Chapter 8
Role of Macronutrients in Plant Growth and Acclimation: Recent Advances and Future Prospective

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Abstract Macronutrients play a very important role in plant growth and development. Their functions range from being structural units to redox-sensitive agents. Generally, application of macronutrient increases yield, growth, and quality of crops. In the recent years, however, plant physiologists, biotechnologists, and ecophysiologists have been working to investigate various other blind features of these minerals and their future prospective, because nutrients are involved in every step of plant life. Every macronutrient has its own character, and is therefore involved in different metabolic processes of plant life. Herein, this chapter deals with the recent progress made in discovering the roles of macronutrients in plant growth and acclimation process as well as future prospective of elemental research in plants.

Keywords Macronutrients · Growth · Acclimation · Stresses

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P. Ahmad et al. (eds.), *Improvement of Crops in the Era of Climatic Changes,* Volume 2,
DOI 10.1007/978-1-4614-8824-8_8,

1 Introduction

The study related to plant mineral nutrients is a subject of marvelous curiosity and issue of immense importance among the plant physiologists, molecular biologists, and agronomists. Therefore, much research has been focused on this aspect to tackle problems related to the mineral nutrition of plants. Various studies demonstrated that plant nutrients are either chemical elements or generally compounds which are essential for growth, development, and better yield while also playing counter roles in external activities and metabolism of plants (Vitousek 1982; Alam 1999; Subbarao et al. 2003; He and Yang 2007). Studies related to nutrient's essentialities for plants were started from sixteenth and seventeenth centuries by renowned chemists Van Helmont, Boyle, Glauber, and Mayow (Street and Opik 1970). The ninetieth century saw an emergence of agricultural chemistry and witnessed the use of artificial fertilizer for improving the crop quality and yield. Furthermore, with the progress of water and sand culture techniques, appreciation of elements which are essential for plants was also discovered, and the essentialities of nitrogen (N), phosphors (P), sulfur (S), potassium (K), calcium (Ca), magnesium (Mg), and iron (Fe) for the plants were identified (Street and Opik 1970). Through the systematic development of elemental research, it has been shown that some plants complete their life cycle in the presence of various elements; however, in their absence, plants were incapable. Therefore, Epstein (1972) has classified elemental requirement in two ways, i.e., essential and nonessential elements. Figure 8.1 clearly reveals the abundance percentage of different elements with respect to plants, soil, and ocean; however, Fig. 8.2 depicts the pathway of mineral translocation from soil to roots and from roots to upper parts of the plants. Table 8.1 describes the basic information of elements regarding their weight percentage, symbol, major forms, order of their abundance on the earth's crust, etc. (http://hyperphysics).

Studies suggested that there are 20 elements which are regarded as essential or beneficial for the survival of plants; however, essentialities of 14 elements for plants are also a matter of enormous debate among the scientists working on elemental dynamics (Marschner 1995; Mengel et al. 2001). Furthermore, carbon, hydrogen, and oxygen are regarded as three major elements which are taken up through both air and water, while remaining elements accumulate through the plant roots from the soil. On the basis of elements' quantity and their requirement on the earth crust, they have been classified in many other ways such as macronutrients, i.e., N, P, K, Ca, and Mg, and micronutrients or trace nutrients which consist of B, Cl, Cu, Fe, Mo, Mn, Ni, Na, and Zn. Studies suggested that these elements enhance the growth and yields, besides performing different dynamic functions to protect the internal or external integrity of plant life (White and Brown 2010). Besides this, some elements like silicon (Si) and cobalt (Co) are characterized as beneficial elements but have not been considered as essential for all plants, nonetheless reaching the criteria of essential elements for some members of Poaceae and Cyperaceae (Tripathi et al. 2011, 2012b; Epstein 1999; Pilon-Smits et al. 2009; Barker and Pilbeam 2010).

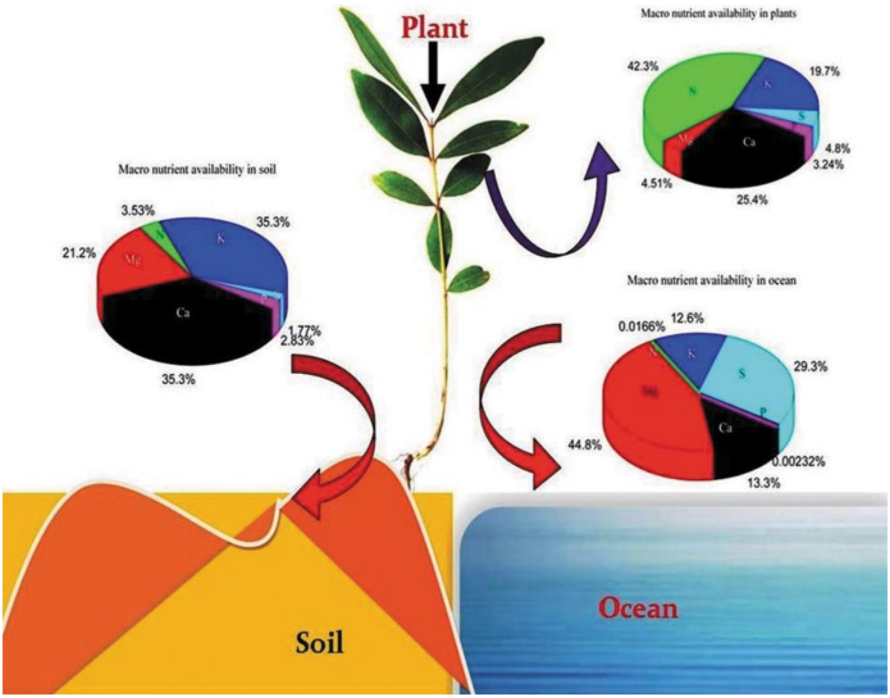

Fig. 8.1 Percent availability of macronutrients in soil, plant, and ocean

The Human body is known to require 22 mineral elements for sustainability of good health, and these mineralsare involved in different activities of human body; conversely, an appropriate diet is a major source of their availability (White and Broadley 2005a; White et al. 2009). It has been mentioned in the reports of Welch and Graham (2002) and White and Broadley (2005a) that 6 billion population of the world (above 60 %) are malnourished. On the other hand, it has also been noticed that, mainly in developed and developing countries, Ca, Mg, and Cu deficiencies are very common, and this has happened because of low amount of minerals in the natural sources such as crops, foods, water, etc.

From the beginning of nutrient evolution in various science disciplines, most of the works have been devoted to know the importance of elements in plants, animals, and ecosystems. However, in recent years, various studies related to the mechanism of elements' translocation from plant roots and subsequent distribution within the plant cells and their molecular dynamics have been well investigated (Sharma and Dubey 2005; Karley and White 2009; Miller et al. 2009; Miwa et al. 2009; Puig and Pen˜arrubia 2009; White and Broadley 2009; White and Brown 2010; Tripathi et al. 2011, 2012). Therefore, in this chapter we have summarized the progress and future prospective of macronutrients in plant science research.

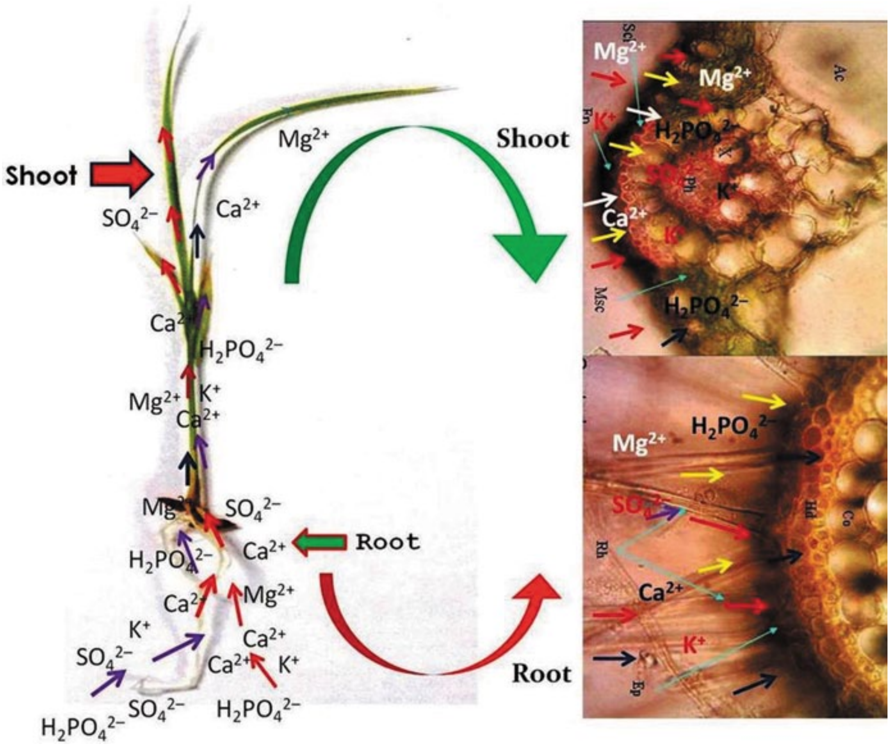

Fig. 8.2 Schematic diagram showing absorption of different macronutrients via plant's roots

Table 8.1 Some of the macronutrients with their order of abundance on the earth crust, major form of abundance, and weight % in the earth crust

Element	Symbols	Order of abundance in the earth crust	Discovered by	Year	Major form of abundance	Weight % in the earth crust
Calcium	Ca	Fifth	Humphry Davy	1808	Ca^{2+}	4.1
Magnesium	Mg	Eighth	Joseph Black Humphry Davy	1755 1808	Mg^{2+}	2.3
Potassium	K	Ninth	Humphry Davy	1807	K^+	2.1
Phosphorous	P	Eleventh	Hennig Brand Antoine Lavoisier	1669 1977	$H_2PO_4^{2-}$	0.1
Sulfur	S	Fifteenth	Antoine Lavoisier	1777	SO_4^{2-}	0.03
Nitrogen	N	Seventh	Daniel Rutherford	1772	NO_3^-	0.002

2 Macronutrients

Macronutrientsbasically performa counter role in various metabolic processes of plants and human beings, and are therefore required in large quantities for their survival. On the basis of their functions, macronutrients have been classified into two groups: primary macronutrients, i.e., N, P, and K, and secondary macronutrients, i.e., Ca, Mg, and S (Ryan et al. 2001; García et al. 2003; Rowley et al. 2012; Morgan and Connolly 2013). These primary and secondary macronutrients play significant role during the entire plant life by performing various beneficial activities in plant metabolism as well as protecting plants from various abiotic and biotic stresses including the stresses of heavy metals, drought, heat, UV radiations, and from diseases and insect pest attacks (Shanker and Venkateswarlu 2011; Rowley et al. 2012; Morgan and Connolly 2013). These macronutrients also help to increase the yield, growth, and quality of various crops (Morgan and Connolly 2013). Moreover, in recent years, plant physiologists, biotechnologists, and eco-physiologists have been working to investigate various other blind features of these minerals and discuss their future prospective because of nutrients involvement at each step of plant life. Every macronutrient has its own unique character, and is therefore involved in different metabolic processes of plant life.

2.1 Primary Macronutrients

2.1.1 Nitrogen

Nitrogen is the 15th group element of the periodic table, which belongs to the P block, and was first identified by Daniel Rutherford in 1772, while Jean-Antoine Chaptal was the first man who gave its name as “nitrogen” in 1790 (http://en.wikipedia.org). Generally, it is found in the form of a colorless and tasteless gas which makes up 78.09% by quantity of the earth’s atmosphere (Keeney and Nelson 1982; Fontana and Zickerman 2010; Alvarez et al. 2012). Nitrogen is required for plants in the greatest amount, which comprises about 1.5–2.0% of plant dry matter, besides approximately 16% of total plant protein (Frink et al. 1999; Craig Jr 2002; Chen et al. 2003; Lima et al. 2007; Alvarez et al. 2012). It has been suggested that in our entire solar system, N is probably the seventh abundant element and most essential component of all existing cells (Frink et al. 1999; Craig Jr 2002; Alvarez et al. 2012). Nitrogen is also regarded as the essential component of all proteinsand enzymes and further performs in various metabolic processes of energy transformation (Street and Kidder 1997). Therefore, sufficient amount of N availability in plants is required, because it is one of the major key factors of crop production (Nadeem et al. 2013). Studies reveled that nitrogen is also an essential constituent of chlorophylls, which is closely associated with photosynthetic process (Nursu’aidah et al. 2014). Furthermore, it facilitates to improve the fruit and seed production along with hasty plant growth, quality of forage crops, and leaf (Mengel and Kirkby 1987; Marschner 2011). In natural ecosystem and agriculture, N occurs in many forms such as nitrate, nitrite, ammonium, amino acids, etc; however, it is taken up by plants from various sources like fertilizers, air, water, rain, and some other sources in molecular form (N_2) directly (Bernhard 2010; Khajuria and Kanae 2013). It is converted into various obtainable forms by several soil organisms. It has been shown that in the past 50 years, owing to the systemic use of N in the form of fertilizer, crop production has almost doubled (Shaviv 2001). However, it is also true that due to the industrial pollution and severe climate change, the natural N cycle has considerably been in trouble (Cleemputa and Boeckxa 2013).

Vidal and Gutierrez (2008) and Lošák et al. (2010) confirmed that under various patterns of N supply, plants have shown elaborate reaction in relation to physiological and morphological levels to regulate their development and growth (Kiba et al. 2011). Additionally, Lošák et al. (2010) again reported the consequences of N on metabolisms of essential and nonessential amino acids of maize crops and declared that 240 kg N/ha application reduced most of the 17 amino acids analyzed in the grain of maize compared to 0 and 120 kg N/ha treatments, and concluded that the application of N in high amount showed a considerable outcome on the maximal accumulation of isoleucine, valine, histidine, leucine, cysteine, phenylalanine, and alanine. Similarly, Kandi et al. (2012) have reported that concentration of methionine and lysine amino acids, which are required for human body and cannot be created biologically, were affected in different varieties of potato under different levels of N, which significantly increased. Effect of N supply on the modification of plant hormonal status was also studied and systematically reported by Glare (2001). Kiba et al. (2011) and Pavlíková et al. (2012) proposed that phytohormones like abscisic acid (ABA), indole-3-acetic acid (IAA), and cytokinins (CK) were strongly connected to nitrogen signaling. Additionally, Takei et al. (2001, 2002) and Cline et al. (2006) reported that N availability is closely connected with the cytokinins in many plant species. Results also suggested that cytokinins' metabolism and translocation were adjusted by N nutritional status in plants (Takei et al. 2001; Sakakibara et al. 2010; Pavlíková et al. 2012). Different N pathways; its fixation; uptake involving genes; genetic, biochemical, and ecological aspects; and future prospects in sustainable agricultural development have been well studied earlier (Simpson 1983; Jamiesona and Semenov 2000; Martre et al. 2003; Zhu et al. 2006; Foulkes et al. 2009; Hirel et al. 2011; Alvarez et al. 2012; Sharma et al. 2013).

2.1.2 Phosphorus

Phosphorus belongs to P block elements of periodic table and is considered as a nonmetallic element, first indentified by Hennig Brand in 1669; however, Antoine Lavoisier acknowledged phosphorus in the form of element in 1777 (Seaborg 1980; Luminaris 2005; http://en.wikipedia.org/wiki/Phosphorus). It is found as white P and red P; however, due to its soaring reactivity, it is never available in the form of free constituent on the earth. Maximally, its compounds are used as fertilizers; however, It also is used frequently in the form of detergents, pesticides, and matches (Diskowski and Hofmann 2005). In cell membranes of the plant, it is abundantly present in the form of phosphate, where it plays vital roles in being the constituent of DNA, RNA, and ATP (Brown and Weselby 2010; http://en.wikipedia.org/wiki/Phosphorus). Thus, it is regarded as an essential component for growth and development of plants; however, its availability in soil is often low, and therefore its high amount in the form of organic phosphate is exogenously used to attain high crop yields (Huang et al. 2011). Among crops, barley (*Hordeum vulgare*) and wheat (*Triticum aestivum*) plants use around 46 % of P in the form of fertilizers (Huang et al. 2011; Hackenberg et al. 2013). But wide-ranging fertilization in the crop fields with extensive P leads to fast exhaustion of nonrenewable P wealth, and therefore contributes to environmental pollution; however, its deficiency in soil causes significant reduction in crop yields (Elliott et al. 1997; Vance et al. 2003; Gahoonia and Nielsen 2004; Huang et al. 2011).

Studies related to various aspects of P utilization, its uptake, and its effect on diverse metabolic processes are the main research scopes for scientists working on agronomical and agricultural issues (Ballantyne 2009). Jia et al. (2011) proposed that phosphate transporters (PTs) are generally involved in uptake and translocation of their inorganic form (Pi) from the soil; however, biological belongings and physiological function of PTs are still lacking. In this context, Jia et al. (2011) demonstrated a PT gene *OsPht1* of family Pht1, which is keenly involved in P homeostasis in rice. Furthermore, Hammond et al. (2011) stated that regulatory hot spots are linked to plant gene appearance under different soil P availability in *Brassica rapa*. In addition, Huang et al. (2011) have shown that P utilization efficiency can be correlated with expression of low-affinity PTs and non-coding RNA, IPS1 in barley. Further, Postma and Lynch (2011) reported that suboptimal availability of P in root cortical aerenchyma improves the growth of maize plants. Due to a modification of cell division or cell elongation factors, leaf growth depression under P deficiency is well recognized (Chiera et al. 2002; Assuero et al. 2004; Kavanova et al. 2006).

Additionally, Kavanová et al. (2006) reported that lack of phosphorus content causes adecline in cell division and cell elongation in the leaves of various grasses. It has been well reported that P is a necessary component of photosynthetic processes which are systematically implicated in creation of sugars, oils, and starches and which further helps in the conversion of solar energy into chemical energy, proper plant maturation, and withstanding stress. It also promotes the rapid growth of plants as well as root systems; therefore, research related to P availability and its consumption is a need of further research from agronomical, agro-economical, as well as agricultural points of view.

2.1.3 Potassium

Potassium (K), which is regarded as one of the most valuable elements for the growth and development of plants, is alkaline in nature, and the term K is related to the Neo-Latin world kalium. It was first introduced and isolated by Humphry Davy in 1807 (Holden 2001). Potassium is a necessary and extremely mobile macronutrient in plants that is abundantly present in young parts of the plants. However, Fernando et al. (1992) reported that cytosol contained its highest amount, i.e., 30–

50 mMm, while 20 mM was found in vascular region of the cells. Mengel (2007) suggested that K plays a major role as a cationic inorganic element in the plants and is therefore regarded as an essential element to all plant life, and plants cannot survive without its presence. It is linked to many physiological processes which help in improving photosynthesis, enzyme activation, water relations, assimilates, transportation, as well as plant growth and development (Pettigrew 2008; Lidon and Cebola 2012; Zlatev and Lidon 2012). Helal and Mengel (1979) revealed that if K^+supply is poor in plants, protein synthesis will be inhibited and, therefore, forerunners of proteins like amino acids, amides, and nitrate could be accumulated. Conversely, Leigh and Wyn Jones (1986) suggested that it also endorses the uptake of amino acids and is also very important for protein synthesis. Furthermore, Anonymous (1998) explained the essentiality of K in plants during protein synthesis, i.e., transcription and translation, and suggested that these two processes would not be possible without ample K supply to the plants (Wakeel et al. 2011). It has also been observed that during the entire protein synthesis process, potassium is frequently associated with binding of transfer RNA (tRNA) to ribosomes (Wakeel et al. 2011).

Pfluger and Mengel (1972) reported that nicotinamide adenine dinucleotide phosphate (NADPH) plays a key function in photosynthesis, whereas K is responsible for the activation of biosynthesis of this coenzyme. Plant cell membranes are relatively permeable to K ions because of the existence of different selective K ion channels, and are therefore involved in control of various processes of the cell (Chrispeels et al. 1999; Yamaguchi and Blumwald 2005). Chrispeels et al. (1999) stated that K is an active constituent of plant metabolic system, which dynamically entails transportation of metabolites, nutrients, phytohormones, and water through xylem and phloem, while deficiency of K ions in plants severely affects the transportation mechanisms. It also helps in stabilization of pH (7–7.5) for proper enzymatic reactions as well as diffusion of various organic anions and other compounds within the plant (Mengel and Kirkby 1980). It has been shown by Anonymous (1998) that the process of opening and closing of stomata in most of the plants is dependent upon K ions, because their movement between the guard cells of stomata checks the loss of water, and therefore helps in minimizing the risk of drought stress. Potassium plays a valuable role in minimizing the worldwide agriculture and agronomical problems like heavy metal stress: Cd, Cr, and Al (Shaviv 2001).

2.2 Secondary Macronutrients

2.2.1 Calcium

Among the list of all available elements, calcium is found to be the fifth most plentiful element on the earth crust, and is also regarded as the fifth most ample liquefied ion in ocean (Krebs 2006). First discovered by Humphry Davy in 1808, calcium belongs to the second group and S block in the periodic table (Enghag 2008). It is one of the most essential elements for all living organisms and is required particularly in the form of calcium ions (Ca^{2+}) that helps as well as participate in many cellular processes (Marschner 1995; White and Broadley 2003). It is important to every plant for their growth and development and is involved in activating the enzymes, inducing water movement and salt balance in plant cells, and also activating K to control the process of opening and closing of stomata (Hepler 2005). It is also required for cell growth, division, elongation, and various essential biological functions (Berridge et al. 2000; Hirschi 2004). Calcium boosts the nutrient uptake, improves the plant tissue's resistance, makes cell wall stronger, and contributes to normal root system development (Berridge et al. 2000; Hirschi 2004). Hepler (2005) noticed that Ca is an essential regulator of plant growth and development and that deficiency in plants causes yellow coloration and black spots on leaves. Further, when deposited in plant tissues, it is immobile. For this, cells have developed several mechanisms for strongly regulating calcium ion (Ca^{2+}) fluxes as well as different Ca pools, and thus it is keenly transported from the cytosol into the mitochondria, endoplasmic reticulum, cell walls, plastids, and vacuoles (Bush 1993; Harper 2001; Pittman and Hirschi 2003; Volk et al. 2004). It has been reported that Ca ions alleviate ionic stress in plants, and various feasible mechanisms have been briefly described by which Ca ions are able to prevent the subsequent damage (Plieth 2005). Kochian (1995) reported that, due to protective behavior of Ca ions, the plants were protected from the Al toxicity.

Additionally, Rodriguez-Serrano et al. (2009) also reported similar observations in which Ca influenced the Cd toxicity in pea plants. Moreover, various studies also revealed that Ca protects plants from various biotic and abiotic stresses through its various advantageous signaling channels such as Ca^{2+}/H^{+} antiporters, Ca^{2+}-ATPases, etc. (Hong-Bo et al. 2008; Kudla et al. 2010) Channels of Ca porous ion are ultimately accountable for drought stress signal transduction (Bush 1995; Norelli and Miller 2004**;** Andjelkovic and Thompson 2006; Ahn and Suh 2007; Hong-Bo et al. 2008; Morgan et al. 2013).

Recently, Yang et al. (2013) suggested that *SlSRs* gene plays diverse roles in response to specific stress signals, and this *SlSRs* gene may act as a coordinator(s) connecting Ca-mediated signaling with other stress signal transduction pathways during fruit ripening and storage. Furthermore, Li et al. (2013) also discovered that under NaCl stress in tobacco, a gene, HSP, successfully expressed the Ca signaling pathways. Several other studies based on Ca response against the stresses suggested that many transcription factors like SR/CAMTA perform greater role against multiple abiotic and biotic stresses, preferably drought, cold, pathogens, and wounding, as well as ethylene, auxin, MeJA, and SA (Reddy et al. 2000; Yang and Poovaiah 2000; Bouche et al. 2002; Yang and Poovaiah 2002; Galon et al. 2010; Reddy et al. 2011; Yang et al. 2013).

2.2.2 Magnesium

Magnesium is a very common element which is found in all living beings on earth; among the comparative list of abundance, it is the eighth most abundant element on the earth crust and ninth in the universe (Ash 2005; Housecroft and Sharpe 2008; Luft 2012). In 1755, Joseph Black was the first scientist who introduced magnesium, though it was first isolated by Humphry Davy in 1808,and the term Mg comes from the Greek word magnesia. It performs several advantageous functions in plants and animals, and is known as one of the essential nutrient elements for the survival. However, with reference to plants, its amount has been found to be 0.2–0.4 % of plant dry matter and its requirement for preeminent plant growth is 1.5–3.5 g kg^{-1} in the vegetative parts (Hopkins and Hüner 2011; Marschner 2012; Chen and Ma 2013). Magnesium is a central atom of chlorophyll and therefore plays a major role in plant photosynthesis, and thus its deficiency degrades the chlorophyll content and leaves become yellowish in color, which is known as chlorosis; however, an adequate supply of Mg makes the plant healthy (Ding et al. 2008; Hermans et al. 2010). Shabala and Hariadi (2005) proposed that low or excess levels of Mg contents in plants may serve diverse impact on photosynthesis. As it is a movable element in plants, chlorophyll of the plants is first decreased in old leaves and the remaining amount of Mg in old leaves is transferred to younger leaves (Hermans et al. 2010). Shaul (2002) also reported that even minute differences in Mg level may affect the various important chloroplast enzymes. Studies suggested that Mg is an active constituent of electron transportation chain; therefore, during the entire process of electron transport chain of the chloroplast, Mg has a significant responsibility. Furthermore, due to the presence of appropriate level of Mg content, the action of antioxidative enzymes and the content of antioxidant molecules were reported to be increased in pepper, maize, bean, mulberry, and *Mentha pulegium* (Cakmak and Marschner 1992; Cakmak 1994; Candan and Tarhan 2003; Tewari et al. 2004, 2006; Anza et al. 2005, Ding et al. 2008; Waraich et al. 2012). Tewari et al. (2006) further suggested that Mg deficiency increases the oxidative stress in mulberry plants by enhancing the generation of ROS and triggering distinct redox changes in the cellular metabolism, and with its sufficiency, activation of antioxidant machinery, including induction of distinct superoxide dismutase (SOD) isoforms, takes place. A study carried out by Ding et al. (2008) clearly revealed that low level of Mg in rice plants was negatively associated with the concentration of Malondialdehyde (MDA) and three antioxidative enzymes; however, exogenous supply of Mg and K in rice plants showed significant interactive effects in shoot biomass, yield, chlorophyll content, photosynthetic rate, and the activities of SOD, catalase (CAT), Peroxidase(POD), and MDA contents (Ding et al. 2008).

Chen et al. (2012) reported that Mg alleviates stress in rice, and this behavior is closely associated with Mg transporter. Further, Chen and Ma (2013) stated that Mg alleviates Al toxicity through functioning of Mg transporters, which are accountable for its adequate translocation, distribution, and uptake in rice plants. Magnesium alleviates heavy metal stresses in other plant species which has also been well studied (Ryan et al. 1994; Tan et al. 1992; Silva et al. 2001; Watanabe and Okada 2005; Yang et al. 2007; Chou et al. 2011; Chen and Ma 2013). Another efficient role of Mg in disease resistance management in different plant species has also been recognized (Sugawara et al. 1998; Rogan et al. 2000; Jones and Huber 2007; Dordas 2009), and in this reference, recently, Jones and Huber (2007) successfully referred the facts that an adequate supply of Mg may control various harmful plant diseases. However, previously, it has been revealed that Mg successfully controlled root rot diseases caused by *Rhizoctonia solani* in bean plant (Bateman 1965). Besides, Thomas and Orellana (1964) reported effective role of Mg against the leaf spot diseases caused by *Botrytis* spp. in Castor bean; however, early blight disease caused by *Alternaria solani* inpotato has also been controlled by Mg addition (Panthee and Chen 2010).

2.2.3 Sulfur

Sulfur (S) is the ninth richest element on the earth's crust, which is naturally found in the form of pure sulfide and sulfate minerals (Khan and Mazid 2011). It is a P block element having the atomic weight of 32.06 and has been discovered in China before 2000 BC and later documented as an element in 1777 by Antoine Lavoisier. It is known as the most beneficial element for all living organisms and performs various dynamic roles for growth, development, and survival of plant life. Therefore, for maximum production, it is regarded as an essential plant nutrient necessary for all crop plants. Generally, plants take sulfur in the form of sulfate (SO_4^{2-}) which is verymobile in soil and recognized as the fourth most necessary element for the plants after N, P, and K (Jamal et al. 2010). Various studies have recognized the importance of S in plants and its possible role in agriculture development (Jamal et al. 2005, 2006a, b, c, 2009, 2010; Scherer 2009; Jamal et al. 2010). Major role of S has been differently recognized, i.e., it plays a crucial role in the synthesis of chlorophyll, proteins, seeds oil content, as well as amino acids methionine and cysteine (Tandon 1986; Jamal et al. 2005, 2006a, 2009; Jamal et al. 2010). Further, activities of various other essential elements like P, N, Mg, and Ca are closely connected with S deposition in plants, and the interaction of these minerals with S is beneficial for crop improvement. Therefore, in these aspects, various studies have been conducted. In the process of protein synthesis, S and N play a key role, while translocation of these two mineral nutrients in plants is highly interrelated and the relationship between these two elements has been well studied (Zhao et al. 1993; McGrath and Zhao 1996; Jamal et al. 2006a, 2010). Moreover, benefits of S and N interaction in the yield of plants has been well studied in many plants such as sunflower, soybean, mustard, and groundnut (McGrath and Zhao 1996; Ahmad et al. 1998, 1999; Ahmad and Abdin 2000; Fazili et al. 2010a, b, Verma and Swarankar 1986; Jamal et al. 2010). Lopez-Jurado and Hunnway (1985) and Jamal et al. (2010) reported that S is a main component of nitrogen fixation in legumes; however, it has also been shown that addition of S extensively improved the nitrogen fixation, growth, and yield of plants. All et al. (2002) reported alleviative effect of S on plant growth under saline conditions and the response of S application on K/Na in sunflower. Further, S has also been reported to alleviate the Cd toxicity in various plant species, i.e., *Arabidopsis thaliana, B. juncea, Nicotiana tabacum, T. aestivum,* and *B. campestris* (Zhu et al. 1999a, b; Harada et al. 2001; Harada et al. 2002; Ashraf and Harris 2004 Sarry et al. 2006; Khan et al. 2007; Anjum et al. 2008; Gill and Tuteja 2011).

Role of S in other aspects cannot be overruled, because S-rich protein may improve the plant defense mechanisms against the pathogens, since its related compounds are closely connected to biotic stress resistance (Rausch and Wachter 2005; Hell and Kruse 2007; Hell and Hillebrand 2008). Additionally, Cooper and Williams (2004) have described the role of S as an induced antifungal material in plant protection, while Williams et al. (2002) reported the role of S and thiol (S-containing group) accumulation in tomato plants against the fungal pathogen stress. Momose and Iwahashi (2001) accounted for the genes of S metabolism pathway in *Saccharomyces cerevisiae* under Cd interaction (Gill and Tuteja 2011).

Besides, two S-regulated genes *Sultr1* and *Sultr2,* which encode two sulfate transporters, have also been found to be affected due to the Cd treatment (Takahashi et al. 2000; Herbette et al. 2006; El Kassis et al. 2007; Khan et al. 2007; Pootakham et al. 2010; Gill and Tuteja 2011).

3 Conclusions and Future Perspective

In conclusion, macronutrients play a very important role in plant growth and development, and thus influence every stage of plant life. However, excess and/or deficit of macronutrients may adversely affect the overall growth and performance of plants. Therefore, the cellular status of an element must be tightly regulated. Report of Welch and Graham (2002) and White and Broadley (2005a) revealed that 6 billion population of the world (above 60 %) are malnourished. Further, it has also been noticed that in developed and developing countries, Ca, Mg, and Cu deficiencies are very common. This condition has been developed due to low amount of minerals in sources such as crops, foods, water, etc. The condition warrants plant scientists to optimize methods in order to maintain the amount of essential nutrients in desired quantity, while simultaneously keeping the toxic element at the least level. This biofortification of crops with desired macronutrient may help to abolish mineral deficiency. Besides this, by managing the amount of particular macronutrient, the unwanted loss of crop productivity due to other stresses will also be minimized, which could help to feed the growing population.

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