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CHLORINE and NICKEL: Essential Elements for Plant Growth

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INTRODUCTION

Essential Elements: Chlorine (Cl)

Chlorine (Cl) or Chloride is the most recent addition to the list of essential elements. In plants, chloride has been shown to be an important element for growth and health. Although chloride (Cl) is classified as a micronutrient, plants may take up as much chloride as they do secondary elements such as sulfur. Chloride is the main ions contributing to soil salinity in many regions but chloride is an essential element necessary for plant growth and development. It also controls the growth of some pathogens in plants. Chloride was recognized as an essential element for the first time in 1954. It plays a role in photosynthetic enzyme activation, osmotic regulation, cell division and plant disease prevention. Many workers have studied the effect of chloride in the prevention of some plant diseases. They used chloride-containing fertilizers plus ammonium chloride and potassium chloride as nitrogen and potassium sources, respectively. Chloride offers some control of rust fungi, mildew, and Fusarium diseases in plants (Halstead et al., 1991; Fixen, 1993). Plants uptake chloride through an active absorption mechanism. The minimum concentration of chloride in plant tissues essential for biochemical processes is about 100 mg/kg dry weight (Fixen, 1993). However, the concentration of this element in plants is usually higher, from about 0.2% to 2.0%, and sometimes rises up to 10%. The amount of chloride that plants take up from the soil varies from 20 kg to 80 kg per hectare depending on the plant type and density in the field (Fixen, 1993). Some non-biochemical roles of chloride (for example, osmotic regulation) need higher concentrations of this element. Unlike other micronutrients, chloride is not toxic when it accumulates to high levels in plants.

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The symptoms of chloride toxicity (higher concentrations) are associated with the osmotic effect of saline soils. Chloride toxicity is also associated with the activity of the nitrate reductase as nitrate and chloride have similar ionic properties and absorption mechanisms. When chloride uptake rises to the toxic level, it is easily converted to toxic compounds (like hypochlorites), before it can be detoxified with the nitrate reductase (Berges et al., 1995; Van Wuk and Hutchinson, 1995)

Primary roles of Chloride in plants:

- Chloride is important in the opening and closing of stomata. The role of the chloride anion (Cl^-) is essential to chemically balance the potassium ion (K^+) concentration that increases in the guard cells during the opening and closing of stomata.
- Chloride also functions in photosynthesis, specifically in the water splitting system.
- Chloride functions in cation balance and transport within the plant.
- Chloride diminishes the effects of fungal infections in an as yet undefined way.
- Chloride competes with nitrate uptake, tending to promote the use of ammonium nitrogen. Lowering nitrate uptake may be a factor in chloride's role in disease suppression, since high plant nitrates have been associated with disease severity.
- Chloride is a critical component in the development of plants.

Chloride Deficiency Symptoms

Too little chloride in plants can cause a variety of symptoms.

- Wilting due to a restricted and highly branched root system, often with stubby tips, and
- Leaf mottling and leaflet blade tip wilting with chlorosis has also been observed.
- In particular, chloride deficiency in cabbage is marked by an absence of the cabbage odor from the plant.

Chloride Deficiency in Wheat and Tomato

Chloride Toxicity Symptoms

Too much chloride in plants results in symptoms that are similar to typical cases of salt damage.

- Leaf margins are scorched and abscission is excessive.
- Leaf/leaflet size is reduced and may appear to be thickened.
- Overall plant growth is reduced. Chloride accumulation is higher in older tissue than in newly matured leaves. In conifers, the early symptom is a yellow mottling of the needles, followed by the death of the affected needles.

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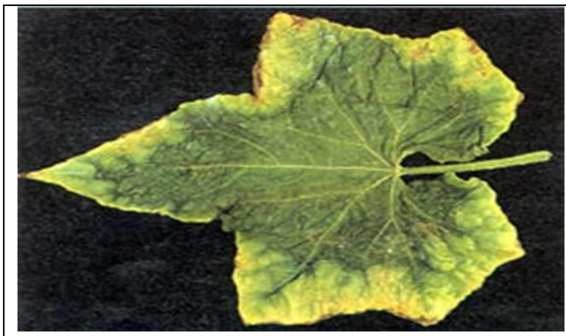

Chloride Toxicity symptoms in leaf

High Response Crops

Alfalfa, broccoli, cabbage, cauliflower, lettuce, oil palm, potato, small grains sugar/table beets, and tomatoes.

Factors affecting Chloride availability

Most soil chloride is highly soluble and is found predominantly dissolved in the soil water. Chloride is found in the soil as the chloride ion. Being an anion, it is fully mobile except where held by soil anion exchange sites. In areas where rainfall is relatively high and internal soil drainage is good, it may be leached from the soil profile. Also, where murate of potash fertilizer is not regularly applied, chloride deficiencies can occur. Atmospheric chloride deposition tends to be rather high along coastal regions and decreases as you progress inland. Chloride, nitrate, sulfate, borate, and molybdate are all anions in their available forms, and in that form they are antagonistic to each other. Therefore, an excess of one can decrease the availability of another. Little information is available on other specific interactions that may occur.

Chloride Supply to Plants

In many cases, more than a sufficient amount of chloride is supplied from the atmosphere and precipitation, as rainwater usually contains a low concentration of Cl. Therefore, chloride might become a limiting factor for plant growth in areas that are far from the sea. The natural sources of chloride in groundwater include weathering of rocks, atmospheric deposition and precipitation. In coastal, arid and semi-arid areas, the available groundwater is saline.

Since the Chloride is an anion (carries a negative charge) it does not adsorb to soil particles and moves readily with the water in the soil. Therefore, water quality and irrigation management are the major factors that affect chloride concentrations in soil. Water of low to medium salinity contains 100-300 mg/liter (=grams/cubic meter) of chloride.

Chloride is also constituent of some fertilizers. For example the most common fertilizer containing chloride is KCl (Murate of potash), which contains 47% chloride and 53% K. Other chloride containing fertilizers include: $CaCl_2$, NH4Cl and $MgCl_2$.

Chloride classification in irrigation water	
Chloride (ppm)	**Effect on Crops**
Below 70	Generally safe for all plants.
70-140	Sensitive plants show injury.
141-350	Moderately tolerant plants show injury.
Above 350	Can cause severe problems.

Essential Elements: Nickel (Ni)

ISSN: 2582 - 7022

Role of Nickel in Plant Culture

This article introduces agricultural and horticultural producers to the role and function of the newest identified essential plant nutrient, nickel (Ni).

The criteria for essentiality of elements for plant growth and development were established by Arnon and Scott (1939), Meyer and Anderson (1939) and Bennett (1993). An essential nutrient is defined as follows:

- A given plant must be unable to complete its life cycle in the absence of the nutrient (life cycle = vegetative state, flower, seed production).
- The function of the element must not be replaceable by another element.
- The element must be directly involved in plant metabolism or must be a component of an essential plant constituent (e.g., nitrogen [N] is a constituent of proteins and chlorophyll).
- Nickel is unique among plant nutrients because its functions in plant growth and development were described in detail before Ni was added to the list of essential elements. Nickel is a key component of selected enzymes (described below) involved in N metabolism and biological N fixation. Plants suffering from Ni deficiency show necrosis initiating from the tip of the leaf. This symptom can be reversed or corrected by applying a dilute Ni solution.

In the past, nickel (Ni) was not considered an important element for plant growth, but research has concluded that it is an essential element for plant growth. The normal range for nickel in most plant tissue is between 0.05-5 ppm. Due to its low requirements (often in parts per billion), it is found in sufficient levels as a contaminant in the soil, water, fertilizer, etc. Nickel deficiency is unusual and is often misdiagnosed as it initially shows no symptoms in plants. This explains why most labs do not test for it and why it is not included in most fertilizers.

Function of Nickel:

Nickel is a component of some plant enzymes, most notably urease, which metabolizes urea nitrogen into useable ammonia within the plant. Without nickel, toxic levels of urea can accumulate within the tissue forming necrotic legions on the leaf tips. In this case, nickel deficiency causes urea toxicity. Nickel is also used as a catalyst in enzymes used to help legumes fix nitrogen. There is evidence that nickel helps with disease tolerance in plants, although it is still unclear how this happens.

Nickel deficiency:

Minor nickel deficiency displays no visual symptoms, but can reduce growth and yield of plants. Significant nickel deficiency will display visual symptoms typically in the old leaves of the plants as nickel is a mobile element. Deficiency symptoms in legumes are exhibited as whole leaf chlorosis along with necrotic leaf tips (caused by the accumulation of toxic levels of urea). In woody ornamentals, symptoms occur in the spring in new emerging growth and may include shortened internodes (giving a rosetting appearance to the plant), weak shoot growth, death of terminal buds and eventual death of shoots and branches. In pecans, the symptoms are similar to woody ornamentals, but also include decreased expansion of the leaf blade and necrosis of the leaf tips. The leaves develop a condition called "mouse-ear" in which the leaflets are small with rounded tips vs. long and pointed.

Like most micronutrients, nickel becomes less available for plant uptake as the pH of the growing medium increases. High levels of zinc, copper, iron, cobalt, cadmium or magnesium in the growing medium can induce nickel deficiency. Crops that are most sensitive to nickel deficiency include legumes (beans and alfalfa), pecans, plum, peach, citrus, barley, wheat and certain wetland plants.

Nickel toxicity:

Nickel toxicity is unlikely to occur in greenhouse crops and has been found to be less toxic than other heavy metals, such as copper. Typically toxicities occur in woody

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plants if tissue levels exceed 80-120 ppm; sensitive plants, such as tomato, may exhibit toxicities above 10 ppm in the tissue. The early stages of nickel toxicity do not show clear visual symptoms, but shoot and root growth is often suppressed. Eventually symptoms are expressed and progress from interveinal or blotchy chlorosis of the new leaves (which is an induced iron, zinc or copper deficiency) and then suppressed leaf expansion to necrosis advancing in from the leaf margins and eventually plant death.

If nickel toxicity occurs, first verify by having the tissue tested. Check your fertilizer sources as sewage sludge and animal manures may contain significant amounts of nickel. Test the irrigation water as industrial chemical waste can contaminate water sources with excessive nickel. Nickel can be tied up in the growing medium if the pH is high (which also makes micronutrients unavailable for plant uptake); also correct any micronutrient deficiencies as they can compete with nickel, reducing excess nickel uptake by the plant.

Where to Find Nickel:

Since nickel is needed in such small quantities and more research needs to be done, it is not added to most fertilizers. It can be found as a contaminant in fertilizer and the irrigation water and it is often found in sewage sludge and animal waste. Nickel can also be applied as a single element application as nickel sulfate or in a chelated form. Use caution as little nickel is needed to correct a deficiency.

Horticulture labs do not test for nickel in the media, tissue or fertilizer solution, since greenhouse crops are typically not sensitive to nickel deficiency or toxicity. If you would like to have this element tested, please contact your lab to find out if they can do it and at what additional cost. For more information about fertilizer nutrients and their role in your crop production, please feel free to contact your Premier Tech Horticulture Grower Services representative.

Ni in Plants:

Nickel is taken up from soils as Ni^{2+}. It is readily mobile in plants, and in some species is preferentially translocated to developing seeds. The Ni concentration of most plant material normally ranges from about 0.1 to 5 ppm dry weight, but can be highly variable depending on its availability in soils, plant species, plant part, and season. Concentration greater than 10 ppm is considered toxic in sensitive species, and when greater than 50 ppm it becomes toxic in moderately tolerant species. Some plants can tolerate levels of Ni in tissue as high as 50,000 ppm dry weight. These are called "hyper accumulators," and are defined as plants that can accumulate at least 1,000 ppm Ni without phytotoxicity.

Pecan is a species that has a relatively high Ni requirement due to its unique physiology. Deficiency in pecan occurs when tissue Ni concentrations fall below 1 ppm, with toxicity occurring when concentrations exceed 100 ppm. The adequate range is estimated to be between 2.5 and 30 ppm; however, these Ni threshold values depend on concentrations of competing cations such as zinc (Zn^{2+}), copper (Cu^{2+}), and iron (Fe^{2+}).

Nickel is known to be an irreplaceable constituent of the urease enzyme. Urease has a Ni metallo-center, making Ni essential for urease activity. The urease enzyme assists in the hydrolysis of urea to ammoniacal-N, which plants can utilize. Nickel is thus important in N nutrition of plants. Under certain conditions where Ni is insufficient and urea is the major source of N, urea can accumulate in leaves to the point of toxicity. This urea toxicity, often manifested as necrosis of leaf tips, is actually a symptom of Ni deficiency. Nickel nutrition has also been shown to play a role in protecting against plant diseases. For example, it is involved in the synthesis of chemicals (phytoalexins) that the plant produces to defend against pathogens.

Ni in Soils:

Nickel is present in nearly all agricultural soils, which commonly have Ni concentrations of 20 to 30 ppm and seldom exceed 50 ppm. The most important single soil factor affecting Ni availability is pH—as soil pH increases Ni plant availability decreases. Therefore plants

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grown in high pH soils may be vulnerable to Ni deficiency. Also, high concentrations of divalent cations such as Zn2+, Cu2+, and Fe2+in soil solution can inhibit uptake of Ni. Soil testing for Ni as a plant nutrient is not an established practice since there has been little research in the area of Ni nutrition of most crops.

Soil application of Ni is rarely needed since most plants are adequately supplied. Also, trace amounts of Ni are contained in some commonly applied fertilizers. Where Ni fertilizer is needed to address a deficiency, it is most often applied as a foliar spray. Nickel salts (e.g., sulfates and nitrate) and organic Ni legends (lignosulfonates, heptogluconates) are effective foliar fertilizers. The Ni-lignosulfonate form is preferred for field use due to potential safety concerns with other sources.

Although it is unlikely that Ni input will be needed in the production of major crops, it is nevertheless a recognized micronutrient, and therefore warrants a brief review. For more on Ni nutrition see IPNI's Nutri-Facts series.

		
Severe leaflet tip necrosis due to nickel deficiency in nitrogen-fixing plants	Nitrogen-fixing cowpea seedlings grown hydroponically with (left) or without (right) nickel and supplied with no inorganic nitrogen source.	Ni-deficient pecan develops "mouse ear," a symptom of nickel deficiency.
		
Branches of Ni-sufficient (left) and Ni-deficient (right) pecan plants	Effect of spring foliar application of Ni on severity of mouse-ear symptoms of pecan trees. The branch on left side of the tree was sprayed with nickel (II) sulfate (3.35 g Ni L^{-1} as $NiSO_4•6H_2O$) Ni, whereas the right branch of the tree was not treated.	Pecan leaf on the right is normal while the leaf on the left has 'mouse-ear' due to nickel deficiency.

Nickel is a functional constituent of seven enzymes. Among the seven, urease (EC 3.5.1.5) (i.e., urea amidohydrolase) is extremely important to N metabolism in plants. As a Ni-metalloenzyme, urease assists in the hydrolysis of urea. Nickel works as a cofactor to enable urease to catalyze the conversion of urea into the ammonium ion, which plants can use as a source of N. Without the presence of Ni, urea conversion is impossible. Nickel is accumulated in plant organs or tissues, such as leaves. The crop plants accumulated 2.5% urea dry weight in the leaves. The leaf tip necrosis symptom of Ni deficiency is even more frequent and extensive when plants are highly dependent on biological N fixation for their N. This concentrated urea kills leaf cells, resulting in the development of necrotic lesions on the legume leaf tips. Nickel-deficient cowpea develops similar symptoms of leaf chlorosis and leaf tip necrosis. These symptoms suggest that urea is formed during normal N metabolism, regardless of the original N source. Application of Ni increases leaf urease activity and prevents urea accumulation.

Ni deficiency also results in delayed nodulation and reduced efficiency of N fixation. This finding suggests leguminous plants might have a unique requirement for Ni.

Therefore, for leguminous crops such as green bean and cowpea, Ni fertilization might be needed, particularly for those soils with high Zn or copper (Cu) concentrations, or with pH > 6.7.

In Ni-deficient pecans, a key morphological symptom of Ni deficiency is the development of "**mouse-ear**" leaves. On branches of Ni-deficient pecans, leaf expansion is both delayed and decreased, bud-break is greatly reduced, and leaves present bronzing, chlorosis, resetting, and tip necrosis. It seems likely that these symptoms are linked to oxalic and lactic acid toxicity, which accumulates because Ni deficiency disrupts pecan's carbon metabolism.

Additionally, a positive effect of Ni application on disease tolerance has been clearly documented. It is thought that Ni may either exert a direct phyto-sanitary effect on pathogens themselves, or that Ni may stimulate plant disease resistance mechanisms. Although Ni's mode of action in plant protection is unclear, it was shown that direct application of Ni to the roots of cowpea, which contained only 0.03 mg kg^{-1} Ni dry weight, effectively reduced leaf-fungal infection by 50%.

Nickel uptake and transport

Plants have two transport systems: low affinity and high affinity. With the low-affinity transport system, plants can absorb Ni^{2+} ions at the low concentration of 4.4 ppb, which is approximately 0.6 ounces Ni per million gallons of water. With the high-affinity transport system, plants can take up 1.8 parts per million (ppm) of Ni^{2+} ions, which is 237.7 ounces per million gallons of water. Nickel is readily re-translocated within the plant, probably as a complex with organic acids, such as citrate, at pH < 5, or an amino acid, such as histidine, at pH > 6.5. When plants experience Ni deficiency, the symptoms usually show up first on mature leaves. Also, due to the transportability of Ni^{2+} ions, up to 70% of Ni in the shoots can be transported to seeds.

Plant tissue nickel content

The Ni concentration in plant leaves ranges from 0.05 to 5 mg kg^{-1}, which is equal to 0.05–5 ppm on a dry weight basis. The critical Ni concentration in plant tissues required for normal shoot growth of urea-fed tomato and zucchini is about 1 ppm. Nickel concentrations > 10 ppm are generally considered to be toxic to sensitive species or cultivars.

Nickel fertilization

As a micronutrient, Ni is required by plants at low concentration. Most annual plants have a requirement for Ni on the order of 0.5 lbs per acre, compared with nitrogen (N) at 80–200 lbs per acre. Application of Ni fertilizers (Ni^{2+}) might be needed in the following growth conditions: 1) urea is the primary N source used for the crop production systems; 2) high applications of other metals, including Zn, Cu, Mn, iron (Fe), calcium (Ca), or magnesium (Mg), have been made for many years; or 3) leguminous crops are being grown in soils poor in mineral content or with a pH > 6.7. Soluble salts like nickel sulfate ($NiSO_4$), which contains the Ni^{2+} ion, are suitable fertilizers to prevent or correct plant Ni deficiency. Applying a foliar spray at a concentration of 0.03–0.06 ppm Ni is sufficient.