CHAPTER 8

Sustainable Crop Nutrition for Ameliorating Biotic Stress in Grain Legumes and Ensuring Food Security

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Abstract: Environmental stress generally causes considerable yield loss in leguminous crop production. This stress could be biotic (Insect pests, disease pathogens, weeds, vertebrate pests, *etc.*) or abiotic (Drought, heat, cold, salinity, flooding, heavy metal contamination, *etc.*). Either biotic or abiotic stress, both are capable of causing total yield loss. Unfortunately, crops are simultaneously exposed to these stress factors on the field. The response and level of tolerance to both stress factors, however, depend on the crop's genetic and nutritional status. The level of infection or infestation is determined by the cropping system and soil nutrient status. The induction of defense mechanisms by plants in response to pathogenic attack is dependent on environmental conditions like plant nutrient status. It means that there is a complex signaling network with crop nutrition that enables the plants to recognize and protect themselves against pathogens and other environmental stresses. The disease severity could be reduced by adequate crop nutrition due to host nutrient availability, plant composition of secondary metabolites, and the effect on the plant defense mechanisms. Shortages in essential nutrients on their own can predispose plants to attack by pests and pathogens. Therefore, the only sustainable method for growing crops in the face of different environmental stresses is good crop nutrition. A well-fed crop is more resistant to environmental hazards than poorly-fed crop. Though leguminous crops can fix atmospheric nitrogen themselves, the nutritional requirements for healthy crop production are more than just one element. The ability to fix nitrogen, if combined with appropriate crop nutrition will place the plant in a better position to withstand environmental stresses. This chapter discusses some of the different nutrient elements required by leguminous crops and their functions, crop nutrition abiotic stress tolerance, and mechanisms of nutrient-induced resistance in leguminous crops.

Keywords: Fertilisers, Legumes, Environmental Stress, Crop health, Crop yield.

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INTRODUCTION

In grain legume production, biotic stress factors such as insect pest attack and pathological diseases have been reported to be the important constraints limiting grain yield [1]. To increase grain yield in the face of biotic stress, different strategies have been proposed. The most important strategy is adequate plant nutrition. A balanced nutrient supply is a basic requirement to protect plants against all forms of stress [2]. The plant growth rate is proportional to nutrient availability and accessibility. A decline in soil fertility has been found to increase the negative crop response and susceptibility to both biotic and abiotic stress. Poor nutrition impairs crop response and tolerance to stress factors. The low grain yields in legumes have been attributed to poor crop management practices and poor soil fertility [1]. Liebig's "Law of the Minimum (1855) stated that 'The genetically fixed yield potential of crops is limited by the nutrition' [2]. The yield potential of any crop is, therefore, determined by the amount of nutrients supplied and taken up by the plant. The presence and availability of essential mineral elements in the soil, therefore, have a significant impact on the plant's health and determine the plant's response to environmental stresses.

Meanwhile, most farmers do not apply additional nutrients to sole cowpea production due to its ability to fix atmospheric nitrogen. But for greater resistance and enhanced tolerance to environmental stress, the addition of fertilizers is needed to boost cowpea tolerance. In fact, nitrogen itself is needed as a starter dose in areas where soils are poor in nitrogen before nodules begin to fix atmospheric nitrogen [3]. Though, nodulation and N fixation can be inhibited by high field N levels due to the inhibition of nitrogenase activity through a feedback mechanism, but moderate/optimal soil nitrogen level is required for effective nodulation [4]. Besides, in the absence of other nutrients like phosphorous, which is critical to cowpea yield, nitrogen fixation is also strongly affected [5]. Phosphorus is the most limiting soil fertility factor for cowpea production in many tropical soils because it stimulates growth, initiates nodule formation, and promotes rhizobium-legume symbiosis apart from other benefits. It means that cowpea nitrogen-fixing ability might also be affected under P deficiency. Again, it has been observed that under stress, the physiological mineral nutrient demand is always higher than that of normal growth. More carbon and nutrients are needed to be able to carry out the stress-induced metabolic activities and ameliorative processes.

The fixed nitrogen might therefore not be able to support leguminous crops under biotic stress. Appropriate and sufficient fertilization is the key to sustainable crop production, especially under stress. The success of pest attack, though, positively correlates with the plant's nutrient status in some reports [6], but the survival or loss encountered is reduced in a well-fed plant. The plant's nutrient status is related to its capacity to ameliorate the negative impacts caused by stress conditions [3, 7]. Best compensatory performance under biotic stress has been reported under proper nutritional management compared to only pest control [6]. Improvement of phosphorus, nitrogen, potassium (P, N, K) and cation contents in the topsoil has been found to increase cowpea grain yield under biotic stress compared to unfertilized fields with pest control [1]. Malnutrition, therefore, predisposes crops to biotic stress. The rate of recovery is also affected or delayed in the absence of balanced nutrition for crops.

Beneficial mineral nutrients should, however, be able to promote growth and yield under stress and strengthen the natural resistance of plants against abiotic and biotic stresses. Apart from mineral nutrients, water is also an essential component of crop nutrition. Legumes like other crops also require more moisture for N fixation. Water is required to export N products from the nodules to the rest of the plant. In the absence of water, N products build up in the nodule and inhibit further fixation by the nodules. With regard to response to biotic stress, lack of water has also been reported to promote insect attack compared to well-watered plants. For instance, aphid performance was found to be the highest in crops subjected to moderate drought stress [8]. Similarly, extreme moisture stress can inhibit nodule initiation or cause nodule shedding in some legume species. It can also reduce N fixation potential by depriving the nodules of sufficient oxygen for rhizobial respiration. Soil nutrient availability and water status can, therefore, have a strong influence and diverse effects on how legumes respond to biotic stresses. The importance of macro and micro-elements in the performance of leguminous crops and tolerance to biotic stresses are discussed in this chapter.

CROP NUTRITION AND BIOTIC STRESS RESPONSES

There are strong interactions between nutrients and other environmental factors, especially, biotic factors. A balanced nutrient supply is the basic requirement to protect plants against all forms of stress. The importance of individual nutrients for maintaining or promoting plant health and growth has been well documented [7]. The level of crop response to biotic stress is dependent on its nutrient status, the type of nutrient available to such crop, and the quantity. It has been observed that an adequate supply of mineral elements in the growth medium is paramount, for plants to survive under different environmental stresses including biotic stress [7, 9]. The growth and survival of leguminous crops under biotic stress are also dependent on the soil nutrient status and ability to fix atmospheric nitrogen effectively. The increased nutrition enables the plants to repair and compensate for the damage caused by insects or pathogens without a reduction in yield. The plant's growth is retarded, the turgor is reduced, and the level of susceptibility to pests and diseases increases under nutrient stress (Fig. **1**).

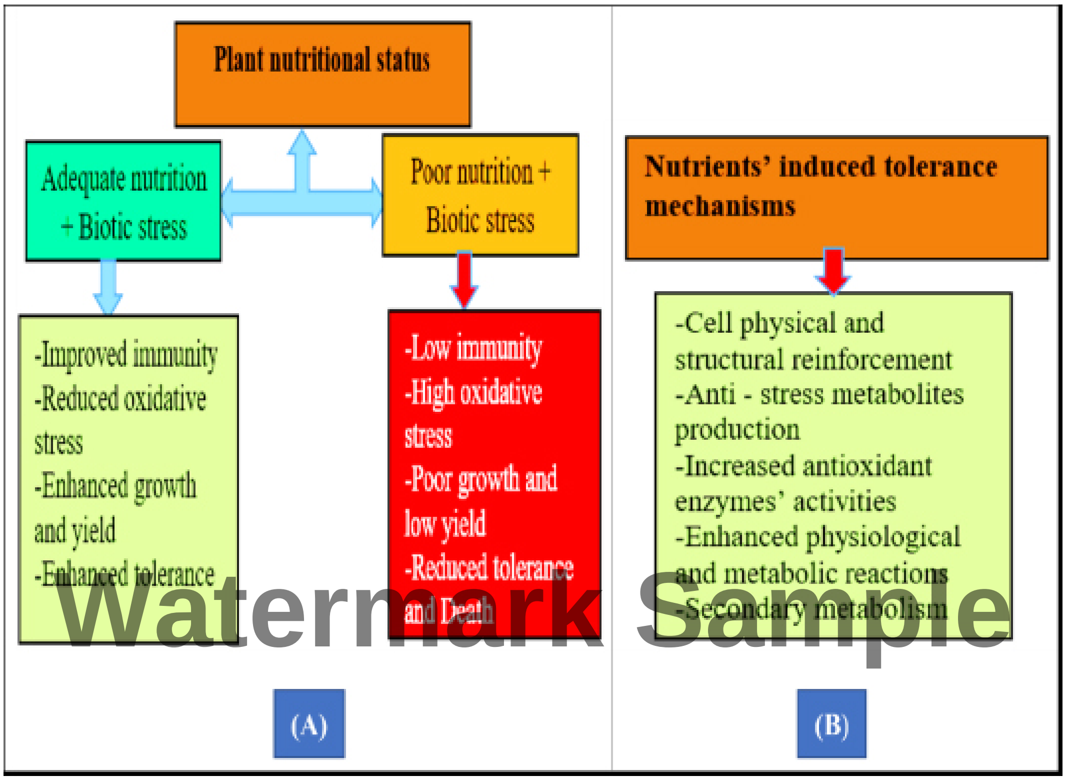

Fig. (1). Crop nutrient status and response to stress (**A**) and the nutrients' induced mechanisms of resistance (**B**).

Nutrient availably or deficiency affects plant-biotic interactions. Plant nutrients, however, function differently in terms of crop response to stress. Some nutrients are antagonistic to disease development, while some are beneficial depending on the nutrient types and concentrations. Lack or presence of nutrients has a direct correlation to pest infestation. For instance, infestation of plants by *Myzus persicae* was not successful in nitrogen-deficient treatment [10]. Meanwhile, the increase in vegetative and reproductive growth in well-nourished plants could serve as attractants to pests and diseases [11]. An increase in the number of flowers because of phosphate treatment was reported to increase the number of cowpea thrips in treated plants compared to the unfertilized ones [6]. Dense canopy formation as a result of nutrient availability has also been reported to provide a suitable micro-environment such as low temperature, high relative humidity, and low light transmission that favoured infestation by *M. vitrata*.

Nutrient's availability therefore has significant effects on the relationship between plant and herbivores because of direct effects of host nutrient availability on the diet of the herbivores and plant's secondary metabolites composition [11]. However, efficient compensatory mechanisms in well-nourished plants would have neutralized the effects of pest infestation. Good nutrition enhances the resistance of cowpeas to insect pests by facilitating the rebuilding of the damaged structures and compensating for the losses caused by the insects. There are different reports on seed priming with various nutrients and water to provide tolerance against biotic stress. Sulphur and silicon-induced resistance against fungal pathogens has also been reported [11, 12]. Silicon for example, though not part of the essential elements, plays a protective role against fungal diseases by positively influencing the structure and function of plant cell walls. It was highly effective against biotrophic and hemi-biotrophic fungi, such as mildew, *Septoria tritici*, and *Fusarium*, after soil application. Cowpea damage by *A. craccivora, M. sjostedti and M. vitrata*was also reduced significantly, and the yield increased with the application of 30 and 45 kg P_2O_5/ha [6].

Mechanisms of Nutrients Induced Resistance

Production of Reactive Oxygen Species (ROS) which consequently leads to oxidative stress is the common effect of environmental stress, either biotic or abiotic. The survival of the plant under oxidative stress depends on its ability to scavenge the ROS as they are being produced. This in turn depends on the plant's nutrient status and vigour. When nutrient deficiency is combined with other environmental stress, the effect is always significant. In well fed plants, the response is quick and the rate of scavenging the ROS is enhanced. Generally, the mechanism for stress alleviation under effective nutrition could be attributed to the activation of antioxidants production in the stressed crop plants and increase in the activities of the antioxidant enzymes. The accumulation of osmoprotectants such as proline (Pro), glycine betaine, glutathione *etc*. is the common physiological response to biotic and abiotic stresses in plants. Stimulation of antioxidative metabolic processes in order to defy oxidative stress is a possible tolerance mechanism being employed under nutrient induced resistance. High nutrition levels have also been reported to alleviate stress damage by sustaining physiological activities like photosynthesis and reduce malondialdehyde (MDA) content under stress [12].

Another important mechanism being induced by sufficient nutrition under stress is the production of secondary metabolites. Several reports indicate the involvement of mineral nutrients in the induction of secondary metabolite synthesis in stressed plants [13, 14]. Carotenoids (Car) pigments for example, are secondary metabolites of isoprenoid origin and are involved in many defense mechanisms, such as membrane stability, light-harvesting, and ROS balance [13]. Synthesis of phytoalexin phenolic compounds has also been reported to be another mechanism employed for Si-induced resistance [2]. The increase in the metabolite production as a result of essential nutrient availability will reduce the success of disease plant interactions. Fortification of the structural integrity of cell walls, the stimulation of the synthesis of defense components, and the contribution to the osmotic adjustment together with ion balance (homeostasis) are also some of the mechanisms being induced for resistance.

Meanwhile, different elements induce different resistance mechanisms in plants under biotic stress. For instance, activities of superoxide dismutase (SOD), peroxidase (POD) and polyphenol oxidase (PPO) have been reported to be enhanced in crops treated with nitrogen ions and exposed to environmental stresses [15]. The glutamine synthetase (GS), and the glutamate synthase (GOGAT) activity increased in all the nitrogen and stress treatments [15]. Silicon has been reported to maintain membrane stability and functions, decrease oxidative damage, and increase antioxidant defence [2, 16]. It increases the structural integrity of cells by incorporating Si (amorphous $(SiO_2)m{\cdot}n(H_2O)$) in cell walls and intercellular spaces, thereby creating a barrier. Orthosilicic acid is also said to be polymerised to amorphous silica ($(SiO_2)m{\cdot}n(H_2O)$) and deposited in specific cells [2].

Calcium signaling is one of the important responses and immunity under biotic stress [17]. The first crucial step being taken by the plant to adapt to adverse growth conditions is to detect the nature and strength of environmental stimuli, interpret them and activate appropriate physiological responses. In plant pathogen interactions, two types of immune system are triggered. These are Pathogen-Associated Molecular Patterns (PAMP)-Triggered Immunity (PTI) and Effector-Triggered Immunity (ETI). They both enhance overall plant's defense and protects plants from subsequent pathogen attack through localized programmed cell death (PCD) [18]. An increase in calcium concentration during immune signaling is needed for gene reprogramming to initiate adequate responses which could be symbiotic or defensive. Proper response to pathogen attack, therefore, requires high cytosolic calcium ion concentration. The roles of calcium in plant immunity, symbiosis and response to herbivory attacks have been well documented [17, 19, 20].

NUTRIENTS REQUIREMENTS BY LEGUMES AND THEIR FUNCTIONS

Generally, about sixteen nutrient elements are essential for normal plant growth and development. They are grouped under macro and micronutrients. A balanced supply of macro- and micronutrients is essential to decrease the susceptibility of plants to biotic and abiotic stresses. Even though leguminous crops could fix atmospheric nitrogen, other elements must, however, be supplied for normal growth and development because nitrogen cannot substitute for other elements. In the absence of any of the essential elements, the susceptibility of legumes to pest and diseases increases.

Macroelements

Among the essential macronutrients needed by leguminous crops are carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) andsulphur (S). Nitrogen is one of the essential elements that are required by every crop (All the essential elements are required by crops). Without it, the plant might not be able to complete its life cycle and its roles cannot be substituted by another element. It is part of the different biomolecules in plant. It is a structural component of proteins and nucleic acids. Some pigments like chlorophyll also contain nitrogen as their major element. Different physiological and biochemical processes are also enhanced by the presence of nitrogen. Therefore, nitrogen must be supplied to boost crop performance [21]. The main source of nitrogen to the plant is through fertilization except in the leguminous plants where atmospheric nitrogen is fixed by *Rhizobium* and other microorganisms that form nodulation in the roots. As important as nitrogen is to the plants, the optimum requirement also varies for different crops. For instance, the optimum nitrogen level that is tolerable to most leguminous crops is 50 kg N/ha but varies across legume species [22]. This is because the nitrogen fixing ability of legumes has been reported to be hindered by elevated level of nitrogen in the field by disrupting the activity of nitrogenase enzyme through a feedback mechanism and stop nodule formation [23].

It means that nitrogen fixing plant must not be treated with excess nitrogen [23]. Thiourea (TU) is an important synthetic organosulfur compound containing nitrogen (36%) and sulfur (42%) that has gained wide attention for its role in plant stress tolerance [13]. Carbon dioxide is incorporated into the plant through photosynthesis. It is the main source of carbon in plant and carbon is the main energy source for plant. Plant's growth and development are determined by the rate of photosynthesis. It provides the basic skeleton to produce other metabolites in plants. In legumes, photosynthate partitioned to roots supports nodule growth, provides energy for N fixation, maintains a functional population of rhizobia, and allows the synthesis of amino compounds produced from N fixation. The inability of the leguminous crops to accumulate enough carbon through photosynthesis or fertilization has deleterious effects on the growth and plant's ability to withstand stress.

Phosphorous is one of the essential macroelements that perform distinct functions in plants. It is needed for the synthesis of Adenosine Triphosphate (ATP) which is a chemical energy in every living organism including plants. It is a constituent of nucleic acid. Unlike nitrogen, P is not fixed but can only be supplied to legumes in the right quantity. The deficiency has been reported to reduce nodule growth due to the high nodular requirement for P, either directly or indirectly. The P deficiency affects different metabolic activities in crops including legumes. The P deficiency has been attributed to a reduction in nodule formation [24]. The decline in ATP has also been reported under P deficiency. Nitrogen fixation by legumes requires higher P due to a reduction in the nodule formation and energy level. Under stressful environmental conditions, lack of P has been blamed for the low rate of nitrogen fixation. Potassium is also essential for different metabolic processes like photosynthesis, translocation of photosynthates, maintenance of plant turgor, and activation of enzymes. Potassium (K) and sodium (Na) supply are indispensable for osmoregulation and stomatal functioning in plants [25]. Yield losses due to an imbalanced K/Na nutrition were as high as 60% in plants [26].

Magnesium plays a significant role as the central element in the porphyrin ring of chlorophyll. Optimized magnesium concentrations in the nutrient medium are important for maximal CO_2 assimilation rate, as well as for the highest water use efficiency. Stomatal conductance depends on light and magnesium supply. Calcium is one of the essential macronutrients needed for plant growth because of its role in maintaining the structural rigidity of the cell walls as well as in membrane structure and function [27]. Calcium is involved in different physiological processes leading to the growth and development of plants. As discussed earlier, it is also involved in the plant's stress response and categorized as the second important messenger after ROS in stress signalling responses. It serves as a messenger in plant-biotic interactions [17].

Micronutrients

Quantitatively, trace elements are negligible chemical constituents of soils, but are essential as micronutrients for plants. Though, some are not useful biologically, but about seventeen trace elements have now been reported to be useful to plants. According to Bowen [28], the grouping of microelements is based on their activities in plants. For example, those incorporated into structural materials are; Si, Fe, and rarely Ba and Sr, those bound into miscellaneous small molecules, including antibiotics, and porphyrin are As, B, Br, Cu, Co, F, Fe, Hg, I, Se, Si, and V; those combined with large molecules, mainly proteins, including enzymes with catalytic properties are Co, Cr (not certain), Cu, Fe, Mn, Mo, Se, Ni (not certain), and Zn; those fixed by large molecules having storage, transport, or unknown functions are Cd, Co, Cu, Fe, Hg, I, Mn, Ni, Se, and Zn and those related to organelles or their parts (*e.g.,* mitochondria, chloroplasts, some enzyme systems) are Cu, Fe, Mn, Mo, and Zn. Among these, seven are biologically important and essential for proper plant growth and development. These include Fe, Cu, Zn, Bo, Co, Mn, Ni, and possibly Si. The trace elements essential for plants are those that cannot be substituted by others in their specific biochemical roles and that have a direct influence on the plant so that it can neither grow nor complete some metabolic cycle.

In leguminous crops, these micronutrients are also very essential, especially in nodule formation and nitrogen-fixing activities of legumes. The symbiotic relationship between legumes and rhizobials requires micronutrients like B, Co, Zn, Cu, Fe, Mo, Ni, Mn and Se. Apart from the roles of micronutrients in nodulation and activities, they also help in increasing resistance to biotic and abiotic stressors [4]. The micronutrients can achieve this due to their importance in enzyme activation. They are common components of the enzymes. Most micronutrients serve as metal activators in enzymes and by so doing, they enhance the activity of the scavenging and detoxifying enzymes [29]. Iron is an essential microelement with broad/widespread roles in plant's physiological and biochemical processes. It occurs in heme and non-heme proteins. It serves as a metal activator in enzymes and is concentrated mainly in chloroplasts where it is involved in photosynthetic electron transfer. It plays a significant role in chlorophyll synthesis and nucleic acid metabolism. In legumes, Fe is the central element of leghemoglobin.

Molybdenum also functions in the metabolism of plants. It is involved in the nucleic acid synthesis by its function in the enzymatic activities. The nodulated roots have been reported to contain more concentration of Mo compared to other parts of the plants because of their participation in the nitrate reductase activities of the root nodules of leguminous crops. Two Mo-containing enzymes in N metabolism are involved in either nitrogen fixation or nitrate reduction. Manganese is also an essential trace element that is involved in oxidation-reduction reactions and serves as a metal activator in enzymes. It participates in the photosynthetic electron transport system. Mn is also essential in the nodule formation and nitrogen fixation in legumes. Its deficiency and excess affect the rhizobia nodule numbers and thus the efficiency of N fixation. Mn is involved in the nitrite reduction step during nitrogen assimilation.

Nickel is an essential component of the enzyme urease and is required by nodulated legumes to transport N from roots to tops in the forms of ureide compounds. The roles of Co in the plant are generally not clear, although there are some evidence of a favorable effect of Co on plant growth. However, the essentiality of Co for both blue-green algae and microorganisms in fixing nitrogen is now well established. With this, it might also be playing essential roles in leguminous crops. In legumes, Co has been found to affect the ability of plants to fix N_2. It has been reported to be chelated at the center of a porphyrin structure called cobamide coenzyme, which is very important in N_2 fixation. It helps in the transfer of the H atom during the formation of the NH_3 compound by the rhizobia. Its deficiency in the leguminous crop has been reported to inhibit the formation of nodule pigment called ' leghemoglobin' which in turn affects nitrogen fixation. Mo is also a key component of nitrogenase, and its deficiency could disrupt leguminous nodulation and nitrogen fixation.

CONCLUSION

In conclusion, the mineral-nutrient status of plants plays a critical role in increasing plant resistance to environmental stress factors. The nutritional status of plants is relevant to their responses to stress. A balanced supply of macro- and micronutrients is essential to decrease the susceptibility of plants to biotic and abiotic stresses. The resistant varieties developed can only tolerate some levels of attack from these organisms, but the ability is reduced under poor nutrition. The low nutrient status of the plants would reduce the tolerance level of the plant to the attack by reducing the metabolite production. Appropriate fertilization is key. Increasing the physical and chemical fertility of cultivated soils by adequate and balanced supply of mineral nutrients will help in minimizing the detrimental effects of environmental stresses on crop production.

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTEREST

The author declares no conflict of interest, financial or otherwise.

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