Micronutrients

Crops

Identification of Petitioned Substance

Chemical Name: See below.

Other Names: See below.

Trade Names: See below.

Other Products: See below.

CAS Number: See below.

Other Codes: See below.

Micronutrients:

Macro- and micro-nutrients are essential components for plant growth[1]. The most important macronutrients are nitrogen (N), phosphorus (P), and potassium (K) if carbon (C), oxygen (O), and hydrogen (H) are set aside. Calcium (Ca), magnesium (Mg) and sulfur (S) are other macronutrients, also called secondary nutrients.

The list of micronutrients varies. A short list generally includes six components: boron (B), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn). A different version includes two more components, sodium (Na) and chlorine (Cl). Yet a long list, after items such as "ultra-micronutrients" or "nano-nutrients" are included, could potentially include those eight components and other components: cobalt (Co), nickel (Ni), selenium (Se), and chromium (Cr), i.e. a list of B, Cu, Fe, Mn, Mo, Zn, Na, Cl, Co, Ni, Se, and Cr. This variability results from the crop variability (i.e. different demand), soil type (i.e. different natural supply), weather condition, and different agricultural practices. For example, manganese deficiency was the most common micronutrient problem in Michigan. Zinc and iron deficiencies were observed on some soils in Nebraska. Zinc deficiency for corn, manganese deficiency for soybean, and boron deficiency for alfalfa were common problems observed in Indiana. Zinc, boron and iron deficiencies for pecans were common problems encountered in Georgia.

Sodium and chlorine are considered as essential nutrients. However, with respect to the minor demand of plants for these two components, the supply of these two components from natural soil is rarely deficient, except from some very sandy soils. Phytotoxicity[2] associated with the excessive supply of these two components is more common.

Selenium is a dual-role component to animals and human, a nutrient at trace levels but a toxic element at higher concentrations. The difference between beneficial and toxic is very narrow. The minimal nutritional level for animals is about 0.05 to 0.10 mg Se kg^{-1} (dry weight, DW) in forage feed. The feed becomes toxic if it contains 2 to 5 mg kg^{-1} of selenium or higher. Plants growing in most soils are low in selenium content, except plants growing in seleniferous, alkaline soils derived from the weathering of seleniferous rocks and shales, such as those areas in Kesterson Reservoir, California. It is true that selenium salts are used as supplemental nutrients in animal feed, and selenium might be purposely applied as fertilizer to plants to raise the plant's

[1] *Essential* means that plants may develop deficiency symptoms and yields may be reduced when the available nutrient components are insufficient. *Macro*- and *micro*- are relevant to the demand but not to the supply. Plants require these *macro*nutrients in large amounts and *micro*nutrients relatively in minor or trace amounts. There are also terms of *ultramicro*nutrient and *nano*nutrient.

[2] *Phytotoxicity* is a term used to describe the degree of toxic effect by a compound on plant growth. Such damage may be caused by a wide variety of compounds, including trace metals, pesticides, salinity, phytotoxin or allelopathy.

selenium content[3]. However, the nutritional value of selenium to plants is debatable. There is no strong evidence to suggest that plants are actively taking up selenium from soil as nutrients (Terry et al., 2000; Ellis and Salt, 2003; Germ and Stibilj, 2007; Zhu et al., 2009). One of the probable mechanisms is the uptake of selenium by plants as sulfur due to the similarity between selenium ions and sulfur ions (such as SeO_4^{2-} and SO_4^{2-}).

Nickel is one of ultra-micronutrients or nano-nutrients. Plants contain 0.1 μg g^{-1} (DW) or less of nickel but show toxicity at 10-50 μg Ni g^{-1} (Dalton et al., 1988; Kramer et al., 1997). Cobalt and chromium are proposed to be micronutrients but their application is far less than the application of other micronutrients.

Micronutrients in general may include but not necessarily be limited to the following substances.

Boron (B): Borax ($Na_2B_4O_7 \cdot 10H_2O$), sodium tetraborate pentahydrate ($Na_2B_4O_7 \cdot 5H_2O$, CAS # 12179-04-3, Granubor 2) [4], disodium octaborate tetrahydrate ($Na_2B_8O_{13} \cdot 4H_2O$, CAS # 12280-03-4, Solubor), boric acid (H_3BO_3)

Copper (Cu): Copper oxide (CuO, CAS # 1317-38-0, Tiger Copper 7%), cuprous oxide (Cu_2O), copper sulfate pentahydrate ($CuSO_4 \cdot 5H_2O$, CAS #, Super Sulphates), copper sulfate monohydrate ($CuSO_4 \cdot H_2O$), cupric ammonium phosphate ($Cu(NH_4)PO_4 \cdot H_2O$), copper hydroxide, copper chelates ($Na_2CuEDTA$, NaCuHEDTA)

Iron (Fe): Ferric sulfate ($Fe_2(SO_4)_3 \cdot 9\ H_2O$), ferrous sulfate ($FeSO_4 \cdot xH_2O$), ferrous ammonium phosphate ($Fe(NH_4)PO_4 \cdot H_2O$), ferrous ammonium sulfate ($FeSO_4 \cdot (NH_4)_2SO_4 \cdot 6\ H_2O$), hydroxyl(oxo)iron ($Fe_3H_2O_4$, CAS # 73905-81-4, Tiger Iron 22%), iron chelates (FeEDTA, NaFeEDTA, NaFeHPDTA, NaFeEDDHA, NaFeDTPA, FeHEDTA, FeEDDHA)

Manganese (Mn): Manganese sulfate ($MnSO_4 \cdot 4H_2O$,), manganous oxide (MnO), manganese oxide (MnO_2, CAS # 1344-43-0, Tiger Manganese 15%), potassium permanganate ($KMnO_4$)

Molybdenum (Mo): Sodium molybdate (Na_2MoO_4), molybdic acid, molybdenum oxide, ammonium molybdate ($(NH_4)_6Mo_7O_{26}$), molybdenum trioxide (MoO_3), molybdenum dioxide (MoO_2)

Zinc (Zn): Zinc oxide (ZnO, CAS # 1314-13-2, Tiger Zinc 18%), zinc sulfate ($ZnSO_4$, $ZnSO_4 \cdot 2H_2O$, $ZnSO_4 \cdot NH_3$-complex), zinc sulfide, zinc carbonate, zinc chelate (Zn-EDTA, Zn-NTA, $Na_2ZnEDTA$, NaZnTA, NaZnHEDTA), Zn-lignosulfonate (Fert-All Zinc), zinc polyflavonoids

Nickel (Ni): Nickel sulfate ($NiSO_4 \cdot 6H_2O$, CAS #10101-98-1 heptahydrate), nickel carbonate ($NiCO_3$, CAS # 3333-67-3), nickel hydroxide

[3] Based on the analyses of mineral and trace element contents in cereals, fruits and vegetables in Finland, and by comparing the results with the similar results obtained 30 years ago, Ekholm et al. (2007) found that the selenium content of foods increased by about 1,600% while the contents of other elements such as Zn, Cu, Fe, Co, and Ni decreased by 25-45% from the 1970s to the 2000s. Ekholm et al. (2007) ascribed the increase in selenium content to the use of selenium-supplemented fertilizers.

[4] Trade names used here are solely for the purpose of providing some examples. It is not implied in any way that these products are recommended.

Cobalt (Co): Cobalt compounds (Information is limited).

Chromium (Cr): Chromium compounds (Information is limited).

Some micronutrients are chelated compounds such as chelates of citric acid, lignosulfonic acid, various amino acids, HEDTA (hydroxyethylenediaminetriaacetic acid), EDTA (ethylenediaminetetraacetic acid), and DTPA (diethylenetriaminepentaacetic acid).

Applying micronutrients is a very common agricultural practice. Extensive information is available (McKenzie, 2001). The application of micronutrients is discussed by the extension services of universities such as Clemson University, Michigan State University, Ohio State University, Purdue University, University of Florida IFAS, University of Guelph (van Straaten, 2002), University of Georgia, University of Hawaii-Manoa, University of Maryland, and University of Nebraska-Lincoln. This list is not exhaustive but just a quick example of widely available information.

Previous Technical Reports:

1995. TAP (Technical Advisory Panel) Review of Micronutrient Sprays.

Characterization of Petitioned Substance

Composition of the Substance:

Micronutrients for plants are mainly compounds of B, Cu, Fe, Mn, Mo, and Zn, as well as some compounds of Ni, Co and Cr. These are simple inorganic compounds such as oxides and sulfates, as well as some carbonates. Some compounds are chelates such as Fe-EDTA. Example compositions of these compounds are listed above.

Soil contains iron-aluminum-silicate minerals and other minerals. Iron, manganese, copper, zinc, nickel, and other components in minerals are held tightly in crystal structure and are mostly not available to plants. These components within minerals are not considered as plant nutrients. Weathering and microbiological activities very slowly release these components from minerals and make these components available for plants.

Micronutrients are mostly applied in compound forms rather than in elemental forms. For example, copper compounds such as copper sulfate or copper oxide are used instead of copper metal. Elemental names, such as boron or copper, are used to refer these compounds for simplicity. Plants actually assimilate dissolved ions as nutrients, such as BO_3^{3-}, Cl^-, Cu^{2+}, Fe^{3+}, Fe^{2+}, Mn^{2+}, MoO_4^{2-}, Ni^{2+}, and Zn^{2+}. Even if elemental copper is applied, it has to be converted to copper ions before being assimilated by plants. On the other hand, no matter in what form these micronutrients are applied, these components will convert to the respective ionic form since these ions are the most stable forms thermodynamically at the normal conditions of soil and surface water.

Traditionally iron, manganese, copper, zinc and boron are applied as sulfates. Recently they have been applied as oxides. Carbonates of these elements are not very soluble. Both of nickel sulfate (solubility: 293 g L^{-1}) and nickel carbonate (solubility: 0.093 g L^{-1}) might be used as micronutrients. However, the nickel in nickel carbonate is much less available to plants than the nickel in nickel sulfate due to its extremely lower solubility than the solubility of nickel sulfate. Silicates of these elements are not commonly synthesized and might not be widely available. Nitrates and chlorides, although very soluble and commonly synthesized, are not listed above since 7 CFR 205.601(j)(6) specifically prohibits use of the nitrates and chlorides of micronutrients in organic production.

Properties of the Substance:

Most of the compounds are white granules or powders at room temperature. Copper compounds may be green ($CuSO_4$) or red (CuO).

Some compounds are chelates such as Fe-EDTA. The solubility of these compounds is usually in the order of chelates ≈ nitrates ≈ chlorides > sulfates >> carbonates ≈ oxides.

Nickel is a transition metal in group VIII of the periodic table, close to Mn, Co, Fe, Cu and Zn. Its oxidation state is Ni(II) under normal environmental conditions such as being in soil or surface water. Chemical identity, physical property, and chemical property of nickel and ten nickel compounds are listed in Table 4-1 and Table 4-2 of ATSDR-Ni (2005). Properties of nickel compounds are also described in 11th Report on Carcinogens – Nickel Compounds and Metallic Nickel).

Nickel	Solubility (water)	Color
Oxide	insoluble (0.001 g L^{-1})	green to black
Carbonate	insoluble (0.093 g L^{-1})	light green
Sulfides	insoluble (0.52 gL^{-1})	green to black
Hydroxide	insoluble	green to black
Acetate	soluble	dull-green
Sulfate	soluble (293 g L^{-1})	yellow, green or blue
Chloride	soluble (642 g L^{-1})	yellow
Nitrate	soluble (2,385 g L^{-1})	

"Nickel oxide also comes in a black crystalline form that has a slightly higher oxygen content than its formula, NiO (Antonsen 1981). The nickel content of black nickel oxide is 76–77% compared with 78.5% for the more stable green nickel oxide. Nickel ammonium sulfate, nickel sulfate, nickel chloride, and nickel nitrate usually exist as hexahydrates, while nickel acetate, nickel cyanide, and nickel sulfamate are in the form of a tetrahydrate," (ATSDR-Ni, 2005).

Specific Uses of the Substance:

Compounds are used as micronutrients for plants.

Approved Legal Uses of the Substance:

Relevant sections of 7 CFR 205.601 – "Synthetic substances allowed for use in organic crop production" are quoted below.

> "(j) As plant or soil amendments.
> (6) Micronutrients not to be used as a defoliant, herbicide, or desiccant. Those made from nitrates or chlorides are not allowed. Soil deficiency must be documented by testing.
> (i) Soluble boron products.
> (ii) Sulfates, carbonates, oxides, or silicates of zinc, copper, iron, manganese, molybdenum, selenium, and cobalt."

Nickel is not included in 7 CFR 205.601(j)(6)(ii) currently.

Action of the Substance:

Boron (B): Boron plays an important role in the movement and metabolism of sugars in the plant and synthesis of plant hormones and nucleic acids. It also functions in lignin formation of cell walls, germination of pollen grains, and growth of pollen tubes.

Copper (Cu): Copper is a component of enzymes, some of which are important to lignin formation in cell walls. It is also involved in photosynthesis. Without copper all crops fail to grow.

Iron (Fe): Iron is a constituent of many organic compounds in plants. Iron is involved in photosynthesis, respiration, chlorophyll formation, and many enzymatic reactions.

Manganese (Mn): Manganese is a component of enzymes and is also involved in photosynthesis and root growth. Additionally, it is involved in nitrogen fixation.

Molybdenum (Mo): Molybdenum is involved in nitrogen fixation (conversion of N_2 to NH_4^+) and nitrification (conversion of NH_4^+ to NO_3^-).

Zinc (Zn): Zinc is a component of many organic complexes and DNA protein. It is also an important enzyme for protein synthesis. Also, zinc is involved in growth hormone production and seed development, and is involved in chlorophyll synthesis.

Cobalt (Co): Cobalt is required by nitrogen-fixing microorganisms and is essential for N-fixing legumes.

Chromium (Cr): Information is limited.

Nickel (Ni): Urease is an enzyme that catalyzes the hydrolysis of urea into carbon dioxide and ammonia. Nickel is required by the urease enzyme in plants, which seems to be the only function of nickel in plants (Bai et al., 2006; Tejada-Jimenez et al., 2009; Hansch and Mendel, 2009; University of Georgia).

Status

Historic Use by Organic Growers:

Deficiency of micronutrients was recognized before the NOP started in the 1990s (e.g. Berger, 1962). Compounds of boron, copper, iron, manganese, and zinc are listed in OMRI as micronutrients. Recently, deficiency of nickel was investigated (Bai et al., 2006). Ni compounds are not listed in OMRI currently.

U.S. Department of Agriculture:

Soluble boron products, sulfates, carbonates, oxides, or silicates of zinc, copper, iron, manganese, molybdenum, selenium, and cobalt are allowed in organic crop production (7 CFR 205.601(j)(6)). Nickel is not included.

U.S. Department of Health and Human Services: See below.

U.S. Environmental Protection Agency: See below.

U.S. Food and Drug Administration: See below.

International: See below.

The Agency for Toxic Substances and Disease Registry (ATSDR), based in Atlanta, Georgia, is a federal public health agency of the U.S. Department of Health and Human Services (DHHS). The ATSDR prepared the toxicological profiles (ATSDR) of nickel and other components in accordance with guidelines developed by the ATSDR and the U.S. Department of Environmental Protection (EPA). The following is quoted from the section of "8. Regulations and advisories" in the nickel profile (ATSDR-Ni, 2005).

> "The Department of Health and Human Services (NTP 2002) has determined that metallic nickel may reasonably be anticipated to be a carcinogen and that nickel compounds are known to be human carcinogens. Similarly, IARC classified metallic nickel in group 2B (possibly carcinogenic to humans) and nickel compounds in group 1 (carcinogenic to humans). EPA has classified nickel refinery dust and nickel subsulfide in Group A (human carcinogen) (IRIS 2005). Other nickel compounds have not been classified by the EPA."

International, national, and state guidelines and regulations regarding exposure to nickel and its compounds are detailed in 3-page "Table 8-1 Regulations and Guidelines Applicable to Nickel and Nickel Compounds", of the profile of nickel (ATSDR-Ni, 2005), and are listed in the 11th Report on Carcinogens – Nickel Compounds and Metallic Nickel. Most of the regulations are not directly related to the potential usage of nickel compounds (nickel sulfate) as micronutrients to plants. Some regulations are listed below.

Drinking water guideline of nickel is 0.02 mg L^{-1} by WHO, but 0.1 mg L^{-1} by U.S. EPA and 0.1 mg L^{-1} in bottled water by U.S. FDA. Nickel is GRAS (generally recognized as safe) as a direct human food ingredient with no limitation other than current good manufacturing practices, as given by U.S. FDA.

EPA – Clean Water Act
- Biosolids Rule: Ceiling concentration of nickel (type not specified) for land application = 420 mg/kg.
- Effluent Guidelines: Nickel and nickel compounds listed as "Toxic Pollutants".
- Water Quality Criteria: Based on fish/shellfish and water consumption = 610 μg/L (nickel, type not specified); based on fish/shellfish consumption only = 4,600 μg/L (nickel, type not specified).

EPA – Comprehensive Environmental Response, Compensation, and Liability Act
- Reportable Quantity (RQ) = 100 lb (nickel, nickel ammonium sulfate, nickel chloride, nickel nitrate, nickel sulfate); 10 lb (nickel carbonyl, nickel cyanide, nickel hydroxide).

EPA – Emergency Planning and Community Right-To-Know Act
- Toxics Release Inventory: Listed substances subject to reporting requirements (nickel, nickel compounds, nickel ammonium sulfate, nickel carbonyl, nickel chloride, nickel cyanide, nickel hydroxide, nickel nitrate, nickel sulfate).
- Threshold Planning Quantity (TPQ) = 1 lb (nickel carbonyl).
- Reportable Quantity (RQ) = 10 lb (nickel carbonyl).

EPA – Resource Conservation and Recovery Act
- Listed Hazardous Waste: Waste codes in which listing is based wholly or partly on substance - P073, P074, F006
- Listed as a Hazardous Constituent of Waste (nickel, nickel compounds, nickel carbonyl, nickel cyanide)

FDA

The color additives ferric ammonium ferrocyanide and ferric ferrocyanide may contain nickel at levels no greater than 200 ppm.

Menhaden oil may contain nickel at concentrations not to exceed 0.5 ppm.

OSHA

Permissible Exposure Limit (PEL) = 1 mg/m^3 (metallic nickel and compounds other than nickel carbonyl); 0.001 ppm (0.007 mg/m^3) (nickel carbonyl).

Evaluation Questions for Substances to be used in Organic Crop or Livestock Production

<u>Evaluation Question #1:</u> Is the petitioned substance formulated or manufactured by a chemical process? (From 7 U.S.C. § 6502 (21).)

Micronutrients occur naturally in soil, as given below in Question #3. On the other hand, commercial micronutrients are generally manufactured as by-products or intermediate products of metal mining and processing industries. Sulfates are manufactured by reacting relevant metals or oxides with sulfuric acid. For example, copper "shot" is dissolved in dilute sulfuric acid to make copper sulfate (Copper.ORG). This dissolution is a chemical process since elemental copper Cu(0) is oxidized to cupric ions Cu(II). An oxidation is a chemical reaction during which electron transfer has occurred.

Elemental nickel is primarily extracted and refined from two different ores, lateritic and sulfidic. "Lateritic ores are normally found in tropical climates where weathering, with time, extracts and deposits the ore in layers at varying depths below the surface. Lateritic ores are excavated using large earth-moving equipment and are screened to remove boulders. Sulfidic ores, often found in conjunction with copper-bearing ores, are mined from underground," (World Bank.Nickel). Laterites are mainly nickeliferous limonite: (Fe, Ni)O(OH) and garnierite (a hydrous nickel silicate): $(Ni, Mg)_3Si_2O_5(OH)$. Sulfidic ores are magmatic sulfide deposits where the principal ore mineral is pentlandite: $(Ni, Fe)_9S_8$.

By using different processing (World Bank.Nickel), nickel matt is produced. "Fluid bed roasting", "chlorine-hydrogen reduction", "carbonyl processing" and other processes are used to produce high-purity nickel pellets. Nickel sulfate can be manufactured by dissolving nickel metal in sulfuric acid. Elemental nickel Ni(0) is converted to nickel ions Ni(II) in the chemical reaction.

Lignosulfonates (lignin sulfonate, or sulfonated lignin) are water-soluble anionic polyelectrolyte polymers, byproducts from the production of wood pulp using sulfite pulping. By 7 CFR 205.601 (j)(4), lignin sulfonate is a chelating agent. The nickel in nickel lignin sulfonate is nickel ion Ni(II).

The production, import/export, use and disposal of nickel metal are substantially (8 pages) described in Section 5 of ATSDR-Ni (2005).

<u>Evaluation Question #2:</u> Is the petitioned substance formulated or manufactured by a process that chemically changes the substance extracted from naturally occurring plant, animal, or mineral sources? (From 7 U.S.C. § 6502 (21).)

Plant micronutrients are a collection of various kinds of substances. Some micronutrients such as copper sulfate (chalcanthite, $CuSO_4 \cdot 5H_2O$) and zinc carbonate (smithsonite, $ZnCO_3$) exist as natural minerals. After physical processing such as breaking and grinding, these natural minerals might be used as micronutrients. Some micronutrients such as copper chelates and nickel sulfate are not found in naturally occurring plant, animal, or mineral sources.

Most nutrient-bearing minerals, such as sphalerite (Zn,Fe)S, nickeliferous limonite(Fe, Ni)O(OH), $(Ni, Mg)_3Si_2O_5(OH)$, and minerals listed in Question #3, are not soluble or very slightly soluble in water. As mentioned above in Question #1, natural minerals are processed by physical and chemical processes for making water soluble micronutrients. The manufactured products such as nickel sulfate are different from the naturally-occurring minerals such as nickeliferous limonite (Fe, Ni)O(OH).

Most micronutrients are common chemical compounds and widely available commercially such as from Fisher Scientific, Mallinckrodt, etc.

Evaluation Question #3: Is the petitioned substance created by naturally occurring biological processes? (From 7 U.S.C. § 6502 (21).)

Minerals in rock, after weathering, erosion, microbiological activities, and anthropogenic processes, undergo changes that cause the formation of secondary minerals and the redistribution of materials in different areas. Soil is naturally derived from parent rock and is a complex mixture of primary minerals, altered minerals, redistributed materials, and other materials after various physical, microbiological, and anthropogenic processes in a very long time during which components in minerals are released as plant micronutrients. As given above in the section of "Composition of the Substance", weathering and microbiological activities very slowly release these components from minerals and make these available as plant micronutrients.

The following is quoted from "Rocks for Crops" (van Straaten, 2002).

> "Natural abundances of micronutrients are closely linked to rock types. For example, igneous ultramafic and mafic rocks (pyroxenites, basalts) contain generally higher amounts of Cu, Co, Fe, and Mn than silica-rich granites. Several sediments are enriched in micronutrients; for example black shales contain elevated concentrations of boron and other trace elements. In general, basalts and shales are rock types with abundant micronutrient elements.
>
> The highest concentrations of micronutrient elements found in rock-forming minerals.
>
> - Boron occurs in tourmaline, in clay minerals and evaporate salts (borax, colemanite , kernite, ulexite) in desert playas,
> - Chlorine is the primary component of common salt, halite (NaCl), and sylvite (KCl),
> - Cobalt is common, in small amounts, in ferromagnesian silicates substituting for Fe, or associated with Mn oxides, or in sulfides, carbonates, and in marine Mn-nodules,
> - Copper is a component in the sulfides chalcopyrite ($CuFeS_2$), bornite (Cu_5FeS_4), chalcocite (Cu_2S), or occurs as carbonates (malachite $Cu_2(OH)_2CO_3$ or azurite $Cu_3(OH)_2(CO_3)_2$),
> - Iron occurs as constituent of certain silicates, and is the main metal compound in the Fe-oxides hematite, magnetite, goethite/limonite, as well as in the sulfides (mainly pyrite FeS_2),
> - Manganese occurs mainly as oxides (pyrolysite MnO_2, hausmannite Mn_3O_4, manganite MnOOH), and less abundantly, as Mn-carbonates and in Mn-silicates,
> - Molybdenum occurs as sulfide (MoS_2), and more rarely as molybdite (MoO_3) or as powellite ($CaMoO_4$) in hydrothermal veins,
> - Zinc occurs as sulfide ZnS, carbonate (smithsonite $ZnCO_3$) or, in small amounts, in magnetite and silicate."

These components in the parent rocks may not be available to plants if they are not soluble in water. After weathering and other alteration processes including microbiological activities, these components in parent rock are transferred to "micronutrients" which are available for plants to assimilate.

Evaluation Question #4: Is there environmental contamination during the petitioned substance's manufacture, use, misuse, or disposal? (From 7 U.S.C. § 6518 (m) (3).)

The following is quoted from World Bank.Nickel about the environmental contamination during the manufacture of nickel metal.

> "**Waste Characteristics**
>
> *Air Emissions* Sulfur dioxide (SO_2) is a major air pollutant emitted in the roasting, smelting, and converting of sulfide ores. (Nickel sulfide concentrates contain 6–20% nickel and up to 30% sulfur.) SO_2 releases can be as high as 4 metric tons (t) of sulfur dioxide per metric ton of nickel produced, before controls. …… Particulate emission loads for various process steps include 2.0–5.0 kilograms per metric ton (kg/t) for the multiple hearth roaster; 0.5–2.0 kg/t for the fluid bed roaster; 0.2–1.0 kg/t for the electric furnace; 1.0–2.0 kg/t for the Pierce-Smith converter; and 0.4 kg/t for the dryer upstream of the flash furnace. Ammonia and hydrogen sulfide are pollutants associated with the ammonia leach process; hydrogen sulfide emissions are associated with acid leaching processes. Highly toxic nickel carbonyl is a contaminant of concern in the carbonyl refining process.
>
> *Liquid Effluents* Pyrometallurgical processes for processing sulfidic ores are generally dry, and effluents are of minor importance, although wet electrostatic precipitators (ESPs) are often used for gas treatment, and the resulting wastewater could have high metal concentrations. Process bleed streams may contain antimony, arsenic, or mercury. Large quantities of water are used for slag granulation, but most of this water should be recycled.
>
> *Solid Wastes and Sludges* The smelter contributes a slag that is a dense silicate. Sludges that require disposal will result when neutralized process effluents produce a precipitate."

Apparently not all extracted and refined nickel metal from nickel ore is made into nickel compounds for agricultural usage. Nickel is primarily used in many industrial and consumer products, including stainless steel, other nickel alloys, magnets, coinage, rechargeable batteries, etc. The following is quoted from ATSDR-Ni (2005) and is useful in estimating the relative magnitude of environmental consequence when nickel compounds are used as micronutrients.

> "The distribution of nickel consumption by use in 2002 was as follows: stainless and heat-resistant steel, 61%; nickel-copper and copper-nickel alloys, 4%; other nickel alloys, 13%; electroplating, 6%; superalloys, 9%; and other, 7%. Other uses include cast iron; chemicals and chemical use; electric, magnet, expansion alloys; steel alloys, other than stainless steel; batteries; and ceramics. Forty-six percent of primary nickel consumption in 2002 was for the production of stainless steel and low-nickel steels, and 33% was used for the production of superalloys and related nickel-based alloys (Kuck 2002)."

The use of nickel compounds as micronutrients should be in the category of "chemicals and chemical use" under "other, 7%".

Evaluation Question #5: Is the petitioned substance harmful to the environment? (From 7 U.S.C. § 6517 (c) (1) (A) (i) and 7 U.S.C. § 6517 (c) (2) (A) (i).)

All of these components including nickel, i.e. simple inorganic compounds of B, Cu, Fe, Mn, Mo, Zn, Ni, and Co, are found existing naturally in soil. Compounds of sulfates and oxides are applied as the micronutrients, but they either stay as solid if the respective solubility is low, or dissolve to the respective ions. These ions, BO_3^{3-}, Cu^{2+}, Fe^{3+}, Fe^{2+}, Mn^{2+}, MoO_4^{2-}, Zn^{2+}, Ni^{2+}, etc, are thermodynamically stable, with respect to the physicochemical conditions of soil and surface water. The chemical reactivity of these compounds (i.e. ions) towards other chemicals/materials is low. The applied micronutrients are not expected to be significantly different from those natural components in terms of concentration and physiological activity, when the applied amounts are under otherwise properly set limits.

When micronutrients are applied as chelates, some chelating agents such as ETDA are synthetic but do not naturally exist in soil. Potentially, these chelating agents may cause the loss of other components in soil by complexing those components and making those components soluble in water.

On the other hand, these components, such as Cu, Zn, Ni, Co, Mo, Fe, and Mn, are also termed as "heavy metals". The contamination of these heavy metals to the environment is well documented. It is a situation of case by case analysis, but the contamination problem such as the contamination of nickel in old orchard where fertilizers have been used extensively might be more general than the deficiency problem (e.g. U.S. EPA's Background report on fertilizer use, contaminants and regulations; U.S. EPA's Nutrient Management and Fertilizer; and USDA's Heavy Metal Soil Contamination).

According to 7 CFR 205.601(j)(6), soil deficiency must be documented before these micronutrients are applied. Currently, nickel is not counted as one of those micronutrients.

Evaluation Question #6: Is there potential for the petitioned substance to cause detrimental chemical interaction with other substances used in organic crop or livestock production? (From 7 U.S.C. § 6518 (m) (1).)

As given above in Question #5, the reactivity of these micronutrients including nickel in soil is low towards other chemicals/substances, these components exist naturally in soil, the applied micronutrients are not expected to be significantly different from those natural components in terms of concentration and physiological activity, and a previously existing soil status would not be substantially modified, when the applied amounts are under properly set limits. Currently, soluble boron products, sulfates, carbonates, oxides, or silicates of zinc, copper, iron, manganese, molybdenum, selenium, and cobalt are allowed in organic crop production (7 CFR 205.601). Nickel is not included in 7 CFR 205.601.

On the other hand, the uptake of one component by plants might be interfered or suppressed by the excess presence of another component among these micronutrients. Table 2 of Ohio State University, "Availability of micronutrients as affected by other micronutrients (antagonism) and macronutrients in soilless mixes," listed the factors affecting the availability of boron, manganese, copper, iron, molybdenum, and zinc. The availability of nickel to pecan trees was reduced by the excess presence of zinc (University of Georgia). The excess presence of nickel suppressed the assimilation of Zn, Cu, Fe, Mn, Ca, Mg, and S nutrients (Yang et al., 1996).

The toxicity effect of one component could be enhanced by another component. For example, scots pine (*Pinus sylvestris* L.) saplings did not survive when individually treated with 150 mg L^{-1} of copper or 150 mg L^{-1} of nickel. The lethal concentration substantially reduced to 15 mg L^{-1} each when these two components were applied simultaneously (Nieminen, 1998).

Evaluation Question #7: Are there adverse biological or chemical interactions in the agro-ecosystem by using the petitioned substance? (From 7 U.S.C. § 6518 (m) (5).)

As it has been discussed above in Questions #5 and #6, the reactivity of these micronutrients in soil and surface water is low towards other chemicals/substances and the added micronutrients are not much different from those natural micronutrients when these are applied under proper limit.

Micronutrients are essential for normal plant growth, but levels above that required for good growth can be toxic and suppress plant growth, and may cause adverse biological or chemical interactions in the agro-ecosystem. The range between benign and toxic might be narrow, depending on crops, soil condition, agricultural practices, micronutrients, and agro-ecosystem.

Currently, soluble boron products, sulfates, carbonates, oxides, or silicates of zinc, copper, iron, manganese, molybdenum, selenium, and cobalt are allowed in organic crop production (7 CFR 205.601). The toxicity of nickel was about 100 times lower than that of copper for water plants (Kupper et al., 1996) and fishes (Dave and Xiu, 1991). Nickel was less toxic than copper and zinc towards the copepod[5] *Acartia tonsa* (Bielmyer et al., 2006) and shrimp (Lussier et al., 1985).

"Toxicity can occur when micronutrients are applied in excess (usually more than one application). Common sources of micronutrients are: the charger in the mix, the irrigation water, and fertilizers applied during the crop cycle. Growers MUST have an idea of how much micronutrient they are adding through each of these sources in order to avoid toxicities. Toxicity symptoms are difficult to recognize visually (only someone with much experience can do it) and are usually mistaken by deficiency symptoms by growers. How do we resolve these problems? First of all, only a correct diagnosis of the problem will lead to the proper solution. Do you have a micronutrient deficiency or is it an excess? Identify the micronutrient causing the problem. Identify the cause of the problem: is the nutrient not present or is it present but unavailable? Answering these questions will help you (and your Extension agent or consultant) tackle the problem," (Ohio State University).

Evaluation Question #8: Are there detrimental physiological effects on soil, organisms, crops, or livestock by using the petitioned substance? (From 7 U.S.C. § 6518 (m) (5).)

As it has been discussed in the above questions (#5, #6, and #7), micronutrients are needed in relatively small quantities. Analyses such as soil analysis and plant analysis are critical to confirm nutrient deficiency problem. Most of the micronutrients naturally exist in soil. The applied micronutrients are not substantially different from those naturally existing micronutrients, after soil and plant analyses are conducted, deficiency problems are confirmed, and proper fertilizing program is established.

A micronutrient disorder may be a deficiency or toxicity. Over-applied micronutrients may cause phytotoxicity effects. Toxicity is relevant to crops, soil conditions, applied micronutrients, and applied amounts. A case by case analysis is necessary. "Secondary and Micronutrients for Vegetables and Field Crops" by Michigan State University described the application and the potential toxicity of calcium, magnesium, sulfur, manganese, zinc, copper, iron, boron and molybdenum. Toxicity effects could all occur if these micronutrients are over-applied, except that "plants appear quite tolerant of high soil molybdenum concentrations. There is no record of molybdenum toxicity under field conditions." Nickel was not discussed in "Secondary and Micronutrients for Vegetables and Field Crops".

[5] Copepods are a group of small crustaceans found in the sea and nearly every freshwater habitat. Many species are planktonic (drifting in sea waters), but more are benthic (living on the ocean floor).

Nickel - deficiency

Evidences suggest that nickel is involved in limited activities of higher plants and is essential to higher plants, but the requirement is minimal (Eskew et al., 1984; Brown et al., 1987; Brown et al., 1990). Nickel in higher plants was mainly found in urease which converts urea to carbon dioxide and ammonium (Bai et al., 2007; Tejada-Jimenez et al., 2009; Hansch and Mendel, 2009).

"Although Ni is a recognized essential mineral nutrient element for higher plants, its agricultural and biological significance is poorly understood. This is largely because of the low levels thought to be needed by plants (about 1–100 ng g^{-1} dry weight) in relation to the relative abundance of Ni in essentially all soils (> 5 kg ha^{-1})," (Bai et al., 2006 and additional references cited therein). Essential micronutrients were found as constituents in over 1500 proteins. While zinc was found in > 1200 proteins, and iron, copper and manganese were found in 50-150 proteins respectively, nickel, as well as molybdenum, was found in less than five proteins (Hansch and Mendel, 2009). That might be why nickel is considered as "ultra-micronutrient," and is not always in the list of "micronutrients" for plants.

The nickel deficiency was especially evident in ureide-transporting woody perennials such as pecan tree (Wood et al., 2006; Bai et al., 2006). One cause of nickel deficiency is the suppressed nickel uptake by the excessive presence of zinc (University of Georgia). The metabolic consequence of nickel deficiency was the accumulation of urea, disrupted metabolism of amino acids, and reduced urease activity. The morphological symptoms of nickel deficiency in a woody perennial were dwarfing of leaves and leaflets with respect to healthy leaves, i.e. so called mouse ear in pecan (Wood et al., 2004; Bai et al., 2006; University of Georgia).

Nickel - phytotoxicity

At high concentrations, nickel might be toxic to plants. The level of toxicity might depend on plant species, stage of growing, cultivation conditions, nickel concentration, and exposure time (Yang et al., 1996).

Natural nickel content in plants is 0.05-10 μg g^{-1} (DW) (Dalton et al., 1988; Kramer et al., 1997). Ni-hyperaccumulator plants are defined as containing at least 1,000 μg g^{-1} (DW) with preferential accumulation in the shoots (Pollard et al., 2002). Nickel toxicity levels are 10 μg g^{-1} (DW) in sensitive species, 50 μg g^{-1} (DW) in moderately tolerant species, and 1,000 μg g^{-1} (DW) in Ni-hyperaccumulator plants, such as *Alyssum* and *Thlaspi* species (Chen et al., 2009).

Chlorosis and necrosis of leaves appeared in sensitive species (barley, wheat, etc) after these plants were treated with nickel at very low concentrations (less than 200 μmol L^{-1}) (Chen et al., 2009). Other effects of toxicity could be retardation of germination, inhibition of growth, reduction of yield, induction of leaf chlorosis and wilting, disruption of photosynthesis, and inhibition of CO_2 assimilation. Respective examples of these toxicity effects are given in the review paper by Chen et al. (2009).

Seeds of wheat (*Triticum aestivum* L., cv. Zyta) were germinated in Petri dishes for two days. The seedlings were then hydroponically cultivated in solutions containing three levels of nickel ($NiSO_4$): control (or zero), 50, and 100 μmol L^{-1}, respectively. After the two-day-old seedlings were cultivated in the nickel solutions for seven days, the seedlings' fresh weight, and other items were measured (Gajewska and Sklodowska, 2009). The concentrations of nickel in the seedlings were 0.6, 73 and 143 μg g^{-1} DW, respectively for the three exposure levels. The results of several other items were fresh weight (FW) (mg, 159, 136 and 84), nitrate (μmol g^{-1} FW, 29, 26 and 23), ammonium (μmol g^{-1} FW, 8.8, 9.8 and 11.8), and nitrate reductase (U mg^{-1} protein, 3.8, 3.2 and 2.3), respectively for the three exposure levels. Changes of 20-40% were also observed from the results of nitrite reductase and nine other items, respectively for the three exposure levels.

The growth of wheat, in this experiment, was more inhibited at higher nickel exposures. This example shows the significant effect of nickel on the "growth of plants", probably when the "plants" were still at the seedling stage.

The accumulation of nickel in non-Ni-hyperaccumulator, chamomile (*Matricaria chamomilla* L.), was investigated by Kováčik et al. (2009), using hydroponically cultivated chamomile plants. Twenty-one-day-old seedlings of chamomile were cultivated for four weeks, then these were further cultivated in Ni-enriched solutions containing control (or zero), 3, 60, and 120 μmol L^{-1} of nickel ($NiCl_2$), respectively. After cultivated for ten days, the concentrations of nickel in the leaf rosettes of chamomile were 3, ~5, ~71, and ~139 μg g^{-1} (DW), respectively for the four exposure levels. Some other results of minerals in the rosettes were potassium (mg g^{-1}, 109, 98, 95, and 78), sodium (mg g^{-1}, 4.1, 4.1, 4.2, and 3.9), magnesium (mg g^{-1}, 3.2, 3.2, 3.2 and 3.1), iron (μg g^{-1}, 136, 134, 315, and 211), and copper (μg g^{-1}, 16, 16, 18 and 18), respectively for the four exposure levels. There was no substantial change in the concentrations of 17 free amino acids in the leaf rosettes, respectively for the four exposure levels. With respect to the substantial change in nickel concentrations at these four exposure levels, there were some changes in all of the other items as given above, but the changes could be judged as insignificant. In other words, the growth of chamomile, in that experiment, was not affected by its exposure to elevated concentrations of nickel. This example shows a "no-effect" of nickel on the "growth of plants", probably when the "plants" were resistant to high nickel concentrations. The applied nickel concentrations in the two examples were close to each other.

Evaluation Question #9: Is there a toxic or other adverse action of the petitioned substance or its breakdown products? (From 7 U.S.C. § 6518 (m) (2).)

Micronutrients may be applied as different compounds (e.g. copper sulfate and copper oxide), but the effect components are the respective ions (e.g. Cu^{2+} for different copper compounds and Ni^{2+} for different nickel compounds). In other words, most of the applied micronutrients are simple ionic forms and will not breakdown any further.

The phytotoxicity of nickel compounds is discussed in Question # 8.

Evaluation Question #10: Is there undesirable persistence or concentration of the petitioned substance or its breakdown products in the environment? (From 7 U.S.C. § 6518 (m) (2).)

As given above in Questions #4-#9, these micronutrients occur naturally in soil. The added micronutrients are not much different from those respective natural components.

Micronutrient nickel and other nickel

Like other micronutrients (such as Cu, Mn, Zn, and Fe), the use of nickel as a micronutrient accounts for a very small percentage of all industrial use (see Question #4). Nickel is released to the environment (air, water, and soil) mainly from industrial sources and other consumer products. "Nickel and its compounds are naturally present in the Earth's crust, and releases to the atmosphere occur from natural discharges such as windblown dust and volcanic eruptions, as well as from anthropogenic activities. It is estimated that 8.5 million kg of nickel are emitted into the atmosphere from natural sources such as windblown dust, volcanoes, and vegetation each year (Bennett 1984; Schmidt and Andren 1980). Five times that quantity is estimated to come from anthropogenic sources (Nriagu and Pacyna 1988). The burning of residual and fuel oil is responsible for 62% of anthropogenic emissions, followed by nickel metal refining, municipal incineration, steel production, other nickel alloy production, and coal combustion (Bennett 1984; Schmidt and Andren 1980)," (ATSDR-Ni, 2005).

The release of nickel from general industry sources to the environment, the environmental fate of the released nickel, and the levels of nickel monitored or estimated in the environment, in terms of air, water and soil, are substantially (30 pages) discussed in ATSDR-Ni (2005).

Nickel in the environment

The following is quoted from ATSDR-Ni (2005).

> "Nickel is a natural constituent of soil; levels vary widely depending on local geology and anthropogenic input. The typical concentrations of nickel reported in soil range from 4 to 80 ppm. …… Median nickel concentrations in rivers and lakes range from ≈0.5 to 6 μg/L. Levels in groundwater appear to be similar to those in surface water. Levels in seawater are typically 0.1–0.5 μg/L."

> "The speciation and physicochemical state of nickel is important in considering its behavior in the environment and availability to biota. For example, the nickel incorporated in some mineral lattices may be inert and have no ecological significance. Most analytical methods for nickel do not distinguish the form of nickel; the total amount of nickel is reported, but the nature of the nickel compounds and whether they are adsorbed to other material is not known. This information, which is critical in determining nickel's liability and availability, is site specific. Therefore, it is impossible to predict nickel's environmental behavior on a general basis."

> "Little is known concerning the chemistry of nickel in the atmosphere. The probable species present in the atmosphere include soil minerals, nickel oxide, and nickel sulfate (Schmidt and Andren 1980). In aerobic waters at environmental pHs, the predominant form of nickel is the hexahydrate $Ni(H_2O)_6^{2+}$ ion (Richter and Theis 1980). Complexes with naturally occurring anions, such as OH^-, SO_4^{2-}, and Cl^-, are formed to a small degree. Complexes with hydroxyl radicals are more stable than those with sulfate, which in turn are more stable than those with chloride. $Ni(OH)_2^0$ becomes the dominant species above pH 9.5. In anaerobic systems, nickel sulfide forms if sulfur is present, and this limits the solubility of nickel. In soil, the most important sinks for nickel, other than soil minerals, are amorphous oxides of iron and manganese. The mobility of nickel in soil is site specific depending mainly on soil type and pH. The mobility of nickel in soil is increased at low pH. At one well-studied site, the sulfate concentration and the surface area of soil iron oxides were also key factors affecting nickel adsorption (Richter and Theis 1980)."

Fate of nickel in soil

Atmospheric nickel and nickel in aquatic system are eventually scavenged, via adsorption, absorption, rain fall, falling, etc to soil and sediment. The follow is quoted from ATSDR-Ni (2005).

> "Nickel is strongly adsorbed by soil, although to a lesser degree than lead, copper, and zinc (Rai and Zachara 1984). There are many adsorbing species in soil, and many factors affect the extent to which nickel is adsorbed, so the adsorption of nickel by soil is site specific. Soil properties such as texture, bulk density, pH, organic matter, the type and amount of clay minerals, and certain hydroxides, as well as the extent of groundwater flow, influence the retention and release of metals by soil (Richter and Theis 1980)."

"Amorphous oxides of iron and manganese, and to a lesser extent clay minerals, are the most important adsorbents in soil. In alkaline soils, adsorption may be irreversible (Rai and Zachara 1984), which limits nickel's availability and mobility in these soils. For example, in recent studies of nickel speciation in ferromanganese nodules from loess soils of the Mississippi Basin, nickel is found to have a higher partition in the soil nodules than in soil clay matrices (Manceau et al. 2003). This is due to the selective sequesterization of nickel by finely divided iron and manganese oxides in goethite and lithiophorite minerals present in the soils. Cations such as Ca^{2+} and Mg^{2+} have been reported to reduce adsorption due to competition for binding sites, whereas anions like sulfate reduce adsorption as a result of complexation. Nickel adsorption depends strongly on metal concentration and pH (Giusti et al. 1993). For each mole of nickel adsorbed by iron and manganese oxide, ≈1–1.5 moles of hydrogen ions are released (Rai and Zachara 1984). For aluminum oxide, as many as 2.3 moles H^+ are released. Mustafa and Haq (1988) found that the adsorption of nickel onto iron oxide at pH 7.0 was rapid and increased with increasing temperature. They also found that two hydrogen ions are released into a solution when nickel is adsorbed. These studies indicate that while Ni^{2+} is the predominant species in solution, $NiOH^+$ is preferentially adsorbed, and that both mono- and bidentate complexes may be formed with the iron/manganese/aluminum oxides."

Evaluation Question #11: Is there any harmful effect on human health by using the petitioned substance? (From 7 U.S.C. § 6517 (c) (1) (A) (i), 7 U.S.C. § 6517 (c) (2) (A) (i) and), 7 U.S.C. § 6518 (m) (4).)

ATSDR developed the toxicological profiles for numerous components. The profiles of those components used as for micronutrients are listed below.

Component	ASTDR Toxicological Profile
Boron	ASTDR-B, 2007 (249 pages)
Copper	ASTDR-Cu, 2004 (314 pages)
Manganese	ASTDR-Mn, 2008 (539 pages)
Zinc	ASTDR-Zn, 2005 (352 pages)
Nickel	ASTDR-Ni, 2005 (397 pages)

Nickel

"Nickel and its compounds have been designated as toxic pollutants by EPA pursuant to Section 307(a)(1) of the Federal Water Pollution Control Act (40 CFR 401.15). As such, permits are issued by the states under the National Pollutant Discharge Elimination System (NPDES) for discharges of nickel that meet the applicable requirements (40 CFR 401.12), "(ATSDR-Ni, 2005).

Nickel compounds are known to be human carcinogens (ATSDR-Ni, 2005; 11th Report on Carcinogens – Nickel Compounds and Metallic Nickel).

The effect of nickel on human health is extensively discussed in ATSDR-Ni (2005). Nickel compounds "can be grouped according to their solubility in water: soluble compounds include nickel chloride, nickel sulfate, and nickel nitrate, and less-soluble compounds include nickel oxide and nickel subsulfide. Both the soluble and less-soluble nickel compounds are important with regard to all relevant routes of exposure. Generally, the soluble compounds are considered more toxic than the less-soluble compounds, although the less-soluble compounds are more likely to be carcinogenic at the site of deposition."

The health effect was discussed in terms of "inhalation exposure", "oral exposure", and "dermal exposure". Genotoxicity, toxicokinetics, and other aspects were discussed. Overall health effects were summarized and given in the section of "2.2 Summary of Health Effects", ATSDR-Ni (2005).

> "The general population can be exposed to nickel via inhalation, oral, and dermal routes of exposure. Based on occupational exposure studies, reports of allergic contact dermatitis, and animal exposure studies, the primary targets of toxicity appear to be the respiratory tract following inhalation exposure, the immune system following inhalation, oral, or dermal exposure, and possibly the reproductive system and the developing organism following oral exposure. The most commonly reported adverse health effect associated with nickel exposure is contact dermatitis. Contact dermatitis is the result of an allergic reaction to nickel that has been reported in the general population and workers exposed via dermal contact with airborne nickel, liquid nickel solution, or prolonged contact with metal items such as jewelry and prosthetic devices that contain nickel. After an individual becomes sensitized to nickel, dermal contact with a small amount of nickel or oral exposure to fairly low doses of nickel can result in dermatitis. Approximately 10–20% of the general population is sensitized to nickel."

The general exposure to nickel was quantitatively described in the 11th Report on Carcinogens – Nickel Compounds and Metallic Nickel.

> "Environmental exposure to nickel occurs through inhalation, ingestion, and dermal contact. The general population is exposed to low levels of nickel because it is widely present in air, water, food, and consumer products. The general population takes in most nickel through food, with the average daily intake from food in the United States estimated to be 150-168 μg. Typical intakes from drinking water and air are 2 μg and 0.1-1 μg, respectively. The general population also is exposed to nickel in nickel alloys and nickel-plated materials such as coins, steel, and jewelry, and residual nickel may be found in soaps, fats, and oils (ATSDR 1997)."

> "EPA's Toxic Chemical Release Inventory (TRI) estimated that in the United States in 2001, 2,258 facilities released 4,481,059 lb (2,033 metric tons) of nickel, while 1,324 facilities released 9,799,196 lb (4,445 metric tons) of nickel compounds to the environment. From 1988 to 2001, the amount of nickel reported released by facilities was reduced by approximately half, while the release of nickel compounds did not change significantly (TRI01 2003)."

> "Occupational exposure to nickel occurs mainly by inhalation of dust particles and fumes or by dermal contact. Nickel workers also can ingest nickel-containing dusts. Occupational exposure is common for workers involved in mining, smelting, welding, casting, spray painting and grinding, electroplating, production and use of nickel catalysts, polishing of nickel-containing alloys, and other jobs where nickel and nickel compounds are produced or used (HSDB 2003)."

Relative toxicity of nickel and other micronutrients

Currently, boron, copper, iron, manganese, molybdenum, zinc and cobalt are included in 7 CFR 205.601 as micronutrients. The oral LD_{50} (rat) values of these components, as well as the LD_{50} value of nickel, are listed below as a general reference (borax, copper sulfate, iron(II) sulfate, manganese sulfate, molybdate, zinc sulfate, cobalt sulfate, and nickel sulfate). A strict comparison should be avoided since different components may have different physiological functions and different toxicities. As given in Question #7, nickel is generally less toxic than copper towards water plants, and fish.

	B	Cu	Fe	Mn	Mo	Zn	Co	Ni
LD_{50} (mg kg^{-1})	3220	300	319	2150	4000	1710	424	264

The health effect resulted from the interaction of nickel with other chemicals is discussed in Section 3.9 "Interactions with other chemicals" of ATSDR-Ni (2005). Nickel and other micronutrient components (Mn, Fe, Co, Cu and Zn) occupy similar positions in the periodic table and possess similar chemical properties. The assimilation of one component could be suppressed by another excessively presented component, which could be expected when multiple components compete for limited spaces. The toxicity of nickel was reduced by the presence of magnesium, iron and zinc (ATSDR-Ni, 2005). However, nickel enhanced the absorption of iron in iron-deficient rats. Further, the enhanced uptake of iron by nickel was only observed when ferric sulfate was given. "No interaction was observed when iron was given as a 60%ferric/40% ferrous sulfate mixture," (ATSDR-Ni, 2005).

Evaluation Question #12: Is there a wholly natural product that could be substituted for the petitioned substance? (From 7 U.S.C. § 6517 (c) (1) (A) (ii).)

Some micronutrients are naturally available, as given above in Questions #2 and #3. Most naturally available minerals of those micronutrient components such as nickel minerals are not soluble or very slowly soluble in water.

Soil naturally provides most micronutrients for plant growth, but the stock is depleted by the harvest of crops (e.g. Table 1 of McKenzie, 2001). Soybean grains remove about 24 g of copper per acre per harvest. Soil is the weathering product of parent rock and will not resupply micronutrients within a short period of time.

Metal-accumulator plants may be grown on some metal-rich soil and the harvest may be used as nutrient source for different locations. This might provide a slow-releasing source of nutrients in a long term, but may not be a quick remediation for nutrient deficiency problems. Most micronutrients are assimilated by plants as simple ionic forms (borate anion BO_3^{3-}, Cl^-, Cu^{2+}, Fe^{3+}, Fe^{2+}, Mn^{2+}, MoO_4^{2-}, Ni^+, Zn^{2+}, etc) (Clemson University, Hansch and Mendel, 2009). The releasing of micronutrients from former crops and the conversion for these components to simple ionic forms take time.

Evaluation Question #13: Are there other already allowed substances that could be substituted for the petitioned substance? (From 7 U.S.C. § 6517 (m) (6).)

Micronutrients are essential for plants, since these components are playing important and specific physiological roles in plant growth. Some examples are listed in the "Action of the Substance" above. Other materials might not play the roles as played by these micronutrients. The following is quoted from Hansch and Mendel (2009).

> "Micronutrients are involved in virtually all metabolic and cellular functions, like energy metabolism, primary and secondary metabolism, cell protection, gene regulation, hormone perception, signal transduction, and reproduction among others."

> "Essential micronutrients were found as constituents in over 1500 proteins where they fulfill catalytic, (co-)activating, and/or structural functions. The largest group (>1200) is formed by zinc-proteins (with transcription factors as major subgroup). Proteins containing iron, copper, or manganese make up groups in

> the range of 50–150 members each, while molybdenum and nickel proteins can be counted on one hand each. Boron and chlorine are very important, but proteins or compounds that were unambiguously shown to contain these micronutrients are very rare and mostly elusive."

Furthermore, "essential" actually means more than "for the normal growth of plants". A plant will only grow and develop to the extent that its most limiting growth factor will allow, as it is specified by the "Law of the Minimum" (The availability of the most abundant nutrient in the soil is as availability of the least abundant nutrient in the soil). When the supply of nutrients to plants is not balanced, plants, limited by some deficiently supplied components, will not assimilate the extra-supplied nutrients. These extra-supplied nutrients are simply wasted and the crop yield is less than planned (McKenzie, 2001).

Evaluation Question #14: Are there alternative practices that would make the use of the petitioned substance unnecessary? (From 7 U.S.C. § 6517 (m) (6).)

The demand of plants for micronutrients is low, as the name of *micro*nutrients implies. Nickel is even considered as a *nano*-micronutrient. There might be sufficient micronutrients in soil already. For example, there may be between 20 to 200 pounds of boron per acre in the surface layer of South Carolina soils, but only a small portion is available to plants (Clemson University). As it was discussed in Question #5 and #7, "contamination by heavy metals" could be difficult to recognize and might be more general than the problem of "deficiency of micronutrients". On the other hand, "diagnosing a micronutrient deficiency can be a difficult and time consuming process" (McKenzie, 2001). Six steps, proposed in the section of "Determining the need for micronutrients" by McKenzie (2001) to identify a micronutrient deficiency, are quoted below.

> "1. Ensure that poor crop growth is not the result of a macronutrient deficiency, drought, salinity, disease or insect problem, herbicide injury or some physiological problem.
> 2. Find out if a micronutrient deficiency has been identified before in a particular crop or soil type in the area.
> 3. Examine the affected crop for specific micronutrient deficiency symptoms.
> 4. Take separate soil samples from both the affected and unaffected areas for complete analysis, including micronutrients.
> 5. Send plant tissue samples from both the affected and unaffected areas for complete analysis that includes tests for micronutrient levels.
> 6. If all indications point to a micronutrient deficiency, apply the micronutrient to a specific, clearly marked out affected area of land to observe results in subsequent seasons."

Several factors might limit the availability of micronutrients to plants. The soil pH greatly determines this availability. In general, the availability decreases with increasing soil pH, except molybdenum. "The level of soil zinc is 'insufficient' or 'low' when extractable zinc is less than 2.0 pounds per acre and the soil pH is less than 6.1, and when extractable zinc is less than 2.5 pounds per acre and the soil pH greater than 6.0," (Clemson University). Lime application causes soil pH to increase while sulfur application reduces soil pH.

pH adjustment might be more important than applying "required" micronutrients for correcting "deficiency" problems. "If the deficiency is due to pH imbalance, the approach is to modify the pH of the mix. In this case, adding micronutrients can make matters worse because the level of individual micronutrients may affect the level in the plant of other micronutrients through a process called antagonism. For example, too much iron may produce manganese and zinc deficiencies, while high levels of manganese may result in iron and zinc deficiencies. Copper and zinc are also antagonistic: too much of one may produce deficiency of the other," (Ohio State University). Heavy metals such as Cu, Zn and Ni are strongly retained in soil. Excessively applied micronutrients remain in soil for a long time and may cause toxic effects to subsequent plants.

The uptake of one micronutrient by plants could be interfered by the abundant presence of other micronutrients or other components. "Calcium, potassium, and nitrogen concentrations in both the soil and plant can affect boron availability and plant function, the calcium:boron (Ca:B) ratio relationship being the most important. Therefore, soils high in calcium will require more boron than soils low in calcium. The chance for boron toxicity is greater on low calcium-content soils," (Clemson University). The uptake of nickel by pecan trees, for example, was suppressed by zinc which was applied for zinc deficiency problem (University of Georgia). Solving the zinc deficiency in an alternative method may alleviate the nickel deficiency problem.

Animal manures usually contain various micronutrients. Various bio-solids such as sewage sludge usually contains elevated concentrations of these micronutrients such Cu, Ni, and Zn (Fuentes et al., 2007). However, these materials might contain other components in addition to these micronutrients and may be limited or prohibited in agricultural applications.

Crop rotation may be an option when one specific area is not fit for a specific crop due to micronutrient deficiency problem.

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