
A Review: Plant Damage Due to Nutrient Imbalance and Strategies to Increase Nutrient Efficiency

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ABSTRACT

The nutritional state of a plant can range from acute poisoning to acute deficiency. For broad purposes, it could be helpful to categorize the nutritional status into four groups: surplus, ideal, inadequate, and extensive. Nutrients that are considered essential include boron (B), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), nickel (Ni), molybdenum (Mo), calcium (Ca), magnesium (Mg), sulfur (S), and chlorine (Cl). Every nutrient has an effect on the metabolism of plants at every stage of their growth. Of course, breeding techniques are used to improve the efficiency with which plants take nutrients, such as enhancing nutritional utilization and optimizing nutritional efficiency through root modifications. In nutrient-poor soils, for instance, optimizing root shape to boost nutrient uptake efficiency can boost plant output. While developing organs, particularly reproductive organs, transpire at low rates, they need a lot of mineral resources to expand actively. Plants' nutritional efficiency may be effectively increased by using genetic engineering to transfer genes from other species, so overcoming the restrictions imposed by genetic variation within the same species.

Keywords: nutrient imbalance, deficiency, toxicity, marker assisted selection

INTRODUCTION

Plants need nutrients for growth and development. A plant's sufficiency range is the range of nutrient amounts required to meet the plant's nutritional needs and maximize growth. Nutrient levels outside a plant's sufficiency range will result in reduced growth and health of the plant due to deficiency or toxicity (McCauley, 2011).

A plant's nutritional status can vary from acute deficiency to acute toxicity. It may be useful for general purposes to divide the nutritional status into four groups: extensive, deficient, optimal and excess. For more accurate assessment of the

nutritional status of plants, detailed categorization is required, in which six different ranges can be distinguished: acute deficiency, marginal or latent deficiency, optimal supply, luxury supply, marginal or slight (latent) toxicity, acute toxicity (Finck, 1992).

There are at least two groupings of nutrients needed by plants, namely essential nutrients, beneficial nutrients. Essential nutrients include: nitrogen (N), potassium (K), phosphorus (P), calcium (Ca), magnesium (Mg), sulfur (S), chlorine (Cl), boron (B), iron (Fe), manganese

(Mn), copper (Cu), zinc (Zn), nickel (Ni), molybdenum (Mo). Meanwhile, beneficial nutrients include: sodium, selenium, cobalt, silicon (Si), and aluminum (White and Brown, 2010). Each nutrient plays a role in plant metabolism and

IMPACT OF NUTRITIONAL IMBALANCE

Nitrogen

Nitrate (NO_3^-) is the more abundant form of nitrogen in soils. NO_3^- is sensitive to uptake by (1) low temperature, (2) inhibitors of both respiration and protein synthesis, and (3) anaerobic conditions (Kacar and Katkat, 2010). Proteins, amino acids, nucleic acids, enzymes, chlorophyll, ATP, and ADP are important organic compounds containing nitrogen (Foth, 1984).

Nitrogen has a great effect on the synthesis of proteins and chlorophyll. It is the basic building block of the plant cell wall. Nitrogen plays a major role in the respiration of the roots, the timeliness of flowering, and the formation and maturation of the fruit (seed). Trees that are well-fed with nitrogen also have increased resistance to pests (Bozgelmez et al., 2001; Guzel et al., 2004).

In nitrogen deficiency, the growth rate of plants decreases. Especially the vegetative development of the plant is negatively affected. The leaf and stem system becomes very weak. Root development and especially branching in the roots are weakened. Flowering and fruit set rate decreases and fruits remain small. Leaf area index decreases and photosynthesis occurs less frequently (Fageria, 2009).

If the deficiency is more severe, chlorosis occurs on the leaves. Chlorosis occurs as a homogeneous yellowing of the leaf. The leaves turn brown and die (Gardiner and Miller 2008). Excess nitrogen prolongs the vegetative development period of the plant, delays flowering, and reduces sugar synthesis. It causes late ripening in fruits (McCauley et al., 2009). Excess nitrogen reduces resistance to diseases (especially fungal diseases). While it reduces the resistance of plants to breakage, it also causes a delay in harvest time (Kantarci, 2000).

each stage of plant growth. In this review, we will explain the imbalance in plant nutrition which will be studied in each nutrient in the language below. These studies describe examples of the effects of nutritional imbalances on several plants.

Potassium

The main roles of K^+ in the plant are (1) turgor production as it forms the main cation of the vacuole, (2) photosynthesis, (3) control of stomatal opening, (4) protein synthesis, (5) preservation of cation-anion balances and (6) enzymatic reactions. activation of enzymes by acting as a cofactor (Hafsi et al., 2014).

In K^+ deficient plants, the decrease in photosynthetic activity and transport of photosynthates from leaves led to oxidative stress, which had detrimental effects on the plants. This causes growth and productivity declines. To cope with K^+ deficiency, plants develop some tolerance strategies, including: (1) increased K^+ uptake and utilization, (2) increased uptake of other cations such as Na^+ , Mg^{2+} , and Ca^{2+} to replace K^+ in some physiological and biochemical functions, and (3) K^+ Circulation of from the oldest leaves to the youngest leaves (Hafsi et al., 2014). Excessive amounts of potassium in the soil do not have a harmful effect on plants, unlike excess nitrogen and phosphorus. However, it is reported that excess potassium negatively affects the manganese uptake of plants (Bosgelmez et al., 2001).

Phosphorus

Phosphorus (P) is an important plant macronutrient, accounting for approximately 0.2% of a plant's dry weight. It is a component of key molecules such as nucleic acids, phospholipids, and ATP, and as a result, plants cannot grow without a reliable supply of this nutrient. P also plays a role in controlling key enzyme reactions and regulating metabolic pathways (McCauley et al., 2009; Foth, 1984).

Phosphorus deficiency is noticed earlier in

young plants, which need more phosphorus, than in older plants. Additionally, phosphorus deficiency may occur in cold (wet) soils at the beginning of the vegetation season. In phosphorus deficiency, generative organs such as flowers, fruits, and seeds are damaged the most. Growth regresses in plants with phosphorus deficiency. Shoot and bud formation in fruits and trees decreases. The leaves become darker green than normal. Root development of plants weakens. The plant's resistance to frost and diseases decreases (Plaster, 1992; Aktas and Ates, 1998).

The effect of excess phosphorus on plants occurs mostly indirectly. On the other hand, since phosphate ions are tightly held in the soil, it becomes difficult for plants to take up phosphate ions. Therefore, excess phosphorus in plants is not a common situation. In case of excess phosphorus, deficiencies in micronutrients such as zinc and iron occur, while calcium, boron, copper, and manganese deficiencies may also occur (Bosgelmez et al., 2001; Theodorou and Plaxton, 1993).

Calcium

Calcium plays an important role in protein formation and transportation of carbohydrates in plants (Plaster, 1992; Cepel, 1996). Calcium deficiency in plants slows down the growth of meristem tissues. The development of the shoot tip buds and the growth tips of the roots stops, and therefore the development of the plant also stops. Young leaves are deformed. Black and brown necrosis occurs on the leaf edges. Leaf tips become more dry or brittle (break easily) and the leaf eventually wilts and dies (Bosgelmez et al., 2001; Kacar and Katkat, 2010). If calcium is present in excess in arid region soils, it has an antagonistic effect on the uptake of some other nutrients, especially micronutrients. For example, if there is too much calcium in the soil, potassium, iron, phosphorus, and other elements turn into forms that plants cannot use (Gardiner and Miller, 2008).

Magnesium

Magnesium has a number of key functions in plants. Specific metabolic processes and reactions carried out by Mg include 1)

photophosphorylation (such as ATP formation in chloroplasts), 2) photosynthetic carbon dioxide (CO₂) fixation, 3) protein synthesis, 4) chlorophyll formation, 5) phloem loading, 6) cleavage of photoassimilates and utilization, 7) generation of reactive oxygen species, and 8) photooxidation in leaf tissues (Aktas and Ates 1998). Leaf yellowing in the form of interveinal chlorosis on older leaves is one of the typical symptoms of Mg deficiency stress. In this state, the leaves have a mottled appearance (Gardiner and Miller 2008).

In some cases, magnesium deficiency may occur even if there is sufficient magnesium in the soil. Ions such as hydrogen, potassium, ammonium and calcium, which are found in high amounts in the soil solution, can reduce magnesium uptake and cause deficiency. In calcareous soils, magnesium available to plants is generally sufficient. Magnesium deficiency can be seen in acidic soils (Bozgelmez et al., 2001; Kantarci, 2000).

Sulfur

The symptoms of sulfur deficiency in plants are similar to the symptoms of nitrogen and molybdenum deficiency. In plants with sulfur deficiency, there is a homogeneous yellowing of the leaves. This situation is very similar to nitrogen deficiency. However, in the case of nitrogen deficiency, the yellowing of the leaves appears first in the old leaves, while in the case of sulfur deficiency, the yellowing of the leaves appears in the young leaves. Protein synthesis is inhibited due to the deficiency of sulfur-containing amino acids such as cysteine and methionine. The growth of the plant is slow, the leaf surfaces become narrower; It gives a woody feeling when touched. In addition, in sulfur deficiency, the plant remains weak and small (stunted), while the trunk becomes thin. In particular, crown development is more affected by sulfur deficiency than root development (McCauley et al., 2009; Ozbek et al., 2001). High sulfur dioxide concentration in the atmosphere has a toxic effect on plants. Sulfur dioxide can also destroy the membranes of chloroplasts. Additionally, in humid regions, sulfur dioxide gas paves the way for the formation of sulfuric acid, and acid rain negatively affects ecosystems, especially primary vegetation (Guzel et al., 2004).

Chlorine

Chlorine is a plant nutrient element needed by plants for photosynthesis and turgor pressure of leaves. It plays a role in the activation of the adenosine triphosphatase enzyme. It is effective in regulating stomatal movements and cell proliferation. It has been determined that chlorine plays a regressive role in nitrification and has a positive and significant effect on the transformation of Mn_{+3} and Mn_{+4} oxides into the Mn_{+2} form that is beneficial to the plant. It is reported that chlorinated fertilizers have a regressive effect on diseases seen in various plants (Plaster, 1992).

Chlorine in the atmosphere and rainwater is at a level that meets the needs of plants. However, some symptoms that occur in cases of chlorine deficiency in plants are as follows: (1) transpiration is affected, (2) chlorosis appears, (3) leaf edges fade, (4) cell proliferation regresses in some plants, and (5) the growth of leaves slows down significantly (Ozbek et al., 2001). Chlorine toxicity occurs in plants grown in saline soils with high chlorine content. In this case, burning on the leaf tips and edges of the plant, bronzing, and premature shedding of the leaves occur. The high chlorine concentration in the soil solution causes an increase in the osmotic potential in the soil water. Plants cannot get the water they need. As a result, there is a drought problem caused by chlorine (Guzel et al., 2004).

Iron

Proton ATPase AHA_2 , Ferric chelate reductase FRO_2 (ferric reduction oxidase), Fe_{2+} regulated transporters iron-regulated transporter (IRT1) and FER-like iron deficiency-induced transcription factor (FIT) are respectively activated under iron starvation. AHA_2 (H^+ -ATPase) increases acidification of the rhizosphere to facilitate iron solubility. FRO_2 reduces ferric iron to ferrous iron, which is imported into the cell via IRT1. Expression of FRO_2 and IRT1 can be induced through FIT interaction with bHLHs and other transcription factors such as EIN3/EIL1 but can be inhibited by DELLA (Zhang et al., 2019).

Low pH and low oxygen availability in

waterlogged soils lead to Fe depletion. Highly available iron can precipitate in the apoplast of the root (escape mechanism) or enter the root cells. Some plant genotypes can sequester most of the iron in the roots (low acropetal transport), while others exhibit high levels of Fe in shoots, leading to oxidative stress. Various plant species and genotypes within a species can benefit from Fe partitioning or chelation, storage in Ferritin, and induction of antioxidant enzymes to cope with high leaf Fe concentrations. When such mechanisms do not function adequately, various physiological processes lead to typical Fe overload symptoms (Sperotto et al., 2010).



Figure 1. ILC 6119, chickpea genotype sensitive to iron deficiency

Boron

The main function of the boron element in the plant is to ensure the formation of cell walls and the regeneration of tissues. Boron activates some dehydrogenase enzymes. It plays a role in carbohydrate biosynthesis. It is effective on nucleic acid and protein metabolisms. It plays a role in the displacement of sugars within the plant (Plaster, 1992).

Damage to plants from boron deficiency manifests itself in the form of chlorosis in young leaves, and also with the death of terminal buds, which are the main growth organs of plants. Accordingly, the growth of the plant slows down. As a result of boron deficiency in plants, due to damage to cell wall growth, leaves and stems become brittle, easily broken, and misshapen. The

leaves curl and turn a dark blue-green color. Leaf tips thicken (Bozgelmez et al., 2001; Kacar and Katkat, 2010; Ozbek et al., 2001).

Its presence in high concentrations in soil and water has a toxic effect on plants. In older leaves, leaf tips turn yellow and necrosis occurs. Later, the symptoms spread towards the leaf edges and midrib. The leaves take on a burnt appearance and fall off early (McCaulay et al, 2009).

Zinc

In zinc deficiency, carbohydrates, proteins, and growth hormones (auxin) are also damaged due to decreased enzyme activity. The chlorophyll content of plants decreases tremendously in zinc deficiency. Chlorosis occurs between leaf veins. While the veins on the leaves remain green, the color of the parts between the veins may be light green, yellow or white. Leaf formation in plants is negatively affected and leaves become sparse. Shoots die and leaves fall prematurely. The number of buds decreases and the rate of bud opening decreases (Hermens et al., 1993; Ren et al., 1993).

The first symptom that manifests itself in most species exhibiting Zn toxicity is the general chlorosis of young leaves. Depending on the degree of toxicity, this chlorosis can progress to browning due to anthocyanin production in young leaves. Plants exhibiting Zn toxicity had smaller leaves than control plants. Brown spots become evident on the leaves of some species. In roots, Zn toxicity is evident as a reduction in the growth of the main root, fewer and shorter lateral roots, and yellowing of the roots (Fontes and Cox, 1995; Lee et al., 1996).

Copper

In case of deficiency of copper element, symptoms such as chlorosis (jaundice) in young leaves of the plant, stunted development, late ripening, and in some cases, excess color substance in the tissues (brown color spot) may be observed. In copper deficiency, plants are especially vulnerable to diseases caused by fungi. In copper deficiency, carbohydrate content is greatly reduced. It has also been determined that nodule formation in legume plants decreases and less N is

fixed (Gardiner and Miller, 2008).

When there is an excess of copper in soils, toxic effects occur. It becomes difficult to absorb iron; That's why chlorosis, similar to iron deficiency, is observed. Other negative situations seen in plants are the weakening of root and shoot development. Additionally, excess copper negatively affects the use of molybdenum (Aktas and Ates, 1998; Kacar and Katkat, 2010).

Mangan

Necrotic brown spotting on leaves, petioles, and stems is a common symptom of Mn toxicity. This spotting begins on the lower leaves and progresses to the upper leaves over time. Another common symptom is known as “wrinkled leaf,” which occurs in the youngest leaf, stem, and petiole tissue and is associated with chlorosis and browning of these tissues. Roots showing Mn toxicity are usually brown and sometimes cracked (Horst and Marschner, 1978; Elamin and Wilcox, 1986; Horiguchi, 1988). A nutrient solution containing high levels of Mn was found to reduce the amount of Fe accumulated on the root surface and the amount of Fe transported to the shoots. Excess Mn causes a decrease in Fe uptake and transport in soybeans (Bachman and Miller, 1995; Le Bot et al., 1990).

Chloroplasts (plant organelles where photosynthesis occurs) are the most sensitive of cell organelles to Mn deficiency (Linge et al., 1963; Safford, 1975). As a result, a common symptom of Mn deficiency is interveinal chlorosis in young leaves. Two well-known Mn deficiencies in arable crops are a gray spot in oats and black pitting and lesions in peas. White streaks on wheat and interveinal brown spots on barley are also symptoms of Mn deficiency (Mengel and Kirkby, 2001; Jacobsen and Jasper, 1991).

Nickel

Plants suffering from nickel deficiency accumulate toxic levels of urea in the leaf tips due to decreased urease activity. In the case of nickel deficiency, the development of aboveground and underground organs of plants decreases, the green color of the plant gradually disappears, and chlorosis and necrosis occur between leaf veins.

However, nickel deficiency is not generally seen in plants (Havlin et al., 1999). Poisoning occurs in plants grown in soils containing high amounts of nickel. Therefore, fertilizing the soil with potassium and calcium prevents the poisonous effect of nickel. On the other hand, it is known that phosphate fertilizers increase the toxic effect of nickel (Fageria, 2009).

Molibdenum

Symptoms of molybdenum deficiency manifest themselves as stunted growth in legumes and chlorosis in leaves. In molybdenum deficiency, nitrate assimilation is prevented. Old leaves turn

yellow. Due to nitrate accumulation, necrosis occurs rapidly on the leaf edges. Symbiotic and symbiotic nitrogen fixation is reduced (Foth, 1984; Bozgelmez et al., 2001). The presence of molybdenum in large amounts in the growing environment has a toxic effect, especially on cattle and sheep grazing on pastures. In other words, it does not have any toxic effects on plants. The reason for this toxicity seen in animals is due to the presence of molybdenum and copper elements in unbalanced proportions in the composition of the feed used in animal nutrition (Bosgelmez et al., 2001; Gardiner and Miller, 2008).

STRATEGY TO INCREASE NUTRIENT EFFICIENCY IN PLANTS

1. Improving Nutritional Efficiency Through Root Changes

Optimization of root morphology to increase nutrient uptake efficiency can increase plant yield in nutrient-poor soils (Hawkesford and Barraclough, 2011). Increasing gene transport and/or enhancing the activities of various transporters has successfully increased the efficiency of obtaining specific nutrients in various plant species (Chen and Liao 2017). In addition to the direct uptake of soluble nutrients, plants secrete root exudates to solubilize otherwise insoluble nutrients, thereby increasing nutrient acquisition efficiency (Plaxton and Tran 2011; Kobayashi and Nishizawa 2012).

2. Improving Nutritional Use

In general, developing organs, especially reproductive organs, have low transpiration rates but require large amounts of mineral nutrients for active growth (Marschner, 1995). Therefore, specific translocation and restabilization of

essential nutrients require element-specific transporters. Removal of assimilated N from senescent leaves greatly affects N use efficiency in cereal crops such as wheat, barley, and rice (Gregersen et al. 2008). Maintaining essential metabolic enzyme activities contributes to N and P metabolic efficiency under both normal and low nutrient conditions (Chen and Liao 2017).

3. Examples of Improving Nutrition Efficiency

Marker Assisted Selection (MAS) breeding approaches are to detect genetic diversity within a plant species. Transferring genes from other species through genetic engineering to overcome the limitations of genetic variation within the same species may provide an effective approach to increasing the nutritional efficiency of plants (Ehdaie et al. 2010). Identification of genes affecting nutrient efficiency will facilitate the breeding of plants tolerant to low nutrient conditions and improve fertilizer use efficiency, thereby increasing yields. (Chen and Liao 2017).

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