Impact of Micro-nutrients on Growth and Development of Fodder Crops under Water Stress Condition: A Review

ABSTRACT

This article delves into the critical significance of micronutrients specifically in fodder crop production, highlighting their profound impact on crop growth, yield, quality, and sustainable farming practices. Despite being required in trace amounts, micronutrients are essential for ensuring the health and productivity of livestock, as they serve as vital components of the forage consumed by animals. Micronutrients act as indispensable cofactors for enzymes involved in crucial metabolic processes essential for plant health and subsequent livestock nutrition. They play a pivotal role in enhancing fodder crop yield and improving its nutritional content, thus directly contributing to the overall health and productivity of livestock populations. Furthermore, proper management of micronutrients in fodder crop production is essential for ensuring the long-term sustainability of agricultural ecosystems. Sustainable farming practices that prioritize micronutrient balance not only optimize crop yields but also promote soil health and environmental sustainability. This research aims to address the complex challenges of ensuring livestock health, meeting global food demands, and promoting responsible agricultural practices within animal agriculture. In conclusion, the role of micronutrients in fodder crop production is paramount for ensuring the health and productivity of livestock, as well as supporting sustainable farming practices. Recognizing the significance of micronutrients in fodder crop production and implementing tailored management strategies are essential steps toward achieving livestock health, sustainable farming practices, and ultimately, food security in the context of animal

Keywords:Micronutrients, forage crop yield, nutrient management, sustainable farming.

1. INTRODUCTION

Fodder crops are an essential component of livestock farming, providing the necessary nutrition to animals for their growth and productivity. In agriculture, these crops are crucial for livestock maintaining soil health and preventing erosion [1]. However, the agriculture sector faces numerous challenges, among which water stress due to changing climate patterns and limited water resources is a critical concern [2]. Water stress can significantly reduce crop yields, including those of fodder crops, and lead to food and forage shortages, threatening food security [3]. Additionally, excessive water use for irrigation can exacerbate water scarcity in many regions. In this context, understanding the impact of micronutrients on fodder crops under water stress conditions becomes increasingly important.

The significance of investigating the effect of micronutrients on yield and quality parameters during water stress in fodder crops is multi-faceted. Firstly, it addresses the urgent need to enhanceagricultural productivity in the face of increasing water scarcity and the growing demand for livestock products. Fodder crops serve as a critical link in the food chain by providing the necessary nutrition to livestock, which, in turn, provides meat and dairy products to human populations[5]. Therefore, improving fodder crop production can help meet the nutritional requirements of both livestock. The significance of investigating the effect of micronutrients on yield and quality parameters during water stress in fodder crops is multi-faceted. Firstly, it addresses the urgent need to enhance agricultural productivity in the face of increasing water scarcity and the growing demand for livestock products [4]. Fodder crops serve as a critical link in the food chain by providing the necessary nutritionto humans. Secondly, this study is essential for sustainable agriculture practices as it seeks to reduce the environmental impact of agriculture by efficiently using water resources and improving crop quality [6].

The primary objectives of this study are twofold. First, we aim to investigate how the application of micronutrients affects the yield parameters of fodder crops under water-stressed conditions. This research will shed light on the potential benefits of micronutrient supplementation in mitigating the negative impact of water stress on fodder crop productivity. Second, we will explore the influence of micronutrients on the quality parameters of these crops, including nutrient content and secondary metabolites. This is important as the nutritional quality of fodder crops directly impacts the health and performance of livestock. By elucidating these objectives, this study seeks to provide valuable insights into sustainable agriculture practices and water resource management in the context of fodder crop production.

2. PRESENT SCENARIO OF FODDER PRODUCTION

Fig 1 shows that the increase of supply of green fodder in 2015 by 21.43% more than in 1995 and the demand in 1995 was 947 and in 2015 the demand was1097. The increasing rate of demand is 15.83% in 2015 over 1995 but in this current scenario, the supply cannot fulfill the demand during the previous year and also in the future. In previous years the supply was half of the demand which was 61.8% lower than demand. According to the report of Punjab Agriculture University on economic production processing and marketing of fodder crops in India stated that in 2025 the supply will vary with demand in a similar trend to previous studies.

The increase of supply of dry fodder in 2020 by 12.35% than in 1995 and the demand in 1995 was 526 and in 2015 the demand was 609. The increasing rate of demand is 19.77% in 2020 over 1995 but in this current scenario, the supply cannot fulfill the demand during the previous year and also in the future.

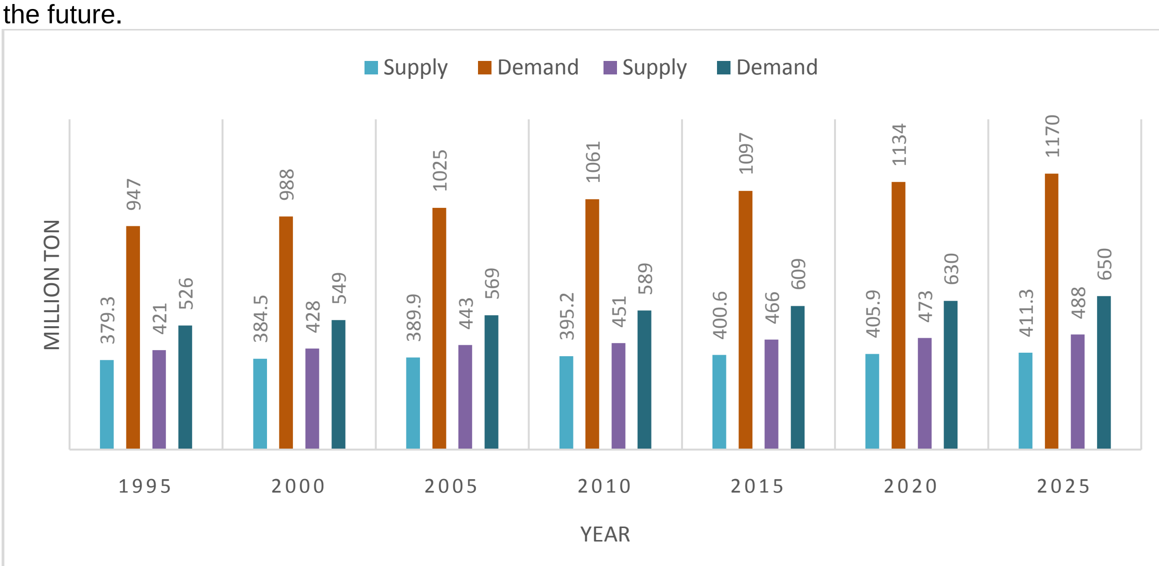

Fig. 1.Based on 10 and 11th five-year plan document vision 2030.

3. UNDERSTANDING WATER STRESS IN FODDER CROPS

Water stress in agriculture refers to a condition where the available water resources, such as rainfall and irrigation, are insufficient to meet the water demands of crops and the overall agricultural ecosystem [7]. It is a growing concern in the context of climate change, population growth, and competition for limited freshwater resources. Water is a fund requirement for plant growth, and its scarcity can lead to reduced crop yields, diminished crop quality, and even crop failure [8]. Water stress can manifest in different forms, including droughts, soil salinity, and inadequate irrigation, all of which pose significant challenges to food security and sustainable agriculture [9]. Insufficient water availability can significantly reduce fodder crop yields, leading to shortages in animal feed and potentially affecting livestock health and productivity [10].

Water stress in fodder crops is a pressing issue within the realm of agriculture, with far-reaching implications for livestock farming and sustainable food production. Fodder crops, including species like alfalfa, clover, and various grasses, serve as primary sources of nutrition for livestock, directly influencing their growth, health, and productivity [11]. Water stress in these crops occurs when the available water resources, including rainfall and irrigation, prove insufficient to meet the crop's water requirements. This condition can manifest as prolonged droughts, limited irrigation availability, or increased soil salinity, ultimately hindering crop growth and reducing forage quality.

The impact of water stress on fodder crops extends beyond agricultural yields, affecting livestock nutrition and food security [12]. When fodder crops experience water stress, their nutritional content can change significantly, leading to lower protein and nutrient levels, which, in turn, affect the health and performance of the animals consuming them [13]. This can result in reduced meat and dairy production, ultimately impacting human populations that rely on livestock products as sources of nutrition.

To mitigate the effects of water stress on fodder crops and livestock, understanding the physiological and biochemical responses of these crops to water stress is crucial [14]. Researchers have explored various strategies, including improved crop varieties and irrigation practices, to enhance water-use efficiency in fodder crop production [15]. Additionally, studies have investigated the potential benefits of micronutrient application to mitigate the negative impacts of water stress on crop productivity and quality [16]. Addressing water stress in fodder crops is an essential aspect of achieving food security and sustainable livestock farming, as it ensures the availability of high-quality forage for animal nutrition.

Water stress, a pervasive issue in agriculture, has numerous consequences that affect crop production, food security, and environmental sustainability. The consequences of water stress are far-reaching and have been extensively studied in the context of agriculture and natural resource management. One of the primary consequences of water stress is a significant reduction in crop yields. Insufficient water availability, whether due to drought, reduced irrigation, or soil salinity, can lead to stunted crop growth and decreased agricultural productivity. This reduction in yields poses a direct threat to global livestock food security, as it limits the availability of essential crops for human consumption and livestock feed [17]. Water stress also impacts the quality of agricultural products. Crops grown under water-stressed conditions often exhibit altered nutrient content, reduced protein levels, and lower overall quality [18]. These changes in crop quality can affect the nutritional value of food and feed, ultimately influencing the health and performance of both humans and animals.

Additionally, water stress in agriculture exacerbates the over-exploitation of water resources, leading to a depletion of freshwater reserves. This overuse of water for irrigation contributes to water scarcity, which can have detrimental effects on ecosystems, aquatic life, and human populations relying on these water sources for various purposes [19] Furthermore, the consequences of water stress extend to increased competition for limited water resources, often leading to conflicts and disputes over access and usage. This is particularly critical in regions where water is a scarce and valuable commodity [4].

Addressing the consequences of water stress in agriculture is crucial for ensuring sustainable food production, maintaining the environmental balance, and achieving global food security and resource management goals. Researchers and policymakers have been exploring various strategies, including improved water-use efficiency and sustainable agricultural practices, to mitigate these consequences and create a more resilient and sustainable agricultural system.

4. EFFECTS OF MICRONUTRIENTS

4.1Effectof Micronutrients On Crop Growth

Micronutrients, also known as trace elements, are essential minerals required by plants in small quantities, yet they play a crucial role in their growth, development, and overall health. These micronutrients are fundamental for various plant functions, and their deficiencies can have detrimental effects on plant growth and crop yields.

Micronutrients include elements such as iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo), and chlorine (Cl). They are involved in various physiological processes, such as photosynthesis, respiration, and enzyme activation. For example, iron is essential for chlorophyll formation, while zinc plays a crucial role in DNA synthesis and cell division [20].When plants lack these micronutrients, they can exhibit specific deficiency symptoms, which vary depending on the nutrient in question. For instance, iron deficiency often results in chlorosis, where leaves turn yellow due to reduced chlorophyll production, while a lack of boron may lead to distorted growth and poor fruit development [21].Plants absorb micronutrients from the soil through their root systems. The availability of these nutrients can be influenced by soil pH, organic matter content, and other factors. Therefore, understanding the mechanisms of micronutrient uptake and transport in plants is important for addressing deficiencies [22].Proper management of micronutrients is essential in agriculture to optimize crop yields and quality. This may involve soil testing, foliar application of micronutrient fertilizers, or selecting crop varieties with better micronutrient uptake efficiency [20].Excessive micronutrient application can have adverse environmental effects, including soil contamination and water pollution. Balancing nutrient management to prevent excess while ensuring plant health is a key challenge in sustainable agriculture[23].

4.2Importance of Micronutrients During Stress

Micronutrients play a pivotal role in plant resilience and productivity, especially during periods of stress. While plants require these elements in small quantities, their absence or deficiency can have significant implications for plant health and overall crop yield. Micronutrients are essential for expressing various stress responses and tolerance mechanisms in plants, contributing to their ability to withstand adverse environmental conditions.

During water stress, for example, micronutrients like zinc (Zn), manganese (Mn), and boron (B) have been found to enhance drought tolerance and improve water-use efficiency in plants [24]. These micronutrients influence the expression of stress-associated genes and the production of osmolytes, which help plants conserve water and maintain cell turgor under drought conditions [25]. In the case of metal toxicity stress, iron (Fe) and copper (Cu) deficiencies can mitigate the toxic effects of excess heavy metals present in the soil. Iron deficiency, for instance, reduces the uptake of toxic metals like cadmium (Cd) in plants, reducing the risk of toxicity [26].

Moreover, micronutrients contribute to the synthesis of antioxidants, which protect plant cells from oxidative damage caused by various stresses, including salinity, heavy metal contamination, and nutrient imbalances. Manganese (Mn), for instance, is involved in the activation of antioxidant enzymes, aiding in the detoxification of reactive oxygen species (ROS) produced under stress conditions [27].

4.3Impact of Micronutrients On Yield

Micronutrients play a crucial role in enhancing the yield of fodder crops by supporting various growth and developmental processes. Here's how specific micronutrients impact the yield of fodder crops.Zinc is vital for photosynthesis, enzyme activation, and growth hormone synthesis in fodder crops. Zinc deficiency can hinder root and shoot development, impacting nutrient uptake and water absorption. Studies indicate that zinc application can significantly boost yields, especially in zinc-deficient soils, thus improving fodder crop productivity [21]. Iron is essential for chlorophyll formation and photosynthesis in fodder crops. Iron deficiency can lead to chlorosis, stunted growth, and decreased yield [28]. Correcting iron deficiencies through applications of iron chelates or other methods can enhance fodder crop yields by promoting healthy growth and maximizing photosynthetic efficiency [29]. Manganese plays a crucial role in enzymatic processes related to energy and nutrient metabolism in fodder crops. Manganese deficiency can impair root development and nutrient uptake, affecting overall growth and yield. Ensuring an adequate supply of manganese can enhance fodder crop growth and productivity [30]. Copper is essential for activating enzymes involved in cell wall lignification in fodder crops. Copper deficiency may lead to reduced root growth and poor nutrient absorption. Studies suggest that applying copper can improve both the yield and quality of fodder crops by supporting essential metabolic processes [31]. Molybdenum is essential for nitrogen fixation[32] in legumes and the synthesis of enzymes involved in nitrogen metabolism in fodder crops. Molybdenum deficiency can limit nitrogen availability, leading to lower yields. Adequate molybdenum supply is crucial for optimizing fodder crop yield, particularly in legume-based fodder systems [33]. Chlorine contributes to photosynthesis and stomatal regulation in fodder crops. While chlorine deficiencies are relatively rare, they can still impact crop growth and yield. Maintaining balanced chloride levels is essential for optimal fodder crop development and productivity [32].

4.4 Impact of Micronutrients on Quality

Micronutrients have a substantial impact on the quality of fodder crops. Though they are required in only small quantities, their presence or absence can significantly influence various quality parameters of agricultural products. Here's an explanation of the impact of micronutrients on the quality of crops. Zinc is crucial for protein synthesis in fodder crops, influencing the nutritional quality of forage. Adequate zinc levels improve protein content, enhancing the nutritional value of fodder, particularly in zinc-deficient soils [15]. Iron contributes to chlorophyll formation in fodder crops, enhancing their green color and visual appeal. Additionally, iron improves the iron content of forage, impacting its nutritional quality [34]. Copper is involved in lignin synthesis and enzyme activation, which affects the structural integrity of plants. Proper copper supply can enhance the texture and storability of crops, impacting their quality attributes [35]. Molybdenum is essential for nitrogen metabolism in fodder crops, impacting their protein quality and nutritional value. Adequate molybdenum levels contribute to a balanced amino acid profile, enhancing the overall quality of forage [36]. Chlorine plays a role in photosynthesis in fodder crops, affecting their sugar content, taste, and smell. Optimal chloride levels enhance the flavor and sweetness of forage, contributing to its overall quality [37].

5. INTERACTION BETWEEN MICRONUTRIENTS AND WATER STRESS

The interaction between micronutrients and water stress in plants is a complex and multifaceted relationship. Micronutrients play a crucial role in how plants respond to and cope with water stress. Water stress, such as drought conditions, can impact the availability and uptake of micronutrients by plants. Changes in soil pH and root activity under drought conditions can hinder the plant's ability to absorb micronutrients, potentially leading to deficiencies that exacerbate the stress response [38]. Micronutrients like zinc (Zn) and manganese (Mn) are crucial for plant stress responses. They activate enzymes involved in antioxidative defense mechanisms, helping plants combat oxidative stress induced by moisture stress. This supports the plant's resilience and ability to withstand adverse conditions [39]. Boron enhances plant tolerance to drought stress by influencing physiological processes such as water uptake and osmoregulation. Adequate boron levels improve water use efficiency in plants, reducing the negative impacts of water stress and enhancing overall stress tolerance [40]. Water stress conditions can affect iron availability and uptake by plants, leading to iron deficiencies that worsen the stress response. Proper iron supply is crucial for maintaining plant health and stress tolerance, as iron is involved in essential metabolic processes and enzyme activation [41]. Copper plays a role in activating enzymes involved in stress responses, such as superoxide dismutase. These enzymes help mitigate the effects of oxidative stress caused by various abiotic stresses, including water stress. Adequate copper levels support enzyme activity, contributing to plant resilience under water stress conditions [42].

6. MECHANISMS OF MICRONUTRIENT ACTION

Micronutrients exert their effects on plants through various intricate mechanisms, influencing a range of physiological processes. These mechanisms are crucial for plant growth, development, and responses to environmental stresses, including water stress. Micronutrients like zinc (Zn), copper (Cu), and manganese (Mn) serve as cofactors for enzymes involved in various metabolic processes. For instance, Zn is essential for enzymes like carbonic anhydrase and superoxide dismutase, crucial for photosynthesis and antioxidant defense, respectively [43]. Iron (Fe) and magnesium (Mg) are vital for chlorophyll synthesis and structure. Chlorophyll captures light energy during photosynthesis. Inadequate iron or magnesium levels can lead to chlorosis, impacting photosynthetic efficiency and overall plant growth [44]. Boron (B) regulates osmotic pressure in plant cells, crucial during water stress. It helps maintain cell turgor by controlling water and solute movement, enhancing the plant's ability to tolerate water stress conditions [45]. Molybdenum (Mo) is necessary for nitrogen metabolism, acting as a cofactor for nitrogenizing enzymes involved in nitrogen fixation. This ensures an adequate nitrogen supply for protein synthesis and overall plant growth [46].Micronutrients like zinc (Zn) and copper (Cu) activate antioxidant enzymes such as superoxide dismutase, catalase, and peroxidases. These enzymes protect plants from oxidative stress induced by environmental factors, including water stress [47].

7. IMPLICATIONS OF MICRONUTRIENTS FOR AGRICULTURE

Micronutrients play a crucial role in agriculture, impacting crop yield, nutrient content, and the promotion of sustainable farming practices. Here, I'll explain each of these implications in detail with references:

7.1 Enhancing Crop Yield

Micronutrients play a vital role in optimizing crop yield by influencing various biochemical pathways and promoting plant growth, photosynthesis, and stress responses. Correcting micronutrient deficiencies can significantly improve crop productivity. Zinc is essential for root development, nutrient uptake, and overall plant growth. Zinc applications, either through soil or foliar fertilization, have been shown to enhance better-quality fodder production in zinc-deficient regions [48].Iron is essential for photosynthesis and chlorophyll formation. Iron-deficient plants suffer from reduced photosynthetic activity, leading to decreased yields. Correcting iron deficiencies, such as through chelate applications, foliar spray of $FeSO_4$ can improve digestibility parameters and improve herbage yield in terms of green and dry forage yield [45].Manganese is crucial for nitrogen metabolism, enzyme activation, and photosynthesis. Adequate manganese supply can enhance forage yield, particularly in manganese-deficient soils [49].

7.2 Improving Nutrient Content

Micronutrients not only influence crop yield but also have a direct impact on nutrient content. Proper micronutrient management can enhance the nutritional quality of agricultural products, making them more valuable for human and animal consumption.Zinc is essential for the synthesis of proteins, including those involved in nutrient storage and transport. Adequate zinc levels in crops can improve their protein content and overall nutritional quality [50].Iron is crucial for plant health and plays a role in the nutritional quality of the leafy part of plants. Adequate iron supply can enhance the iron content of fodders improving their nutritional value [51].

7.3 Effect of Sustainable Agriculture Practices

Micronutrient management is particularly critical in the cultivation of fodder crops, as they serve as primary sources of nutrition for livestock, directly impacting their health and productivity. Implementing sustainable practices in micronutrient management for fodder crops is essential for optimizing yields, maintaining soil health, and ensuring the long-term viability of livestock farming systems.Sustainable practices involve careful monitoring and management of micronutrient levels through soil testing and nutrient management plans tailored to the specific needs of fodder crops. By applying micronutrients judiciously and in the right amounts, farmers can optimize crop growth and minimize environmental impacts [23].

7.4 Promoting Soil Health

Fodder crop production relies on healthy soils to support robust growth and nutrient uptake. Micronutrient management is integral to maintaining soil health, as micronutrients play key roles in various physiological processes essential for plant growth and development. Ensuring proper soil pH, organic matter content, and micronutrient availability is crucial for sustaining fodder crop yields over time and minimizing the risk of nutrient deficiencies [52].

7.5 Micronutrient Bio Fortification

Biofortification presents an innovative approach to enhancing the nutritional quality of fodder crops, thereby improving livestock nutrition and health [53]. By selecting and breeding fodder crop varieties with enhanced micronutrient content, such as zinc or selenium, farmers can contribute to addressing nutritional deficiencies in livestock diets. Biofortified fodder crops offer a sustainable solution to improving animal health and productivity while reducing reliance on external micronutrient supplements [54].

8. FUTURE RESEARCH PROSPECTS

The study of micronutrients in agriculture is an evolving field, and future research directions aim to further our understanding of these essential elements and their interactions with plants, soil, and the environment. Here are some key areas for future research in micronutrients in agriculture:

Research on bio-fortification tectechniques tailored to fodder crops can help enhance their micronutrient content. This includes exploring genetic approaches and agronomic practices to increase the levels of essential micronutrients such as zinc, selenium, and iron in fodder crops. Improving the micronutrient content of fodder can directly contribute to enhancing the health and productivity of livestock, thus improving overall food security and nutrition[55].

Future research should focus on developing sustainable micronutrient management practices specific to fodder crop production. This involves investigating precision agriculture techniques and efficient micronutrient delivery systems tailored to the unique needs of fodder crops. Sustainable management practices can help minimize environmental impacts such as nutrient runoff and soil contamination while optimizing crop yields and quality [21].

Understanding the complex interactions between different micronutrients in fodder crops, as well as their interactions with macronutrients and soil properties, is essential. Future research should explore how these interactions influence nutrient uptake, plant growth, and overall crop productivity in fodder systems. This knowledge can inform more effective nutrient management strategies for fodder crop production [56].

Research should investigate how climate change affects the availability and uptake of micronutrients in fodder crops. Developing climate-resilient fodder crop varieties with improved micronutrient uptake efficiency and tolerance to environmental stresses can help ensure the sustainability of livestock farming systems in the face of changing climate conditions[57].

Research on micronutrient availability and management in organic farming systems, specifically focusing on fodder crops, is essential. Organic agriculture often faces unique challenges in nutrient management, and understanding how to optimize micronutrient use in organic fodder production systems can help improve yields, quality, and sustainability [58].

9. CONCLUSION

The role of micronutrients in fodder crop production is paramount for ensuring the health and productivity of livestock, as well as supporting sustainable farming practices. Despite being required in trace amounts, micronutrients profoundly impact fodder crop growth, yield, and nutritional quality, serving as essential cofactors for enzymes crucial for metabolic processes vital to plant health and subsequent livestock nutrition.Enhancing fodder crop yield and improving nutrient content is critical for meeting the nutritional needs of livestock and ensuring their optimal growth and performance. Proper management of micronutrients not only boosts fodder yields but also enhances the nutritional value of forage, contributing to the overall health and productivity of livestock populations.Moreover, adopting sustainable agriculture practices that prioritize micronutrient balance is vital for maintaining the long-term health and productivity of soil in fodder production systems. By implementing strategies to optimize micronutrient management, farmers can promote sustainable fodder crop production while minimizing environmental impacts and ensuring the resilience of agricultural ecosystems.Therefore, it has been concluded that recognizing the significance of micronutrients in fodder crop production and implementing tailored management strategies are essential for achieving livestock health, sustainable farming practices, and ultimately, food security in the context of animal agriculture.

REFERENCE

1. U. Sekaran, L. Lai, D.A.N. Ussiri, S. Kumar, S. Clay. Role of integrated crop-livestock systems in improving agriculture production and addressing food security–A review. J Agric Food Res2021, 5, 100190.
2. Zheng Q, Siman K, Zeng Y, Teo HC, Sarira TV, Sreekar R, et al. Future land-use competition constrains natural climate solutions. Science of The Total Environment 2022, 838,156409.
3. B. Shiferaw, K. Tesfaye, M. Kassie, et al. Managing vulnerability to drought and enhancing livelihood resilience in sub-Saharan Africa: Technological, institutional and policy options. Weather ClimExtrem2014, 3, 67–79.
4. J. Rockström, M. Falkenmark, L. Karlberg, et al. Future water availability for global food production: The potential of green water for increasing resilience to global change. Water Resour Res2009, 45 (7).
5. Erdaw MM. Contribution, prospects and trends of livestock production in sub-Saharan Africa: a review. International Journal of Agricultural Sustainability 2023, 21(1), 2247776.
6. Gutiérrez-Gordillo S, Lipan L, Durán-Zuazo VH, Carbonell-Barrachina ÁA, Cárceles Rodríguez B, Rubio-Casal AE, et al. Linking sustainability and competitiveness of almond plantations under water scarcity and changing climate. Resources use efficiency in agriculture 2020, 695-728.
7. L.S. Pereira. Water, agriculture and food: challenges and issues. Water Resources Management2017, 31 (10), 2985–2999.
8. Ingrao C, Strippoli R, Lagioia G, Huisingh D. Water scarcity in agriculture: An overview of causes, impacts and approaches for reducing the risks. Heliyon 2023, 9, 18507.
9. N. Ungureanu, V. Vlăduț, G. Voicu. Water scarcity and wastewater reuse in crop irrigation. Sustainability2020, 12 (21), 9055.

10. C.M. Godde, D. Mason-D’Croz, D.E. Mayberry, P.K. Thornton, M. Herrero. Impacts of climate change on the livestock food supply chain; a review of the evidence. Glob Food Sec2021, 28, 100488.
11. S. Chand, Indu, R.K. Singhal, P. Govindasamy. Agronomical and breeding approaches to improve the nutritional status of forage crops for better livestock productivity. Grass and Forage Science2022, 77 (1), 11–32.
12. Rabie TS. Potential climate change impacts on livestock and food security nexus in Egypt. Climate Change Impacts on Agriculture and Food Security in Egypt: Land and Water Resources—Smart Farming—Livestock, Fishery, and Aquaculture 2020, 423-50.
13. N.M. Capstaff, A.J. Miller. Improving the yield and nutritional quality of forage crops. Front Plant Sci2018, 9, 338501.
14. S. Fahad, A.A. Bajwa, U. Nazir, et al. Crop production under drought and heat stress: plant responses and management options. Front Plant Sci2017, 8, 265598.
15. A. Ullah, M. Farooq, A. Rehman, M. Hussain, K.H.M. Siddique. Zinc nutrition in chickpea (Cicer arietinum): A review. Crop Pasture Sci2020, 71 (3), 199–218.
16. El Sabagh A, Hossain A, Barutçular C, Iqbal MA, Islam MS, Fahad S et al., Consequences of salinity stress on the quality of crops and its mitigation strategies for sustainable crop production: an outlook of arid and semi-arid regions. Environment, climate, plant and vegetation growth 2020, 503-33.
17. A. Dai. Increasing drought under global warming in observations and models. Nat Clim Chang2013, 3 (1), 52–58.
18. Bakht S, Safdar K, Khair KU, Fatima A, Fayyaz A, Ali SM, et al. The response of major food crops to drought stress: Physiological and biochemical responses. Agronomic Crops, Stress Responses and Tolerance, 2020, 3, 93-115.
19. D. Zhang, M.S. Sial, N. Ahmad, et al. Water scarcity and sustainability in an emerging economy: a management perspective for future. Sustainability2020, 13 (1), 144.
20. Rengel Z, Cakmak I, White PJ. Marschner's mineral nutrition of plants. Academic Press, 2022.
21. I. Cakmak. Enrichment of cereal grains with zinc: agronomic or genetic biofortification? Plant Soil2008, 302, 1–17.
22. K.S. Karthika, I. Rashmi, M.S. Parvathi. Biological functions, uptake and transport of essential nutrients in relation to plant growth. Plant nutrients and abiotic stress tolerance2018, 1–49.
23. Dhaliwal SS, Sharma V, Shukla AK, Verma V, Kaur M, Shivay, et al. Biofortification—A frontier novel approach to enrich micronutrients in field crops to encounter the nutritional security. Molecules 2022, 27(4),1340.
24. Siddiqui H, Singh P, Arif Y, Sami F, Naaz R, Hayat S. Role of micronutrients in providing abiotic stress tolerance. Microbial Biofertilizers and Micronutrient Availability: The Role of Zinc in Agriculture and Human Health 2022, 115-36.
25. R. Zia, M.S. Nawaz, M.J. Siddique, S. Hakim, A. Imran. Plant survival under drought stress: Implications, adaptive responses, and integrated rhizosphere management strategy for stress mitigation. Microbiol Res2021, 242, 126626.
26. S.-H. Huang, P. Bing, Z. YANG, L. Chai, L. Zhou. Chromium accumulation, microorganism population and enzyme activities in soils around chromium-containing slag heap of steel alloy factory. Transactions of Nonferrous Metals Society of China2009, 19 (1), 241–248.
27. S. Sachdev, S.A. Ansari, M.I. Ansari, M. Fujita, M. Hasanuzzaman. Abiotic stress and reactive oxygen species: Generation, signaling, and defense mechanisms. Antioxidants2021, 10 (2), 277.
28. S.A. Prity, A.M. El-Shehawi, M.M. Elseehy, S. Tahura, A.H. Kabir. Early-stage iron deficiency alters physiological processes and iron transporter expression, along with photosynthetic and oxidative damage to sorghum. Saudi J Biol Sci2021, 28 (8), 4770–4777.

29. A.W.M. Mahmoud, A.A. Ayad, H.S.M. Abdel-Aziz, et al. Foliar application of different iron sources improves morpho-physiological traits and nutritional quality of broad bean grown in sandy soil. Plants2022, 11 (19), 2599.
30. N.K. Fageria, V.C. Baligar, R.B. Clark. Micronutrients in crop production. Advances in agronomy2002, 77, 185–268.
31. B. Printz, S. Lutts, J.-F. Hausman, K. Sergeant. Copper trafficking in plants and its implication on cell wall dynamics. Front Plant Sci2016, 7, 176193.
32. C.-M. Geilfus. Review on the significance of chlorine for crop yield and quality. Plant Science2018, 270, 114–122.
33. S.A. Bursakov, P.Y. Kroupin, G.I. Karlov, M.G. Divashuk. Tracing the Element: The Molecular Bases of Molybdenum Homeostasis in Legumes. Agronomy2023, 13 (9), 2300.
34. E. Mackiewicz-Walec, M. Olszewska. Biostimulants in the production of forage grasses and turfgrasses. Agriculture2023, 13 (9), 1796.
35. J. Kaur, D.S. Bhatti, M. Goyal. Influence of copper application on forage yield and quality of oats fodder in copper deficient soils. Indian Journal of Animal Nutrition2015, 32 (3), 290–294.
36. A. Nandety, A.M. Missaoui. Micronutrients: advances in understanding molybdenum in crop production. Achieving sustainable crop nutrition2020, 455–480.
37. I.P. Acharya. Three overlooked issues: Water quality, forage quality, and forage blends impacting the feed efficiency of dairy cows; South Dakota State University, 2016.
38. M.A. Ahanger, N. Morad-Talab, E.F. Abd-Allah, P. Ahmad, R. Hajiboland. Plant growth under drought stress: Significance of mineral nutrients. Water stress and crop plants: a sustainable approach2016, 2, 649–668.
39. S.S. Dhaliwal, V. Sharma, A.K. Shukla. Impact of micronutrients in mitigation of abiotic stresses in soils and plants—A progressive step toward crop security and nutritional quality. Advances in Agronomy2022, 173, 1–78.
40. Hua T, Zhang R, Sun H, Liu C. Alleviation of boron toxicity in plants: Mechanisms and approaches. Critical Reviews in Environmental Science and Technology 2021, 51(24), 2975-3015.
41. N. Jelali, N. Boukari, W. Dhifi, A. Hichem, C. Abdelly. Effect of iron supply on the growth, nutritional status and antioxidant activity of a forage legume Sulla carnosa. 2017.
42. Rajput VD, Harish, Singh RK, Verma KK, Sharma L, Quiroz-Figueroa FR, et al. Recent developments in enzymatic antioxidant defence mechanism in plants with special reference to abiotic stress. Biology 2021, 10(4), 267.
43. D.K. Tripathi, S. Singh, S. Singh, et al. Micronutrients and their diverse role in agricultural crops: advances and future prospective. ActaPhysiol Plant2015, 37, 1–14.
44. L.R. dos Santos, L. de S. Paula, Y.C. Pereira, et al. Brassinosteroids-mediated amelioration of iron deficiency in soybean plants: beneficial effects on the nutritional status, photosynthetic pigments and chlorophyll fluorescence. J Plant Growth Regul2021, 40, 1803–1823.
45. Nawaz F, Shehzad MA, Majeed S, Ahmad KS, Aqib M, Usmani MM, et al. Role of mineral nutrition in improving drought and salinity tolerance in field crops. Agronomic Crops, Stress Responses and Tolerance, 2020, 3, 129-47.
46. M. Zaib, M. Hussain, S. Mumtaz, et al. Micronutrients and Their significance in Agriculture: A Mini Review with Future Prospects. Int. Res. J. Edu. Tech2023, 5 (4), 234–252.
47. N.-H. Ghori, T. Ghori, M.Q. Hayat, et al. Heavy metal stress and responses in plants. International journal of environmental science and technology2019, 16, 1807–1828.
48. R. Kumar, M. Singh, B.S. Meena, et al. Zinc management effects on quality and nutrient yield of fodder maize (Zea mays). Indian Journal of Agricultural Sciences2017, 87 (8), 1013–1017.

49. U. Zulfiqar, S. Hussain, M. Ishfaq, et al. Foliar manganese supply enhances crop productivity, net benefits, and grain manganese accumulation in direct-seeded and puddled transplanted rice. J Plant Growth Regul2021, 40 (4), 1539–1556.

50. A. Suganya, A. Saravanan, N. Manivannan. Role of zinc nutrition for increasing zinc availability, uptake, yield, and quality of maize (Zea mays L.) grains: An overview. Commun. Soil Sci. Plant Anal2020, 51 (15), 2001–2021.

51. J.C. Soares, C.S. Santos, S.M.P. Carvalho, M.M. Pintado, M.W. Vasconcelos. Preserving the nutritional quality of crop plants under a changing climate: importance and strategies. Plant Soil2019, 443, 1–26.

52. S. Saleem, N.U. Mushtaq, A. Rasool, et al. Plant nutrition and soil fertility: physiological and molecular avenues for crop improvement. In Sustainable plant nutrition; Elsevier, 2023; pp 23–49.

53. S.S. Dhaliwal, V. Sharma, A.K. Shukla, et al. Biofortification—A frontier novel approach to enrich micronutrients in field crops to encounter the nutritional security. Molecules2022, 27 (4), 1340.

54. G. Monika, S.R.M. Kim, P.S. Kumar, et al. Biofortification: A long-term solution to improve global health-a review. Chemosphere2023, 314, 137713.

55. Garg M, Sharma N, Sharma S, Kapoor P, Kumar A, Chunduri V, et al. Biofortified crops generated by breeding, agronomy, and transgenic approaches are improving lives of millions of people around the world. Frontiers in Nutrition 2018, 5, 301899.

56. P.J. White, M.R. Broadley. Biofortification of crops with seven mineral elements often lacking in human diets–iron, zinc, copper, calcium, magnesium, selenium and iodine. New Phytologist2009, 182 (1), 49–84.

57. D. Tulu, S. Gadissa, F. Hundessa, E. Kebede. Contribution of climate-smart forage and fodder production for sustainable livestock production and environment: lessons and challenges from Ethiopia. Advances in Agriculture2023, 2023.

58. Timsina J. Can organic sources of nutrients increase crop yields to meet global food demand?. Agronomy 2018, 8(10), 214.