

47. Hernández R, Olivares B, Arias A, Molina JC, Pereira Y. Identification of potential agroclimatic zones for the production of onion (*Allium cepa L.*) in Carabobo, Venezuela. Journal of the Selva Andina Biosphere. 2018b;6(2):70-82.

    Available:http://www.scielo.org.bo/pdf/jsab/v6n2/v6n2_a03.pdf

48. López-Beltrán M, Olivares B, Lobo-Luján D. Changes in land use and vegetation in the agrarian community Kashaama, Anzoátegui, Venezuela: 2001-2013. Revista Geográfica De América Central. 2019;2(63):269-291.

    Available:https://doi.org/10.15359/rgac.63-2.10

49. Cortez A, Olivares B, Muñetones AY, Casana S. Strategic elements of organizational knowledge management for innovation. Case: Agrometeorology Network. Revista Digital de Investigación en Docencia Universitaria. 2016;10(1):68-81.

    Available:http://dx.doi.org/10.19083/ridu.10.446

50. Cortez A, Olivares B, Parra R, Lobo D, Rodríguez MFY, Rey JC. Description of meteorological drought events in localities of the central mountain range, Venezuela.Ciencia, Ingenierías y Aplicaciones. 2018;I(1):22-44.

    DOI:http://dx.doi.org/10.22206/cyap.2018.vlil.pp23-45

51. Hernández R, Olivares B. Ecoterritorial sectorization for the sustainable agricultural production of potato (*Solanum tuberosum L.*) in Carabobo, Venezuela. Agricultural Science and Technology. 2019;20(2):339-354.

    Available:https://doi.org/10.21930/rcta.vol20_num2_art:1462

52. Pregitzer K, King J. Effects of soil temperature on nutrient uptake. Environmental Science; 2005.

    DOI: 10.1007/3-540-27675-0_10

53. Hernández R, Olivares B. Application of multivariate techniques in the agricultural land’s aptitude in Carabobo, Venezuela. Tropical and Subtropical Agroecosystems. 2020;23(2):1-12.

    Available:https://n9.cl/zeedh

54. Olivares B. Description of soil management in agricultural production systems in the Hamaca de Anzoátegui sector, Venezuela. La Granja: Revista de Ciencias de la Vida. 2016;23(1):14–24.

    Available:https://n9.cl/ycp08

55. Olivares B, Vega A, Calderón MAR, Rey JC, Lobo D, Gómez JA, Landa BB. Identification of Soil Properties Associated with the Incidence of Banana Wilt Using Supervised Methods. Plants. 2022a; 11(15):2070.

    Available:https://doi.org/10.3390/plants11152070

56. Goss MJ, Miller MH, Bailey LD, Grant CA. Root growth and distribution about nutrient availability and uptake. European Journal of Agronomy. 1993;2(2):57-67.

    DOI: 10.1016/S1161-0301(14)80135-4

57. Olivares B, Rey JC, Lobo D, Navas-Cortés JA, Gómez JA, Landa BB. Machine Learning and the New Sustainable Agriculture: Applications in Banana Production Systems of Venezuela. Agricultural Research Updates. Nova Science Publishers, Inc. 2022b;42:133-157.

58. Rey JC, Olivares BO, Perichi G, Lobo D. Relationship of microbial activity with soil properties in banana plantations in Venezuela. Sustainability. 2022;14:13531.

Available:https://doi.org/10.3390/su142013531

59. Mengel D. Roots, growth and nutrient uptake. Agronomy Department, Purdue University, West Lafayette, IN 47907-1150. Department of Agronomy publication # AGRY-95-08; 1995.
60. Staben ML, Ellsworth JW, Sullivan DM, Horneck D, Brown BD, Stevens RG. Monitoring Soil Nutrients Using a Management Unit Approach. PNW 570-E. A Pacific Northwest Extension publication; 2003.
61. Rodríguez-Yzquierdo G, Olivares BO, González-Ulloa A, León-Pacheco R, Gómez-Correa JC, Yacomelo-Hernández M, Carrascal-Pérez F, Florez-Cordero E, Soto-Suárez M, Dita M, et al. Soil Predisposing Factors to Fusarium oxysporum f.sp Cubense Tropical Race 4 on Banana Crops of La Guajira, Colombia. Agronomy. 2023;13:2588.
Available:https://doi.org/10.3390/agronomy13102588
62. Olivares Campos BO. Potential use of soil morphological properties to differentiate levels of banana productivity. in: Banana production in Venezuela. The Latin American Studies Book Series. Springer, Cham; 2023c.
Available:https://doi.org/10.1007/978-3-031-34475-6_6
63. Roman J. The Essential Guide to Micronutrient Management in Soil: Boosting Plant Growth and Yield; 2024.
Available:https://fordragonfliesandme.com/2024/02/03/the-essential-guide-to-micronutrient-management-in-soil-boosting-plant-growth-and-yield/
64. Raji SG, Tzanakakis V, Dorsch P. Bradyrhizobial inoculation and P application effects on haricot and mung beans in the Ethiopian Rift Valley. Plant and Soil. 2019;442:271-284.
DOI: 10.1007/s11104-019-04170-2
65. Olivares Campos BO. (2023b). Identification of the main soil variables correlated with banana productivity. in: Banana production in Venezuela. The Latin American Studies Book Series. Springer, Cham.
Available:https://doi.org/10.1007/978-3-031-34475-6_5
66. Dhaliwal SS, Naresh RK, Mandal A, Singh R, Dhaliwal MK. Dynamics and transformations of micronutrients in agricultural soils as influenced by organic matter build-up: A review. Environmental and Sustainability Indicators. 2019;1–2:100007.
Available:https://doi.org/10.1016/j.indic.2019.100007
67. Mao YM, Li XP, Dick WA, Chen LM. Remediation of saline-sodic soil with flue gas desulfurization gypsum in a reclaimed tidal flat of Southeast China. Journal of Environmental Sciences. 2016;45:224-232
68. Olivares Campos BO. Evaluation of the incidence of banana wilt and its relationship with soil properties. in: Banana production in Venezuela. The Latin American Studies Book Series. Springer, Cham; 2023a.
Available:https://doi.org/10.1007/978-3-031-34475-6_4
69. López M, Olivares B. Normalized difference vegetation index (NDVI) applied to the agricultural indigenous territory of Kashaama, Venezuela. UNED Research Journal. 2019;11(2):112-121.
Available:https://doi.org/10.22458/urj.v11i2.2299.
70. Dal Ferro N, Stevenson B, Morari F, Müller K. Long-term tillage and irrigation effects on aggregation and soil organic carbon stabilization mechanisms. Geoderma. 2023;116398.
Available:https://doi.org/10.1016/j.geoderma.2023.116398
71. Kätterer T, Bolinder MA. Agriculture practices to improve soil carbon storage in upland soil. In Understanding and fostering soil carbon sequestration. ed. C. Rumpel (Cambridge, UK: BurleighDodds Science Publishing). 2023;453–488.
72. Hernández R, Pereira Y, Molina JC, Coelho R, Olivares BY, Rodríguez K. Calendario de siembra para las zonas agrícolas del estado Carabobo en la República Bolivariana de Venezuela. Sevilla, Spain, Editorial Universidad Internacional de Andalucía. 2017;247.
Available:https://n9.cl/sjbvk
73. Olivares B, Verbist K, Lobo D, Vargas RY, Silva O. Evaluation of the USLE model to estimate water erosion in an Alfisol. Journal of Soil Science and Plant Nutrition of Chile. 2011;11(2):71-84.
Available:http://dx.doi.org/10.4067/S0718-95162011000200007

74. Olivares B, Lobo D, Verbist K. Application of the USLE model in erosion plots under soil and water conservation practices in San Pedro de Melipilla, Chile. Revista Ciencia e Ingeniería. 2015;36(1):3-10.

75. Sela G. Crop Rotation. Agriculture, Crop Protection, Pests and diseases, Plant Nutrition. (31 October).
Available:https://cropaia.com/blog/crop-rotation/

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