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Role of Macronutrients and Micronutrients in the Growth and Development of Plants and Prevention of Deleterious Plant Diseases – A Comprehensive Review

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Abstract

Food and nutrients are the essential components for proper growth and development of plants just like all other living organisms. Plants require sixteen essential nutrient elements including oxygen, hydrogen and carbon potentially derived from hydrosphere, lithosphere and atmosphere while remaining thirteen are chlorine, molybdenum, boron, copper, manganese, zinc, iron, sulphur, magnesium, calcium, potassium, phosphorous and nitrogen that are supplied either through soil organic matter and soil minerals or by inorganic and organic fertillizers. Water, heat and light are three essential components that are required in sufficient quantities for proper utilization of macronutrients and micronutrients by plants. Insects, disease control and cultural practices plays important role in good quality crop production. Each plant type is unique and known to have optimum nutrient range along with minimum requirement level below which plants show significant nutrient deficiency symptoms. However, excessive uptake of nutrients can lead towards poor growth rate and high level of toxicity. That is why, appropriate quantities of essential plant nutrients are extremely important. Numerous plant tissue and soil quality tests have recently been developed in order to assess the nutrient contents of plants and soil. Through proper analysis of provided information, plant scientists can determine the need of nutrients for a particular plant in specific soil. In addition to levels of available plant nutrients of soil, pH plays essential role in determination of elemental toxicity and nutrient availability. Fertillizers are known chemical constituents including mixture of nitrates and manure that significantly improves plant growth. Nevertheless, in accordance with holistic farm management approach, aims of organic farming are to create socially beneficial, environmentally benign and economically sustainable system for efficient food production and management.

Key words: Macronutrients, Micronutrients, Bacterial, Viral and Fungal Diseases, Deficiencies and Toxicities, Organic Farming

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1. Introduction

Escalating food demand by a growing and increasingly affluent global population is placing unprecedented pressure on the limited land and water resources of planet, underpinning concerns over global food security and its sensitivity to shocks arising from environmental fluctuations, trade policies and market volatility [1]. Number of undernourished people of the world is continuously increasing since 2014 and reached to an estimated eight hundred fifteen million people till 2016 [2]. In addition to increase in global population that suffers from severe hunger, number of undernourished people has also increased to eight hundred fifteen million up from seven hundred seventy seven million in 2015 [3]. Over past ten years, number of violent conflicts has significantly been increased all across the globe, more specifically in countries already facing food insecurities thereby hitting the rural communities along with negative impacts on availability and production of food. This situation has deteriorated the peaceful settings more specifically those affected by economic slowdowns. Several countries of the world heavily rely on commodity exports which experienced dramatic reduction in exportation and fiscal revenue in recent few years. Therefore availability of food has been affected by decreased import capacity nevertheless food access has deteriorated in part because of reduced fiscal potential in order to protect poor households against rapidly increasing prices of food commodities [4].

In past few years, importance of sustainable agriculture became an important agricultural issue as it deals with utilization and management of agricultural ecosystem in such a way that potentially maintains its regeneration capacity, productivity, vitality, biological diversity and functional ability in order to fulfill social, economic and ecological demands at regional, national and international level without harming other ecosystems [5]. Agricultural sustainability has faced some of the most significant and major challenges of history in recent few years such as (i) globalization (ii) global climate change (iii) over dependence on non-renewable energy resources (iv) increased monetary (v) environmental impacts (vi) rapidly increasing human population and (vii) increased demand for land and resources. Such types of dominant issues are challenging agriculturists to establish rather more sustainable systems of management like no other time in history. In order to meet nutritional needs and food demands for rapidly growing population, agricultural practices need to move forward beyond the past with special emphasis on improved productivity in order to encompass sound environment, social well-being and improved public health. It is also very important to explore alternative measures in order to control deleterious plant diseases which are otherwise harmless to entire environment and known to increase quality of product and per capita yield [6].

Macronutrients and micronutrients prove to be an essential component for proper growth and development of plants as they play significant role in controlling and management of diseases. All essential plant nutrients can significantly affect the severity of diseases. Nevertheless, there is no specific rule, as specific nutrient can reduce the severity of disease but can also enhance the severity of disease incidence of various other diseases or have opposite effects in altered environment. Inspite of all these facts, nutrient's importance in controlling diseases has recently been recognized for few most severe diseases but accurate nutrient management to control diseases in sustainable agricultural practices has unfortunately received little attention. Nutrients are known to affect the tolerance and full resistance against various diseases. Disease resistance of host is its ability to limit the potential penetration, rapid development and appropriate reproduction of invading pathogens. Contrary to that, host's tolerance is its ability to maintain its own yield or growth in spite of mere infections. Extent of resistance depends on types of genes of living organisms, changing environmental conditions and age of plant. Although tolerance and resistance of plant diseases are controlled genetically yet are significantly affected by climatic changes, nutrient deficiencies and toxicities. Many physiological activities of essential plant nutrients are well-understood, but still there are various unanswered questions regarding to dynamic interactions in between nutrients and plant pathogen system [5].

Macronutrients of plants are known to play essential role in proper development and growth of plants as their major functions range from being structural units to redox sensitive agents. Nitrogen helps to enhance seed and fruit production along with better leaf development, high quality forage crops and hasty plant growth whereas phosphorous is known to be an essential constituent of plant's cell membrane where it exist as phosphate and play important role for being a constituent of adenosine triphosphate, ribonucleic acid and deoxyribose nucleic acid. The potassium is extremely mobile and essential macronutrient of plant which is abundantly found in all younger parts of plants. Similarly, calcium is another essential element of living organisms that is specifically required as calcium ion which participates and helps in number of cellular processes. Calcium is an important constituent for growth and development of plants that also involves in enzyme activation including salt balance and water movements in cells of plants thereby activating potassium in order to control opening and closing of small pores called stomata. Similar to that, magnesium is central metal atom of chlorophyll that plays significant role in photosynthesis of plants whose deficiency leads towards degradation of chlorophyll and yellowing of leaves that is also called chlorosis nevertheless adequate magnesium availability keeps plant healthier. Sulphur is the most beneficial plant element for almost all living organisms as it is known to perform number of dynamic roles essential for proper development, growth and survival of plant life. That is why, for maximum production sulphur is regarded as essential nutrient for all crops [7].

Some essential components that are required in small quantities by plants are called micronutrients. Quality and yield of agricultural products increases with increase in concentration of micronutrients thus animal health and human life is protected with feed of enrichment plant materials. All essential plant elements specifically perform their nutritional role in a balanced ratio, necessary for proper growth and development of various species. Divalent ions of manganese are converted into trivalent and tetravalent ions thereby playing significant role in number of oxidation reduction processes such as electron transport chain in photosynthesis. Furthermore, manganese acts as potential activator of several enzymes that are involved in citric acid cycle, phosphorous reactions, carbohydrates metabolism, carboxylation processes and oxidation reactions. Superoxide dismutase and protein manganese enzyme of photosystem-II are two important enzymes among which >90% superoxide dismutase is found in chloroplasts constituting 5% of whole mitochondrial mass. Soil takes the zinc from soil solution in form of divalent cation more specifically in case of calcareous soil having higher pH values. Inside the xylem, zinc is either bonded with organic acid or transmitted to divalent cations via chemical modifications while in phloem sap, zinc forms organic complex having low molecular weight and relatively higher concentrations. Iron is the fourth abundant soil element on earth that is not readily available for microorganisms and plants because of lower mineral solubility, especially in arid regions having alkaline soil conditions [8].

It is extremely important to maintain nutrient availability via fertilizers or by changing soil environment that significantly influences nutrient availability along with control on deleterious plant diseases in an integrated pest management system as nutrient based plant diseases appears to be lethal for commercial scale crop production [5]. Majority of growers utilizes relatively higher concentrations of chemical constituents in order to control diseases of plants irrespective of the fact that mineral nutrition itself have important role in disease control system of plants. In addition to economic consequences, utilization of pesticides tremendously increases food safety and environmental concerns [9]. Deficiency symptoms of nitrogen include stunted growth, reduced cell division, chlorosis, lower protein contents and poor yield. Low availability of potassium causes leaf edge chlorosis, leaf margin scorching, reduced photosynthesis and growth, lodging in stem and poor seed quality. Insufficient availability of phosphorous generally results in improper cell division, stunted growth, and blue green coloration of older leaves, delayed maturity and poor fruit development. Lack of calcium in plants generally results in death of younger brown roots and leaves, limited growth, weakening of stem structure, crinkled leaves and premature blossoms and buds in some plant species. Deficiency symptoms of magnesium include the interveinal chlorosis of older leaves and excessive premature leaf dropping in short interval of time [10].

The limited availability of sulphur usually results in light coloration of veins, delayed maturity and retarded growth whereas deficiency symptoms of boron includes curly thickened leaves, stunted growth, cracked stems, lumpy fruits, splitted calyx and fractured midribs with pith in hollow stem. Poor availability of cupper generally results in apical meristem necrosis, distortion in younger leaves, reduced growth, sprouting on growing points, bleaching of younger leaves and dieback and defoliation of twigs. Shortage of chlorine causes wilting of plants and young leave chlorosis whereas deficiency of iron includes interveinal chlorosis and whitening of younger leaves. Lack of manganese in soil causes chlorosis in younger leaves, greenish grey specks on leaf base and cotyladenous necrosis. Similarly, deficiency symptoms of manganese is mainly responsible for chlorosis of older leaves, inward rolling of leaf margins, marginal leave’s discoloration, stunted growth and restricted flower formation more specifically in all nitrogen fixing leguminous plants. Limited availability of zinc is responsible for band formation at leaf base, discoloration of younger leaves, irregular interveinal chlorosis, reduced fruit formation and stunted growth [10].

Severe economically damaging diseases of plants are caused by pathogenic bacteria that possesses enough potential to cause leaf spots, fruit pustules, mosaic pattern and smelly tuber rot that eventually leads towards death of entire plant. They greatly affects numerous agricultural crops more specifically cucumber, cabbage, potatoes, tomatoes, tobacco and cotton. Plant disease can be systematic causing death of individual part or entire plant thereby affecting roots and entire vascular system [11]. Viruses are infectious microscopic particles that multiply inside the living cells of host. Although viruses are seldom lethal to plant cells but severely affects host in longevity, quality and quantity. Similarly, an advanced array of symptoms can be recognized as expressions of viral plant diseases. Some of these would include abnormal leaf shape, spotting leaf pattern, leaf mottling, abnormal leaf vein pattern and altered leaf colour. Nevertheless, some abnormalities are found in colour, shape and size of fruit and floral colour [12]. Fungi consist of large number of plant pathogens mainly responsible for number of deleterious plant diseases as most of the vegetables are rotted by fungal attack. Fungi damage the plants by damaging the cells thereby causing severe plant stress. Fungal infections are caused by infected weeds, damaged crops, plant debris, contaminated soil and diseased seeds. Fungal spores spread though water splashes and fast moving winds due to movements of plant materials, seedlings, tools, machinery, workers, animals and contaminated soil. They enter the plant body via natural opening called stomata and possess enough potential to make entry via cuts and wounds caused by mechanical damages, diseases, hailing, harvesting and pruning [13].

Fertilizer is any chemical compound that is used to add number of nutritional elements to soil in order to enhance plant growth and promote soil fertility. However, the biggest issue faced while using chemical fertillizers is contamination of groundwater. Nitrogenous fertillizers are chemically converted into nitrates that can travel rather easily through entire soil surface. Nevertheless, accumulative effects of nitrogenous fertillizers are evident to retain for several decades because of more water solubility and relatively higher affinities. Few recent investigations have showed that such types of chemical compounds potentially alter the functions of nervous system, endocrine system and immune system in mice and strongly influence the development of all these systems in developing fetus. Urea is the most popular and historic fertilizer that tends to produce ammonia emanation thereby contributing in ozone layer depletion, groundwater contamination and acid rain because of excessive release of nitrous oxide via denitrification. Contamination of groundwater is known to have direct linkage with stomach cancer, testicular carcinoma, goitre, birth malfunctioning, hypertension and gastric cancer. Excessive nitrogen in water and air because of nitrogenous fertillizers are responsible for cardiac diseases, respiratory illnesses, severe carcinoma, restricted crop growth and plant yield along with increased allergic reactions and numerous vector borne diseases like cholera, malaria and West Nile viruses. But scariest effect of chemical fertilizer is methemoglobinemia and blue baby syndrome [14].

Fertillizers derived from organic compounds such as crop residue, compost materials, decayed vegetable matter, human excreta, animal manure and animal matter play essential role in organic agriculture and known to has long term history of being contentious and is considered by number of inefficient approaches for food production. However, brewages and organic food have rapidly growing market segments in entire global food industry. Some recent experimental investigations revealed that performance of organic fertillizers has generally been evaluated in light of four sustainable key metrics such as social wellbeing, economic viability, environmental impacts and most importantly high productivity. Results of entire study showed that organic system of farming gives lower yields in comparison with conventional agriculture methodologies. Nevertheless, organic farming proves to be environmental friendly approach providing more profitable business and delivering more nutritious food without using pesticidal residues as in case of conventional system of farming. Furthermore, initial evidences showed that organic system of agriculture delivers rather more social benefits and greater ecosystem services as compare to conventional farming practices. Although organic farming has an untapped role to play when it comes to the establishment of sustainable system of farming but still no single approach is known to safely feed the planet. In spite of that, blends of organic farming methodologies and innovative farming systems are more appealing approaches. Nevertheless, significant barriers still exist while adopting these systems therefore diverse policies are requires in order to facilitates their progressive development and practical implementations [15].

2. Types of Essential Plant Nutrients

Plant nutrition via essential minerals including macronutrients and micronutrients are the most significant factors for proper growth and development of various plant species. Plants essentially require thirteen minerals that are prerequisite for all types in varying concentrations. All such types of chemical constituents are known to have various purposes as nitrogen plays structural role for being a structural component of deoxyribose nucleic acid, ribonucleic acid, pyrimidine, purines, porphyrines and various other coenzymes. Nevertheless, activities of soil can be declined if consequent responses of nitrogen are quite high [16]. Potassium is the second most important plant mineral that play essential role in number of biological processes like plant moments, stomatal opening, water supply during cell elongation, protein synthesis, organization of enzymes and photosynthesis. Calcium is highly important plant nutrient which play very significant role in formation of cell membrane and cell wall along with development and maintenance of fruit quality [17]. Moreover, it potentially enhances the chances of opposition for number of viral and bacterial diseases [18]. Calcium ions taken from deeper soil layers are transported toward leaves in a considerable concentration but amount transported from leaves to fruit is almost negligible. Hence, plant require constant supply of calcium for proper canopy growth along with dynamic root and leaf expansion [19]. Phosphorous helps in enlargement of cell and proper cell division along with transference and storage of energy. It also promotes vital cellular processes of plants such as respiration and photosynthesis. It improves growth and early root formation in plant body and significantly improves grain, vegetable and fruit quality that is considered essential for appropriate seed formation [20]. According to an estimate, 85% soil sulphur is evident to found in soil organic matter.

Similarly, microbial mineralization of soil organic fraction is an important source of available plant sulphur for proper growth. Essential micronutrients of plants such as molybdenum, boron, chlorine, copper, manganese, zinc and iron are known to have several important structural and functional roles. Nutrition control in plants not only interrupts yield but also atmosphere and plant strength. According to some recent investigations, proper nourishment is a serious factor which permits crop to get their full yield potential. Mineral nutrients are very important for plant growth and development along with prevention of deleterious nutrient based diseases. Farmers and agriculturists must be aware of plant diet levels that give maximum yield with proper growth and development without any harm. However, most important factor is the assessment of particular nutrient's deficiency among all components as its absence can have destructive effects on development thereby preventing nutrient circulation and optimum uptake by plants. In addition to that, some extra elements in plants can prove to be toxic, potentially upsetting the accessibility of various other soil nutrients. Major goal of healthy crop production is to produce strong crops and vigorous plants. Climatology, ecology and crop management are major fields mainly concerned with plant health. Proper utilization of fertilizer is commonly practiced to attain required strength for viable crop manufacturing. Micronutrients and macronutrients of plants have long been accepted as being related with yield, quality and size of food crops and their potentials to prevent number of harmful diseases. However, increase in concentration of phosphorous and potassium or other microelements had negligible effects on distortion. Interactions among disease causing pathogens, plants and nutrients are extremely complex thus not understood completely yet.

3. Deleterious Plant Diseases

Some features are significant to apprehend that how diseases within the plant host to check the effect that nutrients have on plant diseases. Several plant diseases are consequence of relationships among three major known constituents (a) host plant relationship which provides resistance to pathogens (b) pathogens that possesses enough potential to induce diseases in number of plant species and (c) ratio to biotic and abiotic environment among which biotic components are microbial adversaries and abiotic components are temperature and mineral nutrients.

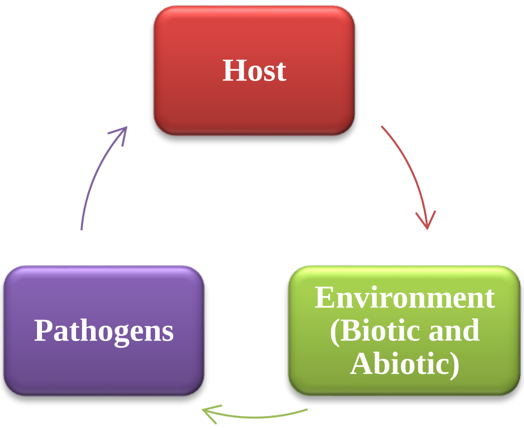

Fig.1 Relationship between host, pathogens and environment

Similarly, nutritional requirements for crops and pathogens are quite different while two major goals of nutrient uses include (a) reduction in plant stress to enable crops to develop defensive power against pathogens in order to ensure the survival of various plant species against pathogenic attacks and (b) improvement in vascular system of plants to effectively transport nutrients and water molecules to fight against diseases and to fulfill nutrient requirements.

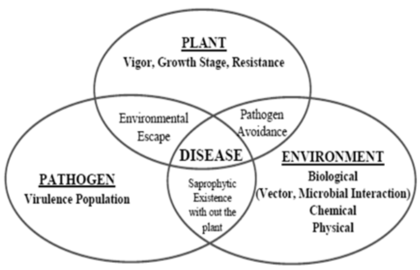

Fig.2 The disease triangle

Diseases of plants are caused by numerous factors that are broadly classified into three major types. Majority of the plant infections are initiated and triggered by viral, bacterial and fungal attacks. The word infection is typically used for intensive injuries in living vegetation. Similarly, decaying of acquired crops and accomplishment of dry rot are same as rots of developing plants; both of these diseases are triggered by fungal and bacterial diseases. Any element which enhances growth and development of disease transmitters or that proves to be harmful for development of plants will lead to rise in extent of damage and probability of infections caused by harmful parasites. Parasitic plant diseases are increased by excessive distribution of viruses and bacteria itself or by spread of reproductive structures of fungi such as fungal spores. Human activities, animals, insects, rain and wind are some important means for the propagation of reproductive parts and spread of pathogenic diseases.

3.1 Bacterial Diseases

Diseases caused by bacteria in plants can broadly be divided into three major types (a) vascular diseases (b) soft rot diseases and (c) leaf spot diseases. Resistance of plants towards range of bacteria in leaves is systematically connected to internal structure and strength of interior cells and intracellular spaces as well as the ability of plants to create and carry potential antimicrobial compounds. Such kinds of disease fighting mechanisms are closely related to certain nutrient elements. Bacterial assortment in host cell is usually done by enzymes manufactured by bacteria which significantly affect the breakdown of proteins. However, production and accomplishment of several pectolytic enzymes is generally repressed by various elements. Furthermore, plant type facing relatively low concentration of these elements needed to build appropriate cell wall along with various other organizational tissues which will be exposed to superior harm from these pathogens. Large numbers of the bacterial diseases are diminished by specially designed xylem vessels that are meant to transport water molecules and other nutrient elements from roots towards leaves. Their consequent incidences hint the production of slime inside the systematized tubes, eventually blocking them and finally leading towards drooping and death of stems and leaves. Certain types of plant nutrients are known to play essential role in spoiling and decreasing the aptitude of bacteria in order to make this slime [22].

3.2 Fungal Diseases

Fungal diseases and infections are caused when spores of fungi develop on the outer surface of plants. When specific fungal spores sprout either between cells or by passing through cells, fungi pierce into the surface of epidermal cells where plants activate their physical resistance as first line of defence through the power of cell wall and intercellular spaces. Essential plant nutrients are known to play major role in spore germination which is also encouraged by various chemical compounds exuded by plants. Several plant nutrients effect the concentration and arrangement of these exudates. Plants generally contain high concentration of amino acids and sugars that promote the establishment of fungal cells even when plants have low level of certain nutrient elements. Natural defensive system of the plants is triggered by initial fungal attack therefore shortage of fundamental plant nutrients reduces the amount of natural antifungal complexes in plants at the site of infection. Conversely, it has been experienced that loss of equilibrium in concentration of nitrogen with respect to other plant nutrients results in fungal diseases due to lack of production of antifungal compounds. As bacteria and fungi attack the tissues of plants, certain enzymes are discharged which potentially dissolve plant tissues. However, activity of these enzymes is restricted by calcium ions but as these enzymes are released by pathogens, potassium is lost by plant tissues which further reduce ability of plants to resist deleterious plant diseases. Similarly, formation of hydrogen peroxide and oxygen radicals is another type of plant response towards fungal infection. These elements and compounds can prove to be destructive for all plant cells and to all consequent pathogens [23].

3.3 Viral Diseases

Different types of viruses are found to live and reproduce inside the living cells by taking nutrition mainly from amino acid and nucleotide molecules. Generally it has been found that ideal nutrient conditions, appropriate for proper plant growth are also favorable for germination of viruses. In certain conditions, symptoms of viral infections can be lessened through improved nutritional components nevertheless it does not nullify the existence of viruses. However, some recent investigations have shown that percentage of infected plant species decreased from 75% in manganese-deficient-plants to 40% after correction of manganese deficiency. While this is a large decrease, there remained a significant infection in the field. Some sucking insects such as fungi and aphids are primary vectors that carry viruses to crops. However, certain plant nutrition can affect both the insects and fungi thereby affecting viruses that they may carry. Generally it has been found that nutrient status of plant affect the population of attacking aphids as evident in 1965 when huge amount of aphids attacked and settled on chlorotic yellow leaves deficient of nutrient. In such conditions, plant suffers from intensive nutrient stress and pathogenic attack. In certain watercress studies, it was reported that high concentration of zinc containing fertillizers improved the control of "crook rot fungus" that is also a vector for chlorotic leaf spot virus [24].

4. Nutrient and Disease Interactions

Essential plant nutrients have long been an essential component of remedies used to control the infectious plant diseases. Most of the soil types, suitable for plant development, also have tendency for extensive pathogenic growth. On the most important level, plants enduring a supplement dread will be not so much active but rather more defenseless to a variety of diseases. Thus, in this regard, all essential plant supplements significantly influence plant sickness; nevertheless, few complementary components are known to have rather immediate and quite pronounced effects on plant sickness in comparison with others. However, each supplement influences the reaction of plant towards disorderness; whether a biochemical reaction is negative, it is constrained for all plant-infection-complexes. Quite similar to that, nutrient-disease-interactions are also not unsurprising. All essential supplements of plants are known to influence the disease risk via plant metabolic changes, thereby creating a highly positive environment for improvement of infections. Time at which any pathogen contaminates plant, proper working of plants, fundamental mineral uptake, complete ingestion, thorough transportation and actual usage are all changed because pathogens can immobilize the supplements in mud or in tainted tissues that can otherwise interfere with usage and translocation of supplements thereby provoking toxicities and lack of supplements. But still, various pathogens might themselves use number of supplements, reducing their accessibility for plants and enhancing helplessness towards contamination.

Plant roots are generally contaminated with soil borne pathogens that significantly reduces plant's ability to uptake water and essential plant supplements. But subsequent insufficiencies may prompt auxiliary contaminations by various pathogens. Not just is the supply of an individual supplement is critical, additionally adjusted, crop particular supplement proportions are essential for enhancing plant safety by enough supplying plant amongst its advancement under shifting ecological conditions. Through a comprehension of sickness associations with every particular supplement, the impacts on plant, pathogen and environment can be adequately changed to enhance infection control, improve generation efficacy and build crop quality [25]. Nevertheless, assumptions have not to be made: a specific mineral supplement may be connected with an increment in seriousness of a certain malady in one product however with suppression of another disease in an alternate harvest or have no impact. Similarly, ecological anxiety generally does not stifle plant resistance. Every association is very particular for specific mineral supplement and specific plant along with particular pathogen.

Recently, it has been investigated that appropriate amount of nitrogen-potassium-phosphorous can lessen the chances of diseases in plants. However, majority of experimental investigations have shown that nutrient-disease relationship is always studied under controlled environmental conditions in nursery. Although these investigations were of great significance but handling conditions were not clear for different types of plants except in a couple of cases where results acquired on a huge scale under appropriate field conditions. Nevertheless, these methods can be considered as standard for devising an alternative route in order to reduce the infections of plants. Movements of pathogens, infectious entities, bearers or obligate vectors inside the living cell can be controlled prior to direct attack on foreign particle or pathogenic organism. Various supplements and mineral components can have critical effects on different parts of disease cycle. However, it may appear to be well-furnished to claim that mineral components can influence the nature. Nonetheless, manure and lime influence the environment of dirt. Supplements also affect the capacity of plants to withstand highly unfavorable climatic conditions. The relation between disease and mineral nourishment is generally discussed in accordance with following considerations: (a) appropriate condition impacting the accessibility of specific nutrient supplement with disease (b) correlation of mineral neuroses in safe tissues in comparison with immobilized tissues and (c) impacts of preparation on seriousness or specific disorder frequency.

Such types of perceptions can be found appropriate for only particular disorders and specific supplements connecting via ecological conditions, plant phase of development and biological movements all of which are known to have pronounced effects on end result. Consequent impacts of various supplements on plant's disorderness have been observed by chance as a result of preparing to advance plant development and afterward affirming observation under controlled conditions in field or nursery. Excessive utilization of manure based on inorganic minerals allows an immediate perception of supplement's belongings that could be summed up when harvest revolution and natural manuring was examined, nevertheless ought not to prohibit thought of the part of soil creates simultaneously. A standard suggestion to keep up ideal N preparation to reduce take-all of grains gets from ahead of schedule perceptions that N lack inclined plants to take-all. It is currently realized that a deficiency of most key supplements will expand seriousness of this sickness.

Constant area fertilizer high in zinc from creature apportions that is connected before planting winter wheat enormously decreases the seriousness of spring curse brought on by *Rhizoctonia cerealis* like giving zinc. Lack of cupper causes infertility in males in gramineous harvests while wheat deficient of cupper is inclined to ergot as the florets open to ensure cross-fertilization. Therefore, adequate amount of cupper in wheat significantly reduces ergot momentum and enhances wheat yield. Resistance of flax and wheat to rust and maize to Stewart's shrivel can be lost under potassium lacking environmental conditions. Similarly, connection of nutritive tissue in infected contrasted and solid, or helpless contrasted and safe plants has given adequate information regarding to supplement-ailment-corporation and large number of special cases are accounted for majority of key supplements. However, relatively high concentration of calcium in tissues is correlated with imperviousness towards *Sclerotinia minor*, *Rhizoctonia solani*, *Pythium myriotylum*, *Fusarium solani* and macerating sickness. Nonetheless, impacts of specific yield turns and arrangements of crops on nitrification were quite steady with impacts of type of nitrogen on specific disease. Various conventional infection control practices collectively work through their impacts on accessibility of mineral supplement. Biochemical transformation of insoluble oxides of Mn^{+3} and Mn^{+4} into soluble Mn^{+2} is exceedingly subjected to ecological elements so that various components including plant to malady do as such through their impacts on manganese accessibility [26].

5. Mechanism of Disease Control in Plants

Number of plant diseases can be avoided by adjusting the associations in between pathogens, plants and their surrounding environment. However, some serious concerns include (i) reproductive assimilations with several other crop production practices (ii) balanced diet and related ions (iii) technique, time and frequency of treatment of nutrient (iv) natural power and predominant form of nutrient that is available or soiled and (v) quantity of innate plant opposition and nutrient accessibility in comparison with plant requirements. Similarly, cultivars that are resilient or acceptable to various plant diseases are generally more reactive towards nutrient utilization as compare to highly vulnerable cultivars whereas the cultivars that are immune to specific infections can be extremely effective in nutrient acceptance. Wheat is quite inefficient in utilization of micronutrients as compare to rye and known to be highly vulnerable to take all. Hybrids of maize impervious to *Gibberella* and *Diplodia* stalk rots are found effective in uptake of nitrogen [27]. It has been experimentally proven that harshness of stalk rot of corn and tan spot of wheat significantly reduces as the level of available nitrogen increases from deficiency to physical abundance. However, excessive nitrogen can decrease the resistance towards stalk rot as pathogenic activity is enhanced or physiological sufficiency of other plant nutrients is imbalanced [28].

Several efforts have subsequently been made to use mineral nutrition as an implement for disease control. Any externally introduced system in plants such as mineral nutrition or pesticides can have positive or negative effects on all components resulting in increase, decrease or no effects on disease severity and disease incidence. Nevertheless, in number of cases these have resulted in failure, seemingly because the approaches of applications have been inadequate and knowledge about nature of interactions among plant disease and mineral nutrient is quite inadequate.

Therefore, it is dire need of the hour to find ways in which to use mineral nutrition to successfully carry a decrease in occurrence of disease without even disturbing the production and quality of food crop. This is possible now-a-days because of availability of better and rather more refined tools for precise application of fertilizer along with proper checking in soilless cultures. The disease resistance in plants is mainly attributed to heritable properties however plant's ability to show natural genetic potential to resist number of diseases can potentially be infected by mineral nutrition. Plant species that are known to have high genetic resistance towards deleterious plant diseases, are likely to be least affected by minor variations in nutrition as compare to plants completely tolerant of diseases. Likewise, various plant species those are genetically vulnerable will likely persist vulnerable with nutritional system which significantly improves disease-resistance in tolerant or less-susceptible plants. Incidence of severe diseases is greatly reduced either by increasing the number of antagonistic members of soil's micro-flora or through direct toxic effects of pathogens via significant reductions in susceptibility of host. Some recent investigations have revealed that nitrogen amendments such as bone meal and meat possesses enough potential to kill sclerotia of soil borne plant pathogens like *Verticillium dahliae* by production of nitrous acid and ammonia that depends on soil pH [29].

Crop fertilization and disease control remedies pose high environmental cost and monetary to present day agricultural practices. According to an estimate, US farmers approximately spend 20 billion USD on pesticides and fertilizers annually but this only represents 80% of actual cost including additional cost caused by damage to human health, ecosystem biodiversity and natural water resource [30]. Number of active and passive approaches for control of infections is being activated over nutrient administration. Similarly plant food absorption action is directly related to plant resistance and pathogenic virulence controlled by nutrients. Acceptable level of nourishment is mandatory to keep high level of resistance against plant diseases. *Fusarium solani*, *Sclerotinia minor* and *Cylindrocladum crotalariae* are known to increase structural consistency and power to components of cell wall, middle lamella and cell membrane to extracellular enzymes produced by pathogens [31]. Nitrogen sources overwhelm the construction of these enzymes while ammonium ions may increase them [27]. Nutrient abundance could bring a broad form of disease resistance by sustaining a high level of inhibitory composites in plant tissues or rather quick response to the invasion of harmful pathogens.

Fast cicatrization near the site of infection or scratch that potentially reduces harmful effects of attacking pathogen, needs excess of manganese and various other micronutrients [27]. Changes in uptake of different nutrients like nitrogen can deny an obligate pathogen of essential intermediate compounds necessarily needed for survival, pathogenesis and reproduction. Cannibalization of structural and physiological proteins that are essentially required for resistance, can be minimized through adequate availability of nitrogen during entire grain fill period that plant will otherwise use to meet the needs of developing kernels [32]. Sufficient availability of nutrients can also reduce susceptible stage of growth for some plant-pathogen-interactions. The end result of fertilization is enhanced plant growth that is indirectly a form of successful disease escape. Nitrogen and phosphorous stimulates the root growth of cereal grains so that nitrogen and phosphorous abundant plants become able to compensate the lost tissues via root rots like *Pythium* and take-all. Some specific plant nutrients like sulphur and nitrogen can change the biotic and abiotic environment of soil to favor biological control, specific nutrient uptake or to increase genetic resistance.

6. Role of Macronutrients

There is large number of naturally existing elements among which sixteen are considered essential for full growth and proper development of food crops. Some chemical elements like sulphur, magnesium, nitrogen, calcium, potassium, phosphorous, oxygen, hydrogen and carbon are used in comparatively large amounts thus called major or macro-nutrients of plants [33].

6.1 Nitrogen

Nitrogen is known to be the element of 15^{th} group in periodic table belonging to p-block. It was first time identified by Daniel Rutherford in 1772 and named by Jean-Antoine Chaptal in 1790 [34].

6.1.1 Role of Nitrogen

Nitrogen is famous to have its role in structural development and physiological functions in plants as it is a major chemical element in protein that is essentially required for plant's ample growth. Therefore, nitrogen is highly valuable plant nutrient and added to soil in form of nitrogenous fertillizers for manufacturing of diverse components of living cells [35]. Two formulas of nitrogen captivated by plants are adapted in different ways and can have severe effects on diseases. Adaptation and uptake of nitrates leads to intensification in pH at the soil-root-interface while ammonium ions in rhizosphere tend to create acidified environment. Basic difference in nitrogen containing groups can have pronounced effects on activity of root-borne-diseases that can be highly sensitive to pH. However, one of the universally accepted relationships in between plant nitrogen and infection is that high concentration of nitrogen results in deleterious plant diseases. In actual practice, nitrogen as nutrition might cause higher levels in comparison with surrounding thereby destroying the infectious entities. Sufficient uptake of nitrogen is essential to materialize various enzymes, proteins and structural components required for proper growth and fight against diseases. But in some cases, even dynamically growing plants can outgrow the most destructive effect of diseases. Conversely, it has been perceived that nitrogen contents in some plants when increases than sufficient level, results in decrease in amount of some important antifungal compounds [36].

6.1.2 Deficiency of Nitrogen

Potato crop deficient of phosphorous or nitrogen is found highly susceptible to *Alternaria solani*, a disease of early blight. Nevertheless, over-fertilization causes excessive but weaker vegetative growth that can enhance the incidence of diseases. Nitrogen fertilizer can decrease the chances of attack of *Gaeumannomyces graminis* in wheat and barley. However, it has generally been accepted that addition of nitrogen enhances susceptibility of individual roots towards infection but excessive nitrogen produces crown roots faster than fungal destruction [35].

6.1.3 Toxicity of Nitrogen

Majority of conflicts in recent scientific researches regarding to effects of nitrogen on plant diseases usually results from failure of recognition of varied effects of different forms of nitrogen [35]. Consequent effects of some nutrients and their rate of application on incidence of plant diseases are well-documented [37]. Generally it is known that sufficient amount of ammonia can only be produced in existence of ammonium ion at pH greater than 8 while nitrous acid and nitrites are usually generated in presence of ammonium ions at the soil pH less than 6. Hence, it can be concluded that infections due to excessive ammonium ions can be decreased by acidifying irrigation water owing to specific pH of solution as a dominant factor in reducing the chances of diseases. More specifically, significant difference in attack of deleterious diseases and uptake of manganese from soil was observed in some plants even with slight variations in pH when they were supplied with nitrate or ammonium ions. Increased concentration of ammonium ions in irrigation water tends to enhance this effect owing to further decrease in pH of substrate. When the pH of leachate exceeds 8, prevalence of disease deteriorates considerably and this influence further increases as the application of nitrate increases. When concentration of nitrates increases, ratio between hydroxyl ion contents of rhizosphere and substrate volume increases; that is why leachates having similar pH values are found to enhance the disease reduction. Nonetheless, this presumption would be considered more appropriate if pathogenic activity were more efficient in rhizosphere in comparison with bulk soil. But the fact is toxicities of nitrogen are quite tricky as at initial stages, plants grows well having thicker lush green leaves but after some time they turn out to be cracked and brittle leaves along with improper development of root system and failure to fruit development.

6.2 Phosphorous

Phosphorous is well-known element of period table belonging to p-block having physiochemical properties similar to non-metallic elements. It was first identified by Hennig Brand in 1669 while acknowledged as element in 1777 by Antoine Lavoisier [7].

6.2.1 Role of Phosphorous

Phosphorous is an essential plant constituent that is gaining global attention as phosphorous fertilizer due to rapidly declining natural phosphorous reservoirs [38]. Accessibility of soil phosphorous for plants is directly related to various characteristics of plants including excessive release of carboxylates [39], pH of rhizosphere [40], number of functional charismas like superficial area and size of roots [41], mycorrhizae [42] and specialized organization of root clusters [43-44]. Some recent investigators have investigated that phosphorous is a highly valuable chemical constituent of plants that significantly influence the commencement and development of root clusters [44]. This chemical element hampers almost all natural processes along with vitality exchange components. Phosphorous is an essential component of major cell proteins and nucleotides that are mainly responsible for development of different plant structures. It is known to be a fundamental supplement of plants as phosphorous deficiency results in loss of several plant generations. Phosphorous plays structural role as being a major component of ribonucleic acid of plant cell and being needed for essential physiochemical processes of plants as protein digestion system, vitality exchange and different capacities [45]. Nevertheless, phosphorous decreases the development of rust and foliar maladies, and is found highly beneficial in reducing the excessive availability of nitrogen.

Contrary to that, excess of phosphorous in sugarcane has been connected with high seriousness of rust. Phosphorous with or without potassium enhances the resistance of wheat towards fine mold. Use of phosphorous in tomatoes expanded Fusarium at pH 6.0 yet oppressed it at pH 7.0 and 7.5.

6.2.2 Deficiency of Phosphorous

Implication of Rhizoctonia disease in soybean unlocked as an outcome of phosphorus deficiency in the dirt, accentuating the significance of adjusted and sufficient nourishment. However, in some cases, phosphorous lessened the rate of attack of certain bacterial maladies and nematodes. There are several different assumptions related to the associations in between plant sickness and phosphorous. It is highly intriguing to note that in certain cases, foliar usage of phosphate salts has been demonstrated to different sicknesses in beans, cucumber and other yielded plants. Similarly, phosphorous administration with other supplements proves to be highly beneficial for control of diseases and enhancement of crop efficiency. Nonetheless, availability of phosphorous must be satisfactory with reference to amount applied and technique adopted for application. These quantities must be balanced in accordance with soil requirements and edaphic conditions. Foliar splashes of phosphorous can provide neighborhood and systematic assurance against number of foliar pathogens like rust on maize and fine mold on pepper, wheat, apple, mango and grapes. Deficiency symptoms of phosphorous are not very difficult to recognize as phosphorous deficient plants have necrotic spots on leaves and are hindered or overshadowed. Lack of phosphorous usually results in incomplete or gradual plant growth along with irregularities and disorganizations in younger parts. In some cases like brassica, corn, lettuce and tomato, phosphorous deficiency causes purpling of stem, petioles and clears out. In case of extreme insufficiencies, there is additional propensity for leaves to add dark blue gloss. In more established leaves under exceptionally serious lack conditions a chestnut netted veining of the leaves may create [46].

6.2.3 Toxicity of Phosphorous

Excessive availability of phosphorous is usually uncommon and generally defended by pH limits. However extra phosphorous can potentially hamper the obtainability of zinc and copper.

6.3 Potassium

The potassium is regarded as one of the most valuable elements of periodic table that is essential for proper growth and development of plants. Corresponding products of potassium are alkaline in nature and its actual name is derived from Neo-Latin world 'kalium'. Potassium was first time introduced and isolated in 1807 by Humphry Davy [47].

6.3.1 Role of Potassium

Potassium is a basic cellular component of plants which involves in proper nourishment, development and growth. It is transported from more seasoned organs to newer ones and preferably stores in vacuole more than any other organ. It doesn’t deliver any complicated particles and purposes as enacted for coenzymes and proteins for about forty six chemicals. Recently, a test had been conducted by different scientists, which showed that potassium plays significant role in enhancement of number of umbellate, yield of seeds and rate of oil in growing plants [48]. Recently some researchers investigated that rate of crucial oil, yield of natural product and number of umbels respond differently to potassium and nitrogen composts and their communication impacts in *Bunium persicum* [49]. Potassium is known to be a fundamental supplement for proper vegetative growth and assumes several vital parts in nourishment of plants. The leaves of potassium deficient plants appear to be chlorotic and indicate exploitation at the edges with plant development and discouraged root advancements. It has usually been competed that potassium-insufficient plants can be preferably inclined to ailments [50] while excessive supply lessen the occurrence of foliar and soil borne diseases. Some more pronounced effects of potassium include diminished sicknesses as *Verticillium wither* is specifically clear in potassium lacking soils. Similarly, with many other supplements, fitting administration practices can enhance the potassium uptake by plants thereby expanding the crop creation and reducing frequency of ailments. Potassium has maximum ability to create tolerance in plants. Thus potassium can enhance the quality and quantity to satisfy current food requirements under reducing irrigation system [51].

6.3.2 Deficiency of Potassium

Deficiency of potassium inclines cotton to *Fusarium shrink*, whereas subsequent potassium treatment enhances plant growth and ensures proper development. Impacts of potassium on plant’s illness in corporation with other nutrient elements are known to have significant influences. Nevertheless, consequent impacts of illness on rice field appear to be low when potassium to nitrogen ratio is high in leaves while rate of infections are high when the potassium to nitrogen ratio is low. In some cases, expanded imperviousness to infection by potassium has been credited to different instruments like diminished defenselessness and diminished cell porousness leading towards maceration along with entrance by pathogens. In addition to this, mixture of potassium and phosphorous prompts the improvement of cell dividers and thicker fingernail skin that mechanically hinders diseases and attack of pathogen. However, suitable administration practices of potassium can significantly enhance the uptake of potassium thereby building crop creation along with diminished ailment frequency. Nevertheless, some leaves show minor corruption at tips while others are more propelled, lacking status and showing putrefaction in interveinal spaces in between fundamental veins alongside interveinal chlorosis. But these side effects are extremely normal for potassium lacking indicators [10].

6.3.3 Toxicity of Potassium

Generally it has been observed that excessive potassium is not absorbed by plants however additional supply may intensify the uptake of iron, zinc, manganese and magnesium from soil [52].

7. Role of Micronutrients

Few chemical elements such as chlorine, manganese, molybdenum, boron, zinc, copper and iron are needed by plants in relatively small quantities for proper vegetative growth and reproductive potentials thus termed as minor or micronutrients of plants [33].

7.1 Magnessium (Mg)

Magnessium is an indispensible chemical constituent of all living organisms abundantly found on earth and known to be the eighth most abundant element of earth's crust and ninth more abundant element of universe [53]. It was first introduced by Joseph Black in 1755 and first isolated by Humphry Davy in 1808. Magnessium is derived from Greek word "magnesia" and considered an essential element for plant growth and development.

7.1.1 Role of Magnessium

Accessibility, source and rate of magnesium is known to have significant influences on all environmental segments such as atmosphere, hydrosphere, lithosphere and biosphere as plant development, natural environment and ground forces are strongly affected by excessive availability or deficiency of magnesium. Magnessium is a vital plant mineral whose impacts on plant diseases have been studied through mineral alterations that resulted in severe infectious diseases and weaknesses [54]. In order to get thorough information about general plant supplements and their consequent impacts on plant growth, it is essential to obtain knowledge about metabolic frameworks that may react contrastingly to a specific supplement contingent about different particles present (Cl^-, NO_3^-, SO_4^{-2}) [55]. But availability of magnesium can shift contingent upon certain ecological conditions such as soil pH, previous yield, microbial movements, weed control and proportions with several other mineral supplements including manganese, potassium and calcium. Magnessium can be chemically bind as distinctive salts like (CO_3^{2-}, Cl^-, O^{2-}, NO_3^{2-}, SO_4^{2-} and so forth), anionic salt portion can have significant influences on dissolvability of magnesium and ailments due to variations in soil pH (CO_3^{2-}) along with physiological capacity of magnesium (Cl^-, NO_3^{2-}, $-S$ and SO_4^{2-}) in plants. Nevertheless, there are least documented connections in between amount of magnesium and plant sicknesses in comparison with different plant supplements in improving and minimizing the infections. Few recent investigations have showed that approximately 22 different types of infections are attributed to excessive magnesium supply among which 17 diseases were expanded and 6 were having variable contingent impacts upon earth [55]. However, these few distinctive connections were reflected in collaboration with or antagonism to different plant supplements where abnormal uptake of calcium and potassium hinders the uptake of magnesium as elevated concentration of magnesium represses uptake of calcium, manganese and potassium [55]. Plants grown in corrosive soil environment are known to have high tendency to be lacking of phosphorous, molybdenum, calcium and magnesium because of debilitated ingestion of all these particles. Under such conditions, plants become more helpless towards different types of diseases in low pH soil and some examples include bacterial delicate decay, club foundation of cabbage and *Fusarium* shrinks. Soil liming with dolomitic lime in order to expand the pH of soil, additionally build magnesium accessibility in order to lessen the sickness. In corn, diminished magnesium convergence stunted plant growth those were contaminated with spiroplasma [56].

7.1.2 Deficiency of Magnessium

Plant leaves deficient of magnesium suffer from severe vein chlorosis along with necrosis that emerge under extreme chlorotic conditions. Shortage of magnesium is quite similar to scarcity of potassium in progressive form. During inavailability of magnesium, symptom of disease starts from development of spotted areas inside the interveinal tissues. Furthermore, interveinal laminae tissues tends to enlarge the proportionality even greater than other leaf tissues thereby creating highly wrinkled surface with puckers top progressively going from chlorotic to necrotic tissues. In some plants of Brassica family such as turnip, rutabaga, rape, mustard, kohlrabi, kale, collards, cauliflower, cabbage, Brussels sprout and broccoli, purplish yellow and yellowish orange colour tends to develop.

7.1.3 Toxicity of Magnessium

Potassium deficiency occurs before the toxic level of magnesium in plants that tends to reduce the proper development and results in stunted growth.

7.2 Calcium (Ca)

Calcium is the fifth most abundant element of earth's crust among all available elements which is also regarded as fifth most ample liquefied ion of ocean [57]. Calcium was first discovered in 1808 by Humphry Davy and is placed in s-block of second group in modern period table [58].

7.2.1 Role of Calcium

Increase in the concentration of calcium in plants tends to empower the cell wall that is supposed to be the most precious part of living cell which yields high structural rigidity due to cross-linking of pectin polysaccharide matrix. With rapid plant growth in excessive availability of calcium, structural integrity of stem, mainly responsible for holding the fruits and flowers is maintained and quality of fruit is enhanced. Many bacteria and fungi potentially poison and invade the enzymes that can dissolve middle lamella. Enzymes that can dissolve middle lamella include pectolytic enzymes as pectate transeliminase and polyglacturonases. Increase in concentration of calcium in tissues astonishingly lowers the activity of petolytic enzymes and polyglacturonases from *Erwinia carotovora* that infects number of vegetable crops and responsible for rot in potato tubers. Increased concentration of calcium in tissues of beans ranging from 1.6 to 3.4% significantly reduces the chances of *Erwinia carotovora* infections. Some recent investigations revealed that plants containing 1.6% calcium contents can be destroyed within six days while plants having 3.4% calcium possesses no infection. Recently, it has been observed that sufficient calcium uptake in plants reduces the chances of fungal infections. Similarly, steady supply of calcium in plants delivered during fertigation through calcium nitrate significantly reduces the activity of *Fusarium oxysporum*, a fungal pathogen that is mainly responsible for crown rot and wilt in tomatoes. Recent researchers claimed that tomato plant receiving low level of calcium was severely infected by *Fusarium oxysporum* in comparison with plants receiving high level of calcium. Fertilization with calcium reduces the chances of root rot and Pythium in citrus and turf grass. Calcium enters the plant cell via calcium-permeable-ion-channel of plasma membrane [59]. However, extremely high concentration of calcium in plants prove to be toxic while a sub-micro-molar concentration of calcium is maintained in undisturbed cell through calcium-ATPases and proton-to-calcium-antiporters [60]. These enzymes remove the cytosolic calcium to either lumen or apoplast of intercellular organelles like endoplasmic reticulum or vacuole. Rapid calcium influx via cation channels in plasma membrane, endoplasmic reticulum or tonoplast generates perturbations of calcium which initiates the cellular responses towards diverse range of environmental challenges and developmental cues [61].

7.2.2 Deficiency of Calcium

Plant leaves having deficiency of calcium are known to exhibit leaf necrosis due to insufficient mobility of calcium ions that significantly influences the indicators of calcium deficiency in plants. Classical indication of the shortage of calcium include blackheart of celery, tip burn of lettuce and blossom-end-rot of tomatoes eventually leading towards death of plants in many plant species. All these symptoms indicate necrosis of soft tissues growing rapidly in areas characterized by poor translocation of calcium instead of low external supply of calcium. Slowly increasing plants having restricted supply of calcium can re-translocate sufficient amount of calcium from older leaves in order to maintain proper growth with merely marginal leaf chlorosis resulting in slow marginal leaf growth thereby causing leaves to cup downward. This symptom leads towards development at a point where petioles show progressive development but leaves do not, leaving behind dark necrotic tissues at the top of each petiole. Plants with chronic shortage of calcium tend to have greater potential of wilting as compare to non-stressed plants.

7.2.3 Toxicity of Calcium

Elevated concentrations of calcium in plants rarely detriment proper plant growth while excessive calcium carbonate in soil ultimately results in high level of soil pH.

7.3 Sulphur (S)

Sulphur is known to be a ninth richest element of earth's crust that is naturally found in soil as sulfate and sulfide minerals [62]. Sulphur is the p-block element of periodic table having atomic weight nearly equals to 32.06. It was discovered before 2000 BC in China and properly documented as an element by Antoine Lavoisier in 1777.

7.3.1 Role of Sulphur

Sulphur is the vital plant nutrient that helps in synthesis of proteins. It encourages the advancement and exploitation of vitamins and enzymes. Sulphur help in materialization of chlorophyll and improves seed construction and root growth. It promotes plant growth and provides opposition to cold. Rainwater is the basic source of sulphur in soil but can additionally be added through fertillizers. Excessive utilization of gypsum enhances sulphur in soil.

7.3.2 Deficiency of Sulphur

Sulphur deficiency in plant leaves generally causes chlorosis but still overall green colour retains. Petioles and strains display a highly distinctive reddish colour. Some graphical symptoms of deficiency of sulphur are quite similar to chlorosis as observed in deficiency of nitrogen. Nevertheless, deficiency of sulphur causes yellowing of plants in a uniform pattern including younger leaves. Undersides of leaves are known to have reddish colour while petioles are characterized by pink colour that is much less vivid than that found in deficiency of nitrogen. Shortage of sulphur in plants causes apparent necrotic spots and brown lesions developing along the leaves and petioles which tend to become more erect and found often brittle and twisted.

7.3.3 Toxicity of Sulphur

For practical considerations, toxicity of sulphur is supposed to be nonexistent. Nevertheless, excessive use of sulphur containing fertilizers often cause decrease in pH of soil and increase in problems that results from lower pH value. In fact, uptake of sulphur is found to decrease with lowering the pH of soil.

7.4 Iron (Fe)

Iron is an essential chemical constituent of plants that belong to transitions metals and known since ancient times. Nevertheless, its exact discovery date and name of discoverer is still unknown. Most of the space objects that tend to fall towards earth from upper atmospheric layers are small stones but even a small iron meteorite constitute about ninety percent of iron contents [63].

7.4.1 Role of Iron

Iron is an essential chemical element of plants that helps in formation of chlorophyll. Basic iron sources are rich soil containing iron chelates and iron sulfates [64].

7.4.2 Deficiency of Iron

Deficiency of iron in plants generally results strong chlorotic symptoms at the base of young leaves along with some green netting. Commonly observed symptoms of iron deficiency are interveinal chlorosis of young leaves that eventually evolves into overall chlorotic plant thereby ending at completely bleached leaves. These decolorized areas have much greater tendency to develop necrotic spots. Up till then affected plant leaves almost become white and can be recovered again upon application of iron. During iron recovery phase, plant veins are first to recover as indicated by their brighter green colour and this regreening is probably the most recognizable symptom among all classical plant nutrition studies. Due to lower mobility of iron, its deficiency symptoms first appear on younger plant leaves while its restricted availability is mainly associated with calcareous soil under anaerobic soil conditions and is often induced by the excess of heavy metals [64].

7.4.3 Toxicity of Iron

Toxicity of iron is directly related to soil pH because it occurs as pH drops thereby allowing massive intake of iron in different parts of plant. Excessive intake of iron occurs when zinc is deficient so its symptoms appear to mimic the deficiency symptoms of zinc. These symptoms include stunted growth and dark green leaves. Following table compile the diseases caused by deficiency of iron.

7.5 Cupper (Cu)

Copper is an essential micronutrient of plants that is required in a very small quantity. Throughout history and advancement in civilization, initial discovery, progressive development and consequent applications of metals has driven the ways that people live and societies have been organically shaped. Cupper is a naturally occuring, highly pure metal that was first discovered around 9000 BC and is found native to many countries of the world. The comprehensive knowledge about metallurgy has been found fundamental to the mankind.

7.5.1 Role of Cupper

Cupper is highly valuable micronutrient of plants that is essentially required for reproductive growth, proper development, complete root metabolism and utilization of essential proteins [65].

7.5.2 Deficiency of Cupper

Inavailability of copper in plant leaves generally results in curled leaf edges and bended petioles. Shortage of cupper can be expressed as overall light chlorosis along with permanent loss of turgor pressure in younger parts of plants. Recently, matured plant leaves tend to exhibit netted, green veining with areas bleaching to a whitish gray coloration. Some leaves develop sunken necrotic spots and has enough tendency to bend down. It has generally been observed that trees under chronic deficiency of cupper develop rosette form of growth and leaves appear to be small having chlorosis and spotty necrosis [10].

7.5.3 Toxicity of Cupper

Excessive availability of cupper causes reduced plant growth followed by the symptoms of stunting, iron chlorosis, reduced branching along with abnormal thickening and darkening of roots. Cupper is an important plant nutrient for proper growth and development but found to be extremely toxic in excess.

7.6 Chlorine (Cl)

Chlorine belongs to 17th group of periodic table, the members of which are commonly known as halogens that are not found as elements but as compounds only. It was first discovered by Carl Wilhelm Scheele in 1774, who mistakenly thought that chlorine constitutes oxygen with it. Chlorine was named so by Humphry Davy in 1810, who cleared that it was basically an element [66].

7.6.1 Role of Chlorine

Chlorine helps in digestion of food taken from deeper soil layers and is itself created inside the soil. It is found to be plentiful for the development of flora and is transportable in soil. It is simply taken by plants in large quantities. Nevertheless, in order to fulfill the physiological requirements of plants, this element is only required in concentration of few ppm thus rarely found deficient [67].

7.6.2 Deficiency of Chlorine

Chlorine deficient leaves are known to have improper plant development and abnormal shape along with interveinal chlorosis. Plants generally require high concentration of chlorine in tissues. Chlorine is abundantly found in soil and reaches even higher in concentrations in saline soil environment. However, chlorine can be deficient in highly leached inland areas. Most common symptoms of deficiency of chlorine are wilting and chlorosis of younger leaves. Chlorosis can occur on smooth flat depressions in interveinal areas of leaf blades. In some advanced cases, there often appears a characteristic bronzing on upper areas of mature leaves. Plants are usually tolerant of chlorine but few plant species like grapevine, stone fruits and avocadoes are highly sensitive to chlorine and exhibit toxicity symptoms even at lower chloride concentration in soil.

7.6.3 Toxicity of Chlorine

Toxicity of chlorine in plants generally causes stunted growth along with brittle and dry plant leaves.

7.7 Boron (B)

Boron is an essential chemical constituent of plants that belongs to 13th group of periodic table comprising thallium, indium, gallium, aluminium, boron and chemically uncharacterized nihonium. It was first discovered by Louis-Jacques Thénard and Louis-Josef Gay-Lussac in France, the city of Paris and Humphry Davy in London, the city of United Kingdom. Boron was first derived from Arabic word "buraq" which was the name of borax [68].

7.7.1 Role of Boron

Boron helps in successful utilization of nutrient and control of other plant nutrients. It promotes production and manufacturing of carbohydrates and sugars and itself essential for development of fruits and seeds. Borax and organic compounds of nature are the major sources of boron in soil [69].

7.7.2 Deficiency of Boron

Leaves, deficient of boron exhibit a general but light chlorosis. Similarly, acceptance of foliage to the levels of boron significantly varies, to the degree that boron application required for plant development partaking a higher boron necessity that can be poisonousness to the plants profound to boron. In the phloem of most plants, boron is under elated with the exception of those plants that use complex form of sugar like sorbitol as a major metabolite of transportation. Some recent investigations have revealed that tobacco plants engineered to manufacture sorbitol were known to have improved boron mobility and better tolerance level to extreme boron deficiency in soil [70].

7.7.3 Toxicity of Boron

Toxicity of boron is an important plant disorder which can limit the growth of plants in soil of semi-arid and arid climate all across the globe. Relatively higher boron concentrations can naturally be found in soil and in fresh groundwater or unintentionally added through mining or intentionally added via irrigation water and boron containing fertilizers. Although boron is of considerable agronomic importance but understanding regarding to boron toxicity is quite limited and rather fragmented. Boron toxicity differ from conventional toxicity effects when explored in detail by considering genotypic variations and physiological differences from tolerance to toxicity and how this variation can be utilized to minimize the growth of plants on high boron soil [71-72].

7.8 Zinc (Zn)

Zinc is a highly valuable chemical constituent of plants that belongs to 12th group and 4th period of periodic table. It was first discovered by P. Moras de Respour, a Flemish metallurgist in 1668 who reported the extraction of metallic zinc from zinc oxide. Nevertheless, in accordance with European scientists, zinc was discovered in 1746 by Andreas Marggraf, a German chemist who recognized it as a new metal [73].

7.8.1 Role of Zinc

Zinc is highly valuable plant nutrient that help in number of cellular processes and known to be the second most copious transition metal after iron. Zinc is a vital plant nutrient whose shortage is a commercial problem in the plants grown in alkaline, calcium holding soil whereas in acidic soil, availability of zinc is generally found to be high. All the physiochemical procedures that tends to regulate the balance of zinc in plants are still not fully known and documented [74-75]. Roots of plants obtain zinc in form of ions and metal is then dispersed through the plant body in a composite sequence of methods. Various different families of plant metal transporters have recently been recognized and documented in past few years [75], with atleast three being involved in transportation of zinc via P1B-type ATPases and cellular membrane [76-79]. Some recent researches have partially characterized the role of these transporters that they play in uptake, efflux, compartmentalization, storage and detoxification of zinc [75]. Just after uptake, zinc is transported to xylem where it is chelated by various smaller molecules [80], constituting several organic acids such as citrate and malate [74]. This metal can form metallic compounds with sulphate, nitrate and phosphate anions. One of the most important and common types of zinc complex in soil is zinc phosphate and zinc sulphate. Zinc is an essential chemical component of plants that aids in carbohydrate transformations as it regulates the consumption of sugars. Zinc is indispensible part of enzyme systems that regulate the development of different components of plants. Zinc chelates, zinc sulphates and zinc oxides are the basic sources of zinc in soil.

7.8.2 Deficiency of Zinc

The plant leaves deficient of zinc are known to show the progressive case of interveinal necrosis. Generally it has been observed that zinc deficient plants tend to lose the integrity of cell membrane thereby increasing the cell permeability in various different crop species [81]. This loss of membrane integrity under zinc deficient conditions can severely affect the accumulation and uptake of sodium at toxic levels in plants. Restricted availability of zinc is a significant nourishing problem of soil all around the world including Turkey that is generally associated with the problem of soil salinity along with Central Anatolia and Australia [82]. Therefore, by improving nutritional status of zinc in plants, salt stress tolerance can significantly be improved. In beginning of zinc shortage, newer plant leaves are converted into yellowish leaves along with development of pits in interveinal exteriors of ripened leaves. In few cases, guttation is also found dominant. As insufficiency progresses, these indications advances into rather strong interveinal necrosis however chief veins remain green as observed in symptoms of recovery from iron deficiency. In number of plant species, more specifically mature trees, plant leaves become small having shorter internodes thereby giving rise to rosette like appearance.

7.8.3 Toxicity of Zinc

Zinc poisonousness is closely relevant to iron deficiency in appearing symptoms. Plant leaves tend to develop yellowish coloration in between leaf vein which start to become necrotic with the passage of time. Overall, plant growth is stunted in zinc toxic soil areas. However, toxicity of zinc also induces severe chlorosis in younger plant leaves that has been suggested to result from zinc-induced magnesium or iron deficiency, based on the fact that all these metals have similar ionic radii [83]. Some other effects of zinc toxicity are decrease in moisture contents of plant tissues and changes in concentrations of magnesium and phosphorous in plants.

7.9 Molybdenum (Mo)

Molybdenum is an important lustrous metal having silvery appearance belonging to 6^{th} group of periodic table. It is known to be the 54^{th} most abundant element of earth’s crust. Molybdenum is an essential plant mineral that has been known to mankind but was first discovered by Carl Wilhelm Scheele in 1778. This metal was first isolated and extracted by Peter Jacob Hjelm in 1781 [84].

7.9.1 Role of Molybdenum

Amount of molybdenum in earth’s crust and soil surface extensively varies but its shortage is rarely found in plants as it is required in extremely smaller quantities by various plant species. In few reported cases excluding fruit trees, it was found that shortage of molybdenum is associated with lower soil pH. Nevertheless, since the molybdenum availability is intensively influenced by soil pH, liming usually has elucidated the problem. However, it helps in effective utilization of soil nitrogen as molybdenum is known to be an important element of enzyme that is involved in metabolism of nitrogen [85].

7.9.2 Deficiency of Molybdenum

Different plant species deficient of molybdenum exhibit dotted spots on leaves with some symptoms of chlorosis in veins. General chlorosis preliminarily indicates the insufficient availability of molybdenum similar to the deficiency symptoms of nitrogen that is mostly deprived of reddish coloration at the foundation of leaves. This outcome from the need of molybdenum in decline of nitrate, that must be reduced proceeding to its absorption by plants. Initial symptoms of molybdenum deficiency are infact very similar to deficiency symptoms of nitrogen. But molybdenum is known to have numerous metallic functions within plant body and therefore there are deficiency indicators even when reduced nitrogen is manageable. However, in number of plants, there is upward leaf cupping along with mottling spots inside the larger interveinal chlorotic areas under simple deficiency [86].

7.9.3 Toxicity of Molybdenum

At the elevated concentrations, molybdenum is known to have distinctive toxicity symptoms particularly in leaves that turn out to be brilliant orange in coloration. These indications sometime misleadingly resemble shortage of nitrogen in plants. Nevertheless, diffuse mottling of leaves, dwarf leaves and highly irregular leaf areas of dead tissues on margins and tips of leaves are major warning symptoms. Long story short, soil is a major known reservoir of molybdenum for plants [87].

7.10 Manganese (Mn)

Manganese is an essential chemical element which belongs to 7th group and 4th period of periodic table. It was first reported by a German chemist; Johann Heinrich Pott in 1740 who observed that pyrolusite contains a newer metal of earth rather than iron, as was commonly believed according to Chemicool and Ignatius Gottfried Kaim, the first Austrian chemist who successfully isolated the manganese in 1770 [88].

7.10.1 Role of Manganese

Manganese involves in number of plant processes such as activation of antioxidative enzymes, respiration and photosynthesis [89]. However, presence of necrotic leaf spots is mainly attributed to different applications. Manganese is known to stimulate number of highly valuable enzymes predominately those that retard manufacturing of nucleotides and fatty acids and is essential for photosynthesis. It harmonically works with natural enzyme system that aids in breakdown of carbohydrates and involved in effective metabolism of nitrogen. Soil is a known reservoir of manganese.

7.10.2 Deficiency of Manganese

Plant leaves deficient of manganese are known to exhibit light chlorosis in between leaf veins throughout the plant. Some initial deficiency symptoms are quite similar to iron deficiency. These deficiency symptoms start with activation of bright chlorosis of newer leaves and acquired veins of ripen leaves more specifically when they are determined by conducted light. With increase in plant stress, leaves tend to show metallic gloomy shine with necrotic areas and darker leaf spots. However, it may also develop purplish coloration and lustrous appearance on upper surface of leaves. Some grain plants like barley, wheat and oats are extremely vulnerable to deficiency of manganese. Plants sometimes develop light chlorosis besides grey specks which elongates and coalescence with the passage of time ultimately leading towards wilting and death of plants [90].

7.10.3 Toxicity of Manganese

Manganese deficiency is known to have two major symptoms (a) intensive blackening of leaf veins and (b) interveinal plant chlorosis. In majority of plants, development of brown leaf spots is an indication of progress in toxicity of manganese in older plant leaves. Successive development of necrosis and chlorosis in plants along with leaf flaking takes place just before decrease in asexual plant growth [91]. Some recently conducted experiments of manganese-induced-brown-spots showed that presence of oxidized phenols and oxidized manganese are basic cause of abnormal coloration in cell wall of epidermis [92]. Thus, development of manganese toxicity is complemented with spatial callose formation in areas characterized with brown spots. Some important physiological functions of callus formation in plants in response to toxic levels of manganese in tissues are still unknown but its recognition serves as supplementary parameter for injuries induced by manganese toxicity in leaf tissues. In *Vigna unguiculata*, the cowpea, apoplast of leaves has been recommended as most significant section for resistance of manganese stress [93]. Oxidation of divalent manganese through hydrogen per oxide has been recommended to be the key response causing toxicity symptoms of manganese, probably accompanied by successive formation of chemical intermediates such as phenoxy free radicals and trivalent cations of manganese.

Table.1 Relative abundance of essential plant nutrients and their functions [21]

Nutrient	Symbol	Relative abundance (%)	Function in plant
Boron	B	0.2	Cell wall component
Calcium	Ca	12.5	Cell wall component
Chlorine	Cl	0.3	Photosynthesis reactions
Copper	Cu	0.01	Component of enzymes
Iron	Fe	0.2	Chlorophyll synthesis
Magnesium	Mg	8	Part of chlorophyll

Manganese	Mn	0.1	Activates enzymes
Molybdenum	Mo	0.0001	Involved in N fixation
Nitrogen	N	100	Proteins, amino acids
Phosphorus	P	6	Nucleic acids, ATP
Potassium	K	25	Catalyst, ion transport
Sulfur	S	3	Amino acids
Zinc	Zn	0.03	Activates enzymes

Table.2 Diseases caused by Iron imbalance

Crop	Common Name	Scientific Name
Apple	Black Rot	*Coletotrichum musae*
Banana	Anthracnose	*Coletotrichum musae*
Cabbage	Virus Vector	*Olpidium brassicae*
Pear	Black Rot	*Coletotrichum musae*
Wheat	Rust	*Puccinia recondite*
Wheat	Smut	*Tilletia sp.*

Table.3 Diseases caused by Cupper

Crop Name	Common Name of Disease	Scientific Name of Disease
Barley	Ergot	*Claviceps purpurea*
Cotton	Wilt	*Verticillium dagliae*
Eucalyptus	Root Rot	*Phytophthora cinnamomi*
Ginseng	Bacterial Leaf Spot	*Pseudomonas cichorii*
Potato	Common Scab	*Streptomyces scabies*
Rice	Blast	*Pyricularia oryzae*
Rye	Ergot	*Claviceps purpurea*
Sugar beet	Nematode	………
Tomato	Wilt	*Verticillium albo-atrum*
Wheat	Mildew	*Blumaria grammis* var. *tritici*
Wheat	Leaf Rust	*Puccinia triticina*
Wheat	Leaf/Glume Blotch	*Septoria*

Table.4 Diseases caused by Chlorine

Crop Name	Common Name of Disease	Scientific Name of Disease
Celery	Fusarium Yellows	*Fusarium*
Corn	Stalk Rot	*Gibberella Zeae*
Corn	Stalk Rot	*Gobbler Fujikuroi*
Corn	Stalk Rot	*Fusarium moniliforme*
Corn	Corn Leaf Blight	*Exserohilum/Helminthosporium*
Millet	Downey Mildew	*Pennisetum typhoides*
Palm Tree	Leaf Spot	*Pestalozzia palmarum*
Potato	Hollow Heart	Physiological disorder, not disease
Potato	Brown Center	Physiological disorder, not disease
Soybean	Sudden Death Syndrome	*Fusarium solani*
Turf	Necrotic Ring Spot	*Leptosphaeria korrae*
Wheat	Stripe Rust	*Puccinia striiformis*
Wheat	Leaf Rust	*Puccinia recondite*
Wheat	Take-All	*Gaeumannomyces graminis var. tritici*
Wheat	Leaf/Glume Blotch	*Septoria nodorum*
Wheat	Tan Spot	*Pyrenophora tritici-repentis*
Wheat/Barley	Root Rot	*Cochliobolus sativus*

Table.5 Diseases caused by Boron

Crop Name	Common Name of Disease	Scientific Name of Disease
Beans	Root Rot	*Fusarium solani*

Beans	Tobacco Mosaic Virus	Tobacco mosaic virus
Cotton	Wilt	*Verticillium albo-atrum*
Crucifers	Club Root	*Plasmodiophora brassicae*
Mung bean	Stem Rot	*Rhizoctonia solani*
Peanut	Charcoal Rot	*Rhizoctonia bataticola*
Potato	Potato wart disease	*Synchytrium endobioticum*
Tomato	Wilt	*Verticillium albo-atrum*
Tomato	Yellow leaf curl virus	Yellow leaf curl virus
Various	Yellows	*Fusarium oxysporum*
Wheat	Mites	*Petrobia latens*

Table.6 Diseases caused by Zinc

Crop Name	Common Name of Disease	Scientific Name of Disease
Chickpea	Root Rot	*Fusarium*
Citrus	Mold	*Penicillium citrinum*
Cotton	Wilt	*Verticillium*
Cotton	Root Rot	*Phymatrotrichopsis omnivorum*
Cranberries	Leaf Spot	*Cladosporium cladosporoides*
Eucalyptus	Crown/Root Rot	*Phytophthora cinnamomi*
Ginseng	Bacterial Leaf Spot	*Pseudomonas cichorii*
Oranges	Root Rot	*Phytophthora Nicotiana*
Pea	Powdery Mildew	*Erysiphe polygoni*
Peanut	Rot	*Rhizoctonia batatic ola*
Rubber Trees	Powdery Mildew	*Oidium heveae*
Soybean	Foot Rot	*Sclerotium rolfsii*
Tomato	Nematode	*Rotylenchulus reniformis*
Various	Root Rot	*Phytophthora megasperma*
Various	Root Rot	*Phytophthora dreschsleri*
Various	Leaf Spot	*Cochliobolus miyabeanus*
Various	Rot	*Trichoderma*
Various	Leaf Spot	*Alternaria*
Various	Leaf Spot	*Epicoccum*
Various	Wilt	*Fusarium*
Various	Stem/Sheath Blight	*Rhizoctonia solani*
Various Trees	Decay and Vascular	*Trametes versicolor*
Various Trees	Wood Rot	*Stereum strigosazonatum*
Watercress	Crook Root	*Spongospora subterranea*
Watercress	Leaf Spot Virus	*Spongospora subterranea (vector)*
Wheat	Take-all	*Gaeumannomyces graminis var. tritici*
Wheat	Head Scab	*Fusarium graminearum*
White Clover	Clover Phyllody	*Phyllody virus*

Table.7 Diseases caused by Manganese

Crop Name	Common Name of Disease	Scientific Name of Disease
Avocado	Root Rot	*Pythium*
Cotton	Wilt	*Verticillium alboatrum*
Norway Spruce	Annosum Root Rot	*Fomes annosus*
Potato	Common Scab	*Streptomyces scabies*
Rice	Blast	*Pyricularia oryzae*
Rice	Leaf Spot	*Alternaria*
Swede	Powdery Mildew	*Erysiphe polygoni*
Wheat	Mildew	*Blumaria grammis var. tritici*

8. Summary and Conclusions

In past few years, importance of sustainable agriculture has significantly enhanced and became a hot topic of recent agricultural researches all across the globe. In addition to that, numerous plant diseases continue to play a major limiting role in number of agricultural productions. However, control of deleterious plant diseases through classical pesticides has raised several concerns mainly relevant to food safety, pesticide resistance and quality of environment that indirectly have dictated the need for several alternative pest management technologies. In short, essential plant nutrients directly affect the disease tolerance and plant resistance towards pathogens. Nevertheless, there are numbers of contradictory reports about effects of nutrients on plant diseases and several factors that affect these kinds of responses are not well-understood. This review article comprehensively illustrate the role, deficiency symptoms and toxicity symptoms of some micronutrients of plants such as manganese, molybdenum, zinc, boron, chlorine, cupper, iron, sulphur, calcium and magnesium along with some macronutrients of plants like phosphorous, nitrogen and potassium. Integrative plant nutrition is an essential component in sustainable agriculture, because in most cases it is more cost-effective and also environmental friendly to control plant disease with adequate amount of nutrients and with no pesticides. Nutrients can reduce disease to an acceptable level or at least to a level at which further control by other cultural practices or conventional organic biocides are more successful and less expensive.

9. Future Perspective

There are several established approaches in order to ensure the various ecofriendly systems of farming. A common thread on all school is an emphasis on biological system to supply fertility and pest control rather than chemical inputs. Organic farming can be defined as production system which avoids or largely exclude the usage of synthetically compounded fertilizers, growth regulator, pesticides and livestock feed additives. To the maximum extent, feasible organic farming system rely on crop rotations, animal manures, crop residues, green manure, legumes, off-farm organic wastes and aspects of biological pest control insets and pest weeds etc. Organic farming methods are widely used in underdeveloped and developing countries, largely because of economics and a lack of chemicals. However, they are becoming widely accepted in developed countries as a reaction or factory conditions.

References

[1] S. Suweis, J.A. Carr, A. Maritan, A. Rinaldo, P. D'Odorico. (2015). Resilience and reactivity of global food security. Proceedings of the National Academy of Sciences. 201507366.

[2] G. Riches. (2016). First world hunger: Food security and welfare politics. Springer: pp.

[3] Food, A.O.o.t.U. Nations. (2017). The State of Food Security and Nutrition in the World 2017: Building Resilience for Peace and Food Security. FAO: pp.

[4] R. O'Connell, L. Hamilton. (2017). Hunger and food poverty. The violence of austerity. 94-100.

[5] C. Dordas. (2008). Role of nutrients in controlling plant diseases in sustainable agriculture. A review. Agronomy for sustainable development. 28(1): 33-46.

[6] A. Camprubí, V. Estaún, M. El Bakali, F. Garcia-Figueres, C. Calvet. (2007). Alternative strawberry production using solarization, metham sodium and beneficial soil microbes as plant protection methods. Agronomy for sustainable development. 27(3): 179-184.

[7] D.K. Tripathi, V.P. Singh, D.K. Chauhan, S.M. Prasad, N.K. Dubey, Role of macronutrients in plant growth and acclimation: recent advances and future prospective. In *Improvement of Crops in the Era of Climatic Changes*, Springer: 2014; pp. 197-216.

[8] M.T. Tavakoli, A.I. Chenari, M. Rezaie, A. Tavakoli, M. Shahsavari, S.R. Mousavi. (2014). The importance of micronutrients in agricultural production. Advances in Environmental Biology. 31-36.

[9] N.K. Fageria. (2016). The use of nutrients in crop plants. CRC press: pp.

[10] R. Uchida. (2000). Essential nutrients for plant growth: nutrient functions and deficiency symptoms. Plant nutrient management in Hawaii's soils. 31-55.

[11] N. Hudson. (2015). Soil conservation: fully revised and updated. New India Publishing Agency: pp.

[12] P. Sivasankar, A. Anix Vivek Santhiya, V. Kanaga. (2015). A review on plants and herbal extracts against viral diseases in aquaculture. Journal of Medicinal Plants Studies. 3(2): 75-79.

[13] J.D. Pujari, R. Yakkundimath, A.S. Byadgi. (2015). Image processing based detection of fungal diseases in plants. Procedia Computer Science. 46: 1802-1808.

[14] S. Agarwal, J. Rathore. (2012). Understanding the effects of chemical fertilizers. Journal of Progressive Agriculture. 3(1): 89-90.

[15] J.P. Reganold, J.M. Wachter. (2016). Organic agriculture in the twenty-first century. Nature plants. 2(2): 15221.

[16] M.P. Waldrop, D.R. Zak. (2006). Response of oxidative enzyme activities to nitrogen deposition affects soil concentrations of dissolved organic carbon. Ecosystems. 9(6): 921-933.

[17] T. Kadir, A. Zisserman, M. Brady In *An affine invariant salient region detector*, European conference on computer vision, 2004; Springer: 2004; pp. 228-241.

[18] K. Fouda. (2017). Effect of Interaction among N Forms and Calcium Sources on Quality and Chemical Composition of Tomato (Lycopersicon).

[19] F.D. Amor, L. Marcelis. (2003). Regulation of nutrient uptake, water uptake and growth under calcium starvation and recovery. The Journal of Horticultural Science and Biotechnology. 78(3): 343-349.

[20] C.R. Buell, V. Joardar, M. Lindeberg, J. Selengut, I.T. Paulsen, M.L. Gwinn, R.J. Dodson, R.T. Deboy, A.S. Durkin, J.F. Kolonay. (2003). The complete genome sequence of the Arabidopsis and tomato pathogen Pseudomonas syringae pv. tomato DC3000. Proceedings of the National Academy of Sciences. 100(18): 10181-10186.

[21] R. Roy, A. Finck, G. Blair, H. Tandon. (2006). Plant nutrition for food security. A guide for integrated nutrient management. FAO Fertilizer and Plant Nutrition Bulletin. 16: 368.

[22] L.C. van Loon, M. Rep, C.M. Pieterse. (2006). Significance of inducible defense-related proteins in infected plants. Annu. Rev. Phytopathol. 44: 135-162.

[23] C.T. Ingold. (2012). The biology of fungi. Springer Science & Business Media: pp.

[24] T. Davey. The importance of Potato mop-top virus (PMTV) in Scottish seed potatoes. Heriot-Watt University, 2009.

[25] D. Walters, I. Bingham. (2007). Influence of nutrition on disease development caused by fungal pathogens: implications for plant disease control. Annals of Applied Biology. 151(3): 307-324.

[26] A.C. Ross, B. Caballero, R.J. Cousins, K.L. Tucker, T.R. Ziegler. (2014). Modern nutrition in health and disease. Lippincott Williams & Wilkins: pp.

[27] D.M. Huber, R.D. Graham. (1999). The role of nutrition in crop resistance and tolerance to diseases. Mineral nutrition of crops: fundamental mechanisms and implications. 169: 206.

[28] R.D. Graham, M.J. Webb. (1991). Micronutrients and disease resistance and tolerance in plants. Micronutrients in agriculture. (micronutrientsi2): 329-370.

[29] G. Lazarovits, M. Tenuta, K.L. Conn. (2001). Organic amendments as a disease control strategy for soilborne diseases of high-value agricultural crops. Australasian Plant Pathology. 30(2): 111-117.

[30] E.M. Tegtmeier, M.D. Duffy. (2004). External costs of agricultural production in the United States. International Journal of agricultural sustainability. 2(1): 1-20.

[31] H.C. Kelman, V.L. Hamilton, Crimes of obedience. In New Haven, CT: Yale University Press: 1989.

[32] S.C. Huber. (1986). Fructose 2, 6-bisphosphate as a regulatory metabolite in plants. Annual review of plant physiology. 37(1): 233-246.

[33] M. Imran, Z.A. Gurmani. (2011). Role of macro and micro nutrients in the plant growth and development. Science Technology and Development (Pakistan).

[34] N.A. Wahocho, M. Laghari. (2016). Role of Nitrogen for.

[35] I.A. Thompson, D.M. Huber. (2007). Manganese and plant disease. Mineral nutrition and plant disease. 139: 153.

[36] I. Prost, S. Dhondt, G. Rothe, J. Vicente, M.J. Rodriguez, N. Kift, F. Carbonne, G. Griffiths, M.-T. Esquerré-Tugayé, S. Rosahl. (2005). Evaluation of the antimicrobial activities of plant oxylipins supports their involvement in defense against pathogens. Plant Physiology. 139(4): 1902-1913.

[37] Y. Ben-Yephet, L. Tsror, M. Reuven, A. Gips, Z. Bar, A. Einstein, Y. Turjeman, P. Fine. (2005). Effect of ecosoil and NH_4 in controlling soilborne pathogens. Acta horticulturae.

[38] D. Cordell, J.-O. Drangert, S. White. (2009). The story of phosphorus: global food security and food for thought. Global environmental change. 19(2): 292-305.

[39] P. Ryan, E. Delhaize, D. Jones. (2001). Function and mechanism of organic anion exudation from plant roots. Annual review of plant biology. 52(1): 527-560.

[40] P. Hinsinger. (2001). Bioavailability of soil inorganic P in the rhizosphere as affected by root-induced chemical changes: a review. Plant and soil. 237(2): 173-195.

[41] S. Abel, C.A. Ticconi, C.A. Delatorre. (2002). Phosphate sensing in higher plants. Physiologia plantarum. 115(1): 1-8.

[42] E. Baggs, R. Rees, K. Smith, A. Vinten. (2000). Nitrous oxide emission from soils after incorporating crop residues. Soil use and management. 16(2): 82-87.

[43] H. Lambers. (2003). Introduction, dryland salinity: a key environmental issue in southern Australia. Plant and soil. 257(2): 5-7.

[44] M.W. Shane, H. Lambers. (2005). Cluster roots: a curiosity in context. Plant and soil. 274(1-2): 101-125.

[45] A.S. Prabhu, N.K. Fageria, D.M. Huber, F.A. Rodrigues. (2007). Potassium and plant disease. Datnoff, LE, WH Elmer, and DM Huber: Mineral

Nutrition and Plant Disease. The American Phytopathological Soc. Press, Saint Paul. 57-78.
[46] R.G. Linderman, Effects of mycorrhizas on plant tolerance to diseases. In *Arbuscular mycorrhizas: Physiology and function*, Springer: 2000; pp. 345-365.
[47] D. Ciceri, D.A. Manning, A. Allanore. (2015). Historical and technical developments of potassium resources. Science of the Total Environment. 502: 590-601.
[48] V. Römheld, E.A. Kirkby. (2010). Research on potassium in agriculture: needs and prospects. Plant and soil. 335(1-2): 155-180.
[49] J. Kim, J.E. Lee, S. Heynen-Genel, E. Suyama, K. Ono, K. Lee, T. Ideker, P. Aza-Blanc, J.G. Gleeson. (2010). Functional genomic screen for modulators of ciliogenesis and cilium length. nature. 464(7291): 1048.
[50] A. Amtmann, S. Troufflard, P. Armengaud. (2008). The effect of potassium nutrition on pest and disease resistance in plants. Physiologia plantarum. 133(4): 682-691.
[51] I. Cakmak, W.H. Pfeiffer, B. McClafferty. (2010). Biofortification of durum wheat with zinc and iron. Cereal Chemistry. 87(1): 10-20.
[52] I. Cakmak. (2005). The role of potassium in alleviating detrimental effects of abiotic stresses in plants. Journal of Plant Nutrition and Soil Science. 168(4): 521-530.
[53] F.C. Luft, Whither magnesium? In Oxford University Press: 2012.
[54] D.M. Huber, S. Haneklaus. (2007). Managing nutrition to control plant disease. Landbauforschung Volkenrode. 57(4): 313.
[55] D.M. Huber, J.B. Jones. (2013). The role of magnesium in plant disease. Plant and soil. 368(1-2): 73-85.
[56] S. Cherian, M.M. Oliveira. (2005). Transgenic plants in phytoremediation: recent advances and new possibilities. Environmental science & technology. 39(24): 9377-9390.
[57] R.E. Krebs. (2006). The history and use of our earth's chemical elements: a reference guide. Greenwood Publishing Group: pp.
[58] P. Enghag. (2008). Encyclopedia of the elements: technical data-history-processing-applications. John Wiley & Sons: pp.
[59] P.J. White, M.R. Broadley. (2003). Calcium in plants. Annals of Botany. 92(4): 487-511.
[60] H. Sze, F. Liang, I. Hwang, A.C. Curran, J.F. Harper. (2000). Diversity and regulation of plant Ca2+ pumps: insights from expression in yeast. Annual review of plant biology. 51(1): 433-462.
[61] D. Sanders, J. Pelloux, C. Brownlee, J.F. Harper. (2002). Calcium at the crossroads of signaling. The Plant Cell. 14(suppl 1): S401-S417.
[62] T. Khan, M. Mazid. (2011). Nutritional significance of sulphur in pulse cropping system. Biology and medicine. 3(2): 114-133.
[63] A.F. Trendall, R.C. Morris. (2000). Iron-formation: facts and problems. Elsevier: pp.
[64] S.A. Kim, M.L. Guerinot. (2007). Mining iron: iron uptake and transport in plants. FEBS letters. 581(12): 2273-2280.
[65] H. Karakurt, R. Aslantas. (2010). Effects of some plant growth promoting rhizobacteria (PGPR) strains on plant growth and leaf nutrient content of apple. Journal of Fruit and Ornamental Plant Research. 18(1): 101-110.
[66] R. Siegfried. (1959). Humphry Davy and the elementary nature of chlorine. Journal of Chemical Education. 36(11): 568.
[67] W. Garner, J. McMurtrey Jr, J. Bowling, E. Moss. (1930). Role of chlorine in nutrition and growth of the tobacco plant and its effect on the quality of the cured leaf. J. Agr. Research. 40: 627-648.
[68] M. Ozalp. (2008). The investigation of borax pentahydrate influences with double components in varnish applications of wood materials. Wood Res. 53(4): 121-128.
[69] R. Hänsch, R.R. Mendel. (2009). Physiological functions of mineral micronutrients (Cu, Zn, Mn, Fe, Ni, Mo, B, Cl). Current opinion in plant biology. 12(3): 259-266.
[70] P.H. Brown, N. Bellaloui, H. Hu, A. Dandekar. (1999). Transgenically enhanced sorbitol synthesis facilitates phloem boron transport and increases tolerance of tobacco to boron deficiency. Plant Physiology. 119(1): 17-20.
[71] U.C. Gupta, Y. Jame, C. Campbell, A. Leyshon, W. Nicholaichuk. (1985). Boron toxicity and deficiency: a review. Canadian Journal of Soil Science. 65(3): 381-409.
[72] A. Leyshon, Y. Jame. (1993). Boron toxicity and irrigation management. Boron and its role in crop production. 207-226.
[73] R. Suryanarayanan, Zinc oxide: from optoelectronics to biomaterial—a short review. In *ZnO Nanocrystals and Allied Materials*, Springer: 2014; pp. 289-307.
[74] M.R. Broadley, P.J. White, J.P. Hammond, I. Zelko, A. Lux. (2007). Zinc in plants. New phytologist. 173(4): 677-702.
[75] U. Krämer, I.N. Talke, M. Hanikenne. (2007). Transition metal transport. FEBS letters. 581(12): 2263-2272.
[76] D. Hussain, M.J. Haydon, Y. Wang, E. Wong, S.M. Sherson, J. Young, J. Camakaris, J.F. Harper, C.S.

Cobbett. (2004). P-type ATPase heavy metal transporters with roles in essential zinc homeostasis in Arabidopsis. The Plant Cell. 16(5): 1327-1339.

[77] A. Papoyan, L.V. Kochian. (2004). Identification of Thlaspi caerulescens genes that may be involved in heavy metal hyperaccumulation and tolerance. Characterization of a novel heavy metal transporting ATPase. Plant Physiology. 136(3): 3814-3823.

[78] A. Gravot, A. Lieutaud, F. Verret, P. Auroy, A. Vavasseur, P. Richaud. (2004). AtHMA3, a plant P1B-ATPase, functions as a Cd/Pb transporter in yeast. FEBS letters. 561(1-3): 22-28.

[79] R.F. Mills, A. Francini, P.S.F. da Rocha, P.J. Baccarini, M. Aylett, G.C. Krijger, L.E. Williams. (2005). The plant P1B-type ATPase AtHMA4 transports Zn and Cd and plays a role in detoxification of transition metals supplied at elevated levels. FEBS letters. 579(3): 783-791.

[80] M.J. Haydon, C.S. Cobbett. (2007). Transporters of ligands for essential metal ions in plants. New phytologist. 174(3): 499-506.

[81] I. Cakmak. (2000). Tansley Review No. 111 Possible roles of zinc in protecting plant cells from damage by reactive oxygen species. The New Phytologist. 146(2): 185-205.

[82] Y. Genc, J.M. Humphries, G.H. Lyons, R.D. Graham. (2005). Exploiting genotypic variation in plant nutrient accumulation to alleviate micronutrient deficiency in populations. Journal of Trace Elements in Medicine and Biology. 18(4): 319-324.

[83] S. Clemens. (2006). Toxic metal accumulation, responses to exposure and mechanisms of tolerance in plants. Biochimie. 88(11): 1707-1719.

[84] N.E. Holden. (2001). History of the origin of the chemical elements and their discoverers. Prepared for the 41st IUPAC General Assembly. 29.

[85] B.N. Kaiser, K.L. Gridley, J. Ngaire Brady, T. Phillips, S.D. Tyerman. (2005). The role of molybdenum in agricultural plant production. Annals of Botany. 96(5): 745-754.

[86] S. Agarwala, C. Sharma, S. Farooq, C. Chatterjee. (1978). Effect of molybdenum deficiency on the growth and metabolism of corn plants raised in sand culture. Canadian Journal of Botany. 56(16): 1905-1908.

[87] D.G. Barceloux, D. Barceloux. (1999). Molybdenum. Journal of Toxicology: Clinical Toxicology. 37(2): 231-237.

[88] C.W. Henderson. (1926). Mining in Colorado: a history of discovery, development and production. Govt. Print. Off.: pp.

[89] G. Santandrea, T. Pandolfini, A. Bennici. (2000). A physiological characterization of Mn-tolerant tobacco plants selected by in vitro culture. Plant Science. 150(2): 163-170.

[90] V. Lanquar, M.S. Ramos, F. Lelièvre, H. Barbier-Brygoo, A. Krieger-Liszkay, U. Krämer, S. Thomine. (2010). Export of vacuolar manganese by AtNRAMP3 and AtNRAMP4 is required for optimal photosynthesis and growth under manganese deficiency. Plant Physiology. 152(4): 1986-1999.

[91] S. Yang, H. Deng, M. Li. (2008). Manganese uptake and accumulation in a woody hyperaccumulator, Schima superba. Plant Soil Environ. 54(10): 441-6.

[92] M.M. Fecht-Christoffers, H.-P. Braun, C. Lemaitre-Guillier, A. VanDorsselaer, W.J. Horst. (2003). Effect of manganese toxicity on the proteome of the leaf apoplast in cowpea. Plant Physiology. 133(4): 1935-1946.

[93] M.M. Fecht-Christoffers, P. Maier, W.J. Horst. (2003). Apoplastic peroxidases and ascorbate are involved in manganese toxicity and tolerance of Vigna unguiculata. Physiologia plantarum. 117(2): 237-244.