Chapter

Influence of Heavy Metals on the Nitrogen Metabolism in Plants

Vitor Nascimento, Glauco Nogueira, Gabriel Monteiro, Waldemar Júnior, Joze Melissa Nunes de Freitas and Cândido Neto

Abstract

As an essential element, Nitrogen is needed in large quantities for being an important component of cellular constituents and for plant metabolism, and its deficiency is one of the most common limitations for plant development. The study of the toxic effects of metal in plants involves a complex system of reactions that can be better determined once having a large attention of the different backgrounds of occurence to determinate how to proceed. The objective of this review is to add scientific knowledge, addressing the main functionalities and characteristics of this relation heavy metals – nitrogen metabolism in plant. Increasing industrialization and urbanization had anthropogenic contribution of heavy metals in biosphere and had largest availability in ecosystems. This toxicity in plants varies with plant species, specific metal, concentration, soil composition, as many heavy metals are considered to be essential for plant growth. Were provided data and reviews regarding the effect of heavy metals on nitrogen metabolism of plants and the responses of plants and the cross-talk of heavy metals and various stressors factors. Is clear to understand the relation between metals amount and the benefit or harm caused on plants, determining then, which mechanism should be activated to protect your physiological system.

Keywords: Plant physiology, human activities, industrialization, plant stress, toxicity

1. Introduction

Nitrogen (N) is an essential nutrient required by all living organisms and often limits primary production in aquatic and terrestrial ecosystems. This element is needed in large quantities, as it is an essential component of proteins, nucleic acids and other cellular constituents. Proteins alone comprise 60% or more of the N of plants and microbial cells [1]. It is also an essential element for plant metabolism and its deficiency is one of the most common limitations for plant development [2]. The preference of plants for the source of N can vary according to the selective pressures and consequent physiological adaptations [3].

The most common and available forms in the soil are the nitrate (NO_3^-) and ammonium (NH_4^+) forms, the first being more abundant and better assimilated by plants [4], as a result of the nitrification process by bacteria. However, depending on soil conditions, the ammoniacal form may be the most abundant due to the

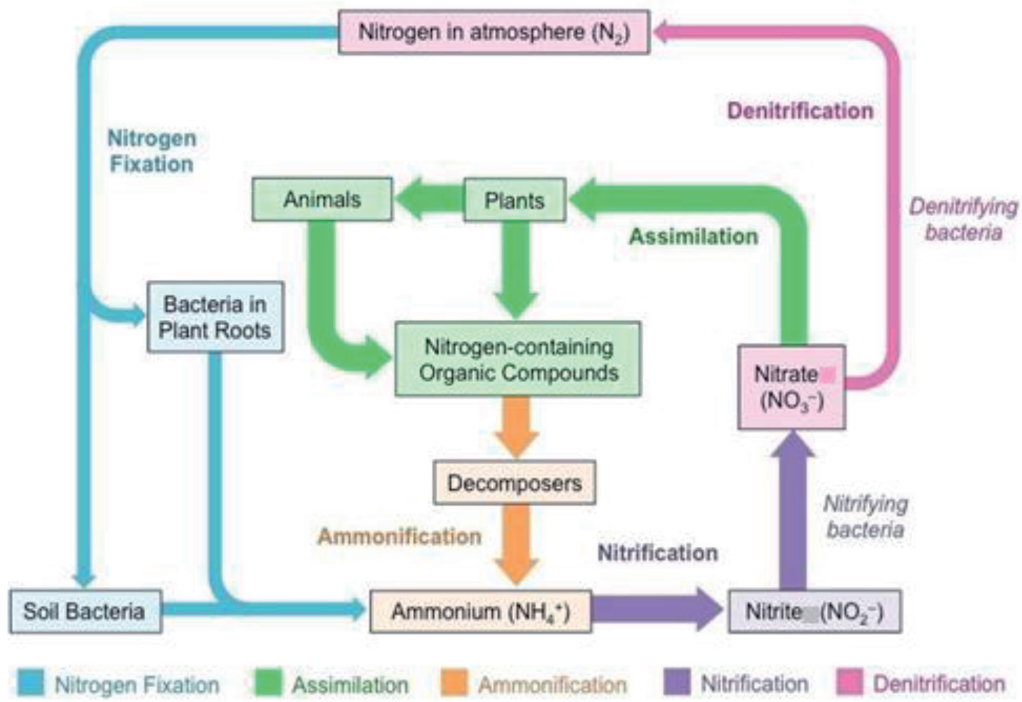

Figure 1.
Nitrogen metabolism in plants. Source: Biology Experts Notes.

inhibition of these organisms [5]. Once in the leaves, it is known that different sources of N can affect plant metabolism differently. The accumulation of NH_4^+ can lead to decreased photosynthesis [6], while the excess of NO_3^- can lead to the formation of reactive species inducing oxidative stress [7].

The metabolism of nitrogen is also closely linked to that of carbon (C), and the photorespiratory process is one of the points of connection between these, in addition to being a metabolic route that naturally produces a reactive oxygen species (**Figure 1**).

The study of the toxic effects of metal in plants involves a complex system of reactions that can be better determined once having a large attention of the different backgrounds and regions of occurence to determinate how to proceed. Therefore, the objective of this review is to add scientific knowledge, addressing the main functionalities and characteristics of this relation heavy metals – nitrogen metabolism in plant.

2. Heavy metals

According to Lenntech [8], heavy metals were significant environmental pollutants because their toxicity is a problem of increasing significance for ecological, evolutionary, environmental and nutritional reasons. Including copper (Cu), manganese (Mn), lead (Pb), cadmium (Cd), nickel (Ni), cobalt (Co), iron (Fe) and others, they are group of metals and metalloids with atomic density greater than 4 g/cm^3, or 5 times or more, greater than water [9]. Environmentally it is defined as total circumstances surrounding an organism or group of organisms especially, the combination of external physical conditions that influence and affect the growth, survival and development of the organisms [10].

Heavy metals are most found in rock formations with a dispersed form. Increasing industrialization and urbanization had anthropogenic contribution of heavy metals in biosphere and had largest availability in soil and aquatic ecosystems and to a relatively smaller portion in atmosphere as vapors or particulates. This toxicity in plants varies with plant species, specific metal, concentration, chemical form, pH and soil composition, as many heavy metals are considered to be essential for plant growth. According to Mildvan [11], some of these heavy metals like Cu and Zn could serve as activators of enzyme reactions and cofactor, exhibiting metallic properties such as ductility, malleability, cation stability, conductivity and ligand specificity were characterized by relatively high density and high relative atomic weight with an atomic number greater than 20, as said by Raskin et al. [12].

In Brazil, the reference levels for investigating the levels of heavy metal and other chemical substances in soils and groundwater are defined in CONAMA Resolution No. 420 [13], which facilitates the assessment of contamination and the creation of indicators that control and take care of the areas exposed to metals and the living beings in it. All forms of life can be affected by the presence of heavy metals depending on the dose and chemical composition [14]. Another key factor to be considered is the degree of exposure that is directly related to the amount of bioavailability in the environment, as the free ions of the metal can be linked to organic matter, reducing bioavailability [15].

3. Heavy metals in plants

According to Becher et al. [16], responses of plants to environmental stresses involve defenses, as well as stress-inducible reactions. Stimulation of important tolerance routes, such as enhancement of antioxidant enzymes activity, osmolyte accumulation, induction of membrane-localized transporters. Therefore, plants have developed mechanisms for homeostasis of ions that enable them to cope with a certain limited excess of heavy metals. Plants in the course of evolution demonstrate tolerance or even an adaptation to various biotic and abiotic stress factors.

According to Hall and Williams [17] chaperons, chelators and specific transmembrane transporters have evolved. In plants non-adapted to given environmental conditions, that are challenged with excess of ions, an enhanced biosynthesis of complexing substances such as metallothioneins, phytochelatins and/or organic acids can occur (**Figure 2**) [18, 19].

Nitrogen assimilation is an important plant metabolic process, which not only controls development plant growth but also plays an important role in plant survival under stress conditions. As said by Burger and Jackson [20], NO_3^- and NH_4^+ are major nitrogen sources and are required during different metabolic processes. Nitrate is converted into NH_4^+ via a process constituted of two steps; during the first step, NO_3^- is converted into nitrite with the action of the enzyme nitrate reductase, and in the second step nitrite is converted into NH_4^+ with the action of nitrite reductase.

Pérez-Tienda et al. [21] reported that nitrate reductase is located in the cytoplasm, while nitrite reductase is located in chloroplast and uses energy and some reductants such as NADH or NADPH from respiration or photosynthesis process to carry out such NO_3^- to NH_4^+ conversion reaction. The first step of this reaction occurs in the cytosol, while the second step occurs in the plastid. Following NH_4^+ production, it has to be incorporated in carbon skeleton, and this process occurs primarily via GOGAT cycle.

Moreover, as related by Mevel and Prieur [22], is possible to visualize two isoforms of GS, GOGAT and their localization has been found in a tissue-specific manner, e.g., in roots, GS1 and NADHGOGAT are primarily involved in the assimilation of nitrogen, in leaves the GSII and GOGAT are predominantly involved in the nitrogen assimilation.

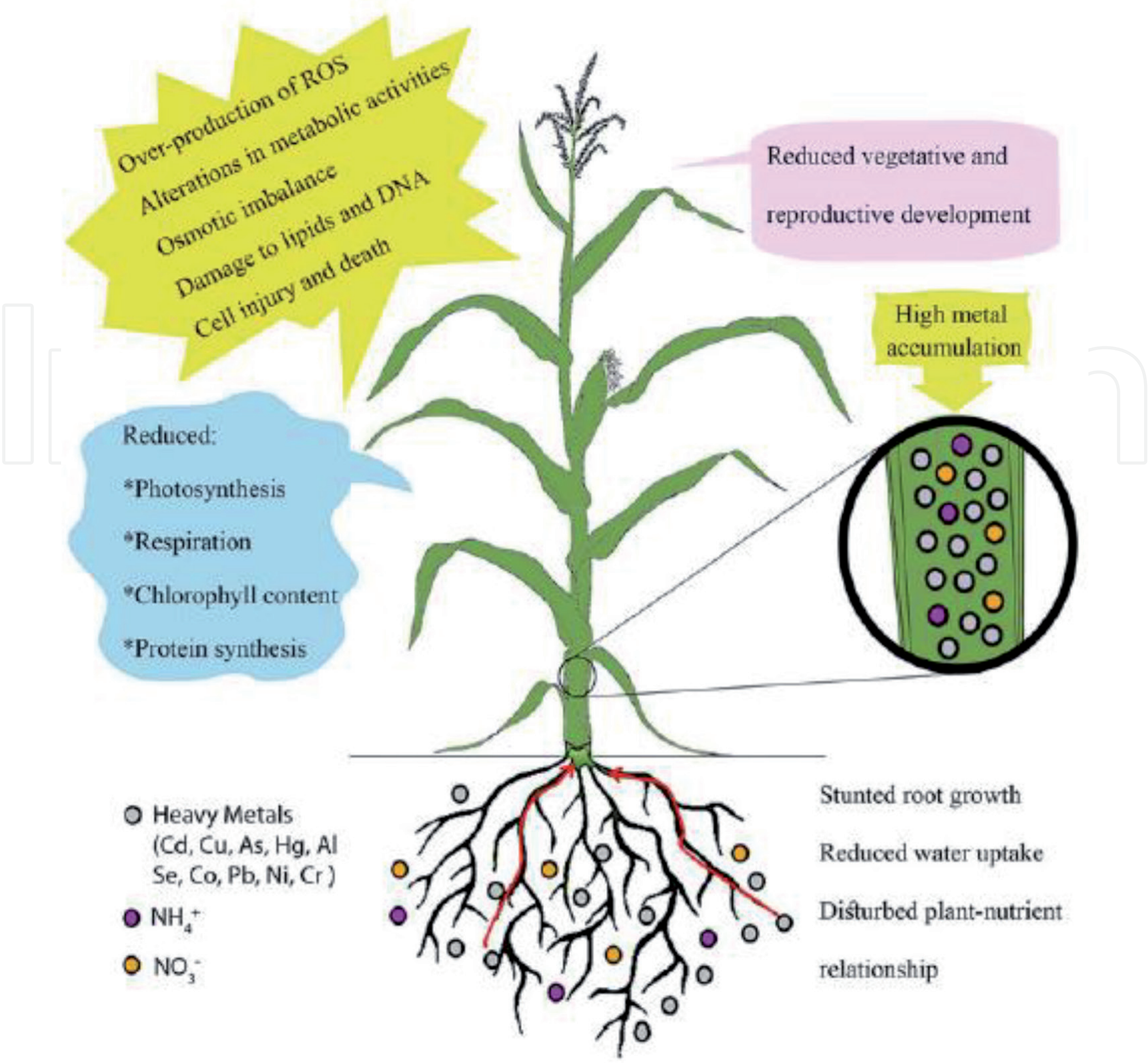

Figure 2.
Morphophysiological responses of plants to metal toxicity in soil.

Metal toxicity significantly reduces nitrogen assimilation process. However, the level of reduction depends on the sensitivity and localization of enzymes to heavy metal toxicity. Moreover, concentration, mobility and duration of heavy metal ions in growth medium further aggravate alterations in the process of nitrogen assimilation.

The exposure to metals at higher concentrations could result in severe damage to various metabolic activities leading consequently to the death of plants. The exposure of excess levels of metals to plants inhibits physiologically active enzymes [23], inactivates photosystems [24], and can possibly destroy the mineral metabolism. Janas et al. [25] have analyzed the impact of Cu on lipid peroxidation, growth, localization in lentil seedlings and phenolic compound accumulation. According to Xie et al. [26] and Chen [27] previous experiments have reported that dissolved soil organic substances have significant effects on heavy metal transformations by increasing the solubility of metal, plant uptake and root growth.

4. The effects of some heavy metals on plants

4.1 Cu

According to Burkhead *et al*. [28], due to the ability to cycle between the reduced Cu and oxidized Cu states, it is involved in biological processes such as photosynthesis, respiration, oxygen superoxide scavenging, ethylene sensing, lignification and cell wall metabolism. As an essential element, Cu can also be highly toxic [29]. Cu in a free form catalyzes reactions that generate hydroxyl radicals causing damage to lipids, proteins and DNA [30]. According to Bernal *et al.* [31], copper also has been reported to interfere with iron homeostasis. A highly reduction of plant biomass, inhibition of root growth, chlorosis, and necrosis are the most reported symptoms of a excess od Cu due to increased production of reactive oxygen species and harmful interactions at the cellular level.

4.2 Zn

The roles that zinc plays in cellular processes is a good example of the diverse biological utility of metal ions. Zn is involved in protein, lipid metabolism, carbohydrate and nucleic acid. Moreover, Zn is critical to the control of biological processes regulated by proteins containing DNA-binding Zn-finger motifs and gene transcription [32]. The precise cause of Zn toxicity is unknown, but the metal may bind to inappropriate intracellular ligands, or compete with other metal ions for transporter proteins or enzyme active sites. In order to play these diverse roles in cells, and because it cannot passively diffuse across cell membranes, Zn must be transported into the intracellular compartments of the cell where it is required for these Zn-dependent processes.

4.3 Ni

Ni is essential to several metabolic phenomena and is extremely toxic to plants when present at excessive levels in nutrient solutions or in the soil to which plants are exposed. According to Rahman et al. [33], the general signs associated with Ni toxicity in plants, include: reduced shoot and root growth, poor development of the branching system [34], deformation of various plant parts [35], abnormal flower shape [36, 37], decreased biomass production [33], leaf spotting [38], mitotic root tip disturbances [36], inhibition of germination [39], Fe deficiency leading to chlorosis [40, 41], and foliar necrosis [42].

4.4 Cd

According to Chen et al. [43], among all the heavy metals, cadmium (Cd) is considered to have high toxicity to humans and all other living organisms as it has no known biological functions in aquatic or terrestrial organisms. Through its effects on various biochemical and physiological processes in plants, Cd could inhibit plant growth and cause cell death above critical levels [44, 45]. Studies by Hassan et al. [46] reported that cadmium-induced growth reduction might be explained on the basis of inhibition of carbon fixation due to a decrease in photosynthetic rate and chlorophyll content.

5. Conclusion

In the presented chapter, we have provided data and reviews regarding the effect of heavy metals on nitrogen metabolism of plants and the responses of plants and the cross-talk of heavy metals and various stressors factors. Moreover, is clear to understand the relation between metals amount and the benefit or harm caused on plants, determining then, which mechanism should be activated to protect your physiological system. Additionally, we briefly show physiologically how this process occurs.

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