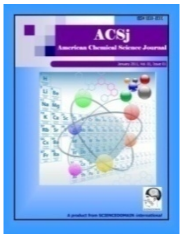

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An Overview on Manganese in Nature

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Authors' contributions

This work was carried out in collaboration between all authors. Author GVS fulfilled the literature review on manganese in plant, in living organisms, wrote the first draft of the manuscript, and corrected the final form of the review. Author LI documented on manganese in soil, plant and wrote the "Manganese in soil" section, corrected the final form of the manuscript. Author CC managed the literature searches regarding section "Manganese - occurrence and uses", "Manganese in living organisms", wrote corresponding sections, and corrected the final form of the manuscript. All authors read and approved the final manuscript.

Review Article

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ABSTRACT

Manganese is the most 12th prevalent element on Earth that occurs in 11 oxidation states (from -3 up to +7). An essential element present in all living organisms, manganese is required for growth, development and maintenance of health. It is naturally present in soil, plants, water.

In soil, it occurs as exchangeable manganese, manganese oxide, organic manganese and a component of ferromagnesian silicate minerals. The amount of available manganese is mostly influenced by soil reaction, organic matter content, moisture and soil reaction.

In plants, it activates a large number of enzymes that catalyzes oxidation-reduction processes, decarboxylation, fatty acids synthesis or hydrolysis. Plants absorb divalent form of manganese from soil solution. Mn^{+2} suffer easily an oxidation process to Mn^{+3} and Mn^{+4} and due to this behavior are involved in redox processes.

Manganese deficiencies appear usually on acidic soils, low in native Mn or soil with pH above 6.5, poorly drained calcareous soils and organic matter rich. Symptoms of

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manganese deficiency include interveinal chlorosis with dark-green veins.
In human body, the role of manganese as co-factor for enzymes represent one of the most important functions of this element. Mn-dependent enzymes are oxidoreductases, transferases, hydrolases, lyases, isomerases, meanwhile manganese metalloenzymes include arginase, glutamine-synthetase, phosphoenolpyruvate decarboxylase, Mn-superoxide dismutase. Manganese deficiency in humans is uncommon, but high levels lead to manganism with manifestations similar to Parkinson disease (generalized bradykinesia and widespread rigidity). Unlike idiopathic Parkinson's disease, patients with manganism may have a less frequent resting tremor, more frequent dystonia, easily fall backward and failure to respond to levodopa.
The uses of manganese are manifold and include steel production, production of potassium permanganate, glass, textile bleaching. Manganese coordination compounds present antimicrobial properties or are used in magnetic resonance image of the liver.
Taking into account that manganese presents a significant role for plants and human beings, this paper present a review of literature that illustrates the importance of manganese.

Keywords: Manganese; soil; deficiency; toxicity; plant; manganism.

1. MANGANESE – OCCURRENCE AND USES

The beginning of manganese utilization can be traced back to ancient times when people were using manganese dioxide as paint for caves or, later to decolorize glass. Nowadays, it is used to remove green color in glass caused by iron. Carl Wilhelm Scheele proposed manganese to be an element in 1771 but was discovered by Johan Gottlieb Gahn in 1774 after heating manganese dioxide with charcoal. In 18th century, manganese dioxide became the raw material for the synthesis of chlorine. Bleaching agents that contain chlorine and hypochlorite are obtained using manganese ores.

Manganese is the 12th most prevalent metal on Earth and is not encountered as free metal in the environment. It is found combined with other elements in more than 100 minerals (sulphides, carbonates, phosphates, borates), the most widespread one being pyrolusite (MnO_2) followed by rhodocrosite ($MnCO_3$), hausmannite (Mn_3O_4) (Table 1) [1-3].

Manganese in elemental form is a silver-stained metal and in nature it occurs combined with other elements such as oxygen, carbon, silicon, sulphur and chlorine in manganese-compounds (Table 2). Even if exists in many oxidation states (from -3 up to +7), the most common one is +2. In nature, the $Mn^{+2,+3,+4}$ present biological relevance [4]. The major sources of manganese exist in Russia, Australia, Gabon, Brazil, South Africa and India [4].

Table 1. Some common manganese minerals [5]

Manganese containing mineral	Chemical name	Chemical formula
Bixbyite	Manganese sesquioxide	Mn_2O_3
Braunite	Silicate mineral with both Mn(II) and Mn(III)	$3Mn_2O_3{\cdot}MnSiO_3$
Hauerite	Manganese disulphide	MnS_2
Hausmannite	Manganese (II, III) oxide	Mn_3O_4
Knebelite	Iron manganese silicate	$(MnFe)_2SiO_4$
Manganese blende	Manganese (II) monosulphide	MnS
Manganite	Manganese oxide hydroxide	$Mn_2O_3{\cdot}H_2O$
Pyrolusite	Manganese (IV) dioxide	MnO_2
Rhodamite	Manganese silicate	$\sim MnSiO_3$
Rhodochrosite	Manganese (II) carbonate	$MnCO_3$
Tephroite	Manganese silicate	$\sim MnSiO_3$

In the deep of the ocean are encountered ocean nodules, an important source of metals, including manganese (20-25%). These could be an important source of manganese in the future but deep-sea mining method sand recovering is supposing difficulties. Some researchers suggest as recovering method, the using of oxidizing bacteria [6].

The uses of manganese and its compounds are manifold: iron and steel production (improve hardness, strength, stiffness), manufacture of dry cell batteries, production of potassium permanganate, manufacture of glass, textile bleaching, matches and fireworks [7].

Nowadays, a manganese compound of concern is methylcyclopentadienyl manganese tricarbonyl (MMT) that was introduced as an octane boosting and "anti-knock" agent. The combustion of MMT in the automobile with the expected increase in ambient manganese level has raised concerns about the health risks associated with environmental exposure to manganese [8].

Table 2. Commonly used manganese compounds [5]

Compound	Synonyms	Chemical formula
Mn(IV) dioxide	Manganese (IV) oxide, manganic oxide, pyrolusite	MnO_2
Mn(II) oxide	Manganese (II) oxide, manganous oxide, manganosite, manganese green	MnO
Manganese (II, III) oxide	manganomanganic oxide, hausmannite	Mn_3O_4
Manganese sulphate	Manganese sulphate, manganous, sulphate, sulphuric acid-manganese salt	$MnSO_4$
Potassium permanganate	Permanganic acid-potassium salt, chameleon mineral, Condy's crystals	$KMnO_4$
Manganese (II) carbonate	Manganous carbonate, rhodochrosite	$MnCO_3$
Manganese (III) fluoride		MnF_3
Manganese (II) dichloride tetrahydrate	Manganous chloride 4-hydrate	$MnCl_2{\cdot}4H_2O$
Manganese (II) sulphide	Manganese monosulphide, alabandite, manganblende	MnS
Manganese (II) nitrate	Manganous nitrate	$Mn(NO_3)_2$

Beside these, newer uses include an antifungal compound for foliage (manganese-ethylene-bis-dithiocarbamate, Maneb) and the coordination compounds that are used in medicine for treatment of various diseases. The first known therapeutic use of manganese was the treatment of psoriasis, in combination with vitamin B1 in 1966 [9].

A large number of manganese complexes present antibacterial properties and could be used accordingly. It is notable the use of Mn(II) agent named Mangafodipir trisodium (manganese-dipyridoxyl diphosphate, Mn-DPDP) in magnetic resonance imaging (MRI) of the liver. An improved capability for lesion detection and the ability to characterize tumors of hepatocellular origin have been demonstrated [10]. Mangafodipir trisodium is a manganese coordination compound derived from vitamin B6 (Fig. 1).

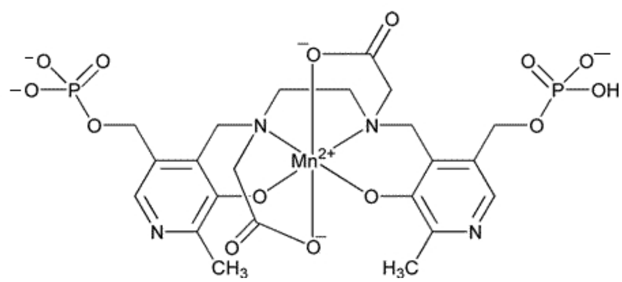

Fig. 1. Structure of Mangafodipir trisodium (Mn-DPDP)

2. MANGANESE IN SOIL

Manganese makes up about 1000 ppm (0.1%) of the Earth's crust, making it the twelfth most abundant element there. Soil contains 7-9000 ppm of manganese with an average of 440 ppm. Manganese occurs in soil as exchangeable manganese, manganese oxide, organic manganese and a component of ferromagnesian silicate minerals. The amount of available manganese is mostly influenced by soil reaction, organic matter content, moisture and soil reaction.

2.1 Soil Reaction

Manganese biogeochemistry in soils is complex, because it is present in several oxidation states (0, II, III, IV, VI and VII), while in biological systems it occurs preferably as II, III and IV. Divalent manganese (Mn II) is the most soluble form of Mn in soil, whereas the solubility of Mn III and Mn IV is very low [11]. Mn interacts with both cations and anions in oxidation-reduction reactions involving Mn. A variety of physical, chemical and microbiological processes influences these processes [12].

In acidic soils with pH lower than 5.5and an increased redox potential of Mn, oxides can be easily reduced in the soil exchange sites [13], increasing the concentration of soluble Mn^{2+} [14]. This form is predominant in the soil solution and the most available for plants [15]. In the case of soils with higher pH (up to pH 8), chemical Mn^{2+} auto-oxidation is favored over MnO_2, Mn_2O_3, Mn_3O_4 and even Mn_2O_7, which are not usually available to plants [16-18]. Furthermore, high pH allows Mn adsorption into soil particles, decreasing their availability [19]. Abundant pluviometry during winter accentuates soil acidification, causing the main cations to leak from the soil [20]. On the other hand, lime application is a key factor in decreasing soluble Mn in acid soils with a high Mn content, given that it can increase soil pH [21,22].

On alkaline soil and lime application conditions, it is found available manganese in small quantities, taking place immobilization by hydrolysis processes under the HO^- influence, followed by oxidation:

$$Mn^{2+} + 2HO^- \rightarrow Mn(OH)_2$$
$$2Mn(OH)_2 + O_2 \rightarrow 2MnO_2 + 2H_2O$$

2.2 Organic Matter

Soils with high organic matter content (more than 6%) combined with pH above 6.5 may lead to deficiency in manganese. The increase of organic matter content is correlated with the decrease of the amount of exchangeable manganese due to the formation of manganese complexes [23].

Higher organic matter also intensifies microbiological activity, which can further decrease the availability of Mn [24]. Soil aeration and moisture levels also influence these conversions. Poor soil oxygen level caused by high moisture conditions combined with a high rate of microbe activity fuelled by organic matter, consume oxygen and convert less available forms of Mn to more reduced or available forms. Under prolonged wet conditions, available Mn can leach out of the root zone. Under continued waterlogged conditions these forms of Mn can plug the tile when exposed to the air in the tile runs [24].

2.3 Moisture and Aeration

Weather conditions affect the cycling of Mn as well. Obviously excess rain can increase availability (reduction) as described previously and drought can increase the deficiency symptoms [24].

Excess moisture along with high microbial activity causes poor soil aeration. As a result, manganese oxide is converted to soluble manganese. Under prolonged waterlogged conditions, soluble manganese leaches out of the soil. Temporary waterlogged conditions are conducive to manganese toxicity; prolonged wet conditions can results in manganese deficiency [23].

3. MANGANESE IN PLANTS

J. S. McHargue discovered the essentiality of manganese for higher plants in 1922. His studies revealed the role of manganese in the promotion of rapid photosynthesis [18]. Manganese activates a large number of enzymes that catalyzes oxidation-reduction processes, decarboxylation, fatty acids synthesis or hydrolysis. Manganese-containing enzymes are Mn-SOD (protect tissues from harmful oxygen radicals) [26] and manganese-protein in photosystem II (PSII is specialized protein complex that uses light energy to transfer electrons from water to plastoquinone, leading to oxygen) [27]. It is involved in the photosynthetic evolution of O_2 in chloroplasts (Hill reaction) and inhibition of photosynthesis occurs even at moderate manganese deficiency [18].

Manganese has an effective role in lipids metabolism, and due to its effective role in the nitrate reduction enzymes, nitrate will accumulate in leaves, which are facing with manganese deficiency [28].

Plants absorb divalent form of manganese, Mn^{+2} from soil solution. Mn^{+2} suffers easily an oxidation process to Mn^{+3} and Mn^{+4} and due to this behavior is involved in redox processes [29].

Root secretions influence the narrow region of soil (rhizosphere) strongly involved in mineral plant nutrition. According to Millaleo and coworkers [30] mobilization of Mn^{+2} is produced by rhizosphere acidification (release of H^{+}, organic acids) or due to soil microorganisms (Fig. 2).

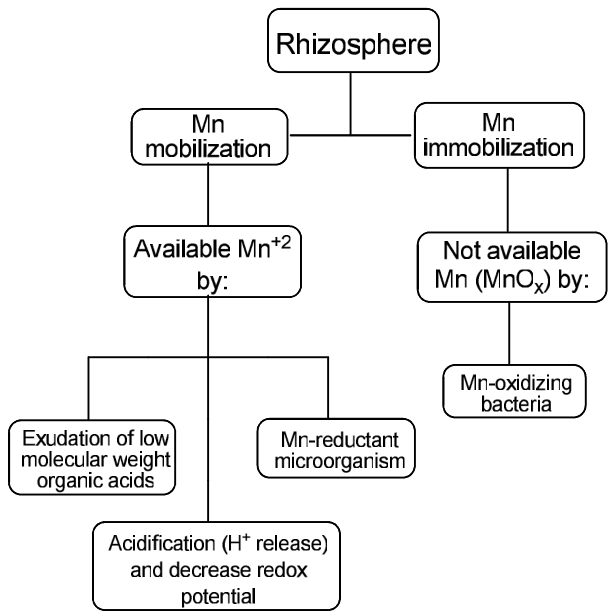

Fig. 2. The role of soil rhizosphere in the mobilization and immobilization of Mn in the soils [30]

After it is incorporated into plant tissue, manganese is quite immobile, is not retranslocated and due to this behavior, the deficiency symptoms appear firstly on younger leaves. In addition, high levels of Ca^{+2}, Zn^{+2}, Mg^{+2}, NH_4^{+} may inhibit Mn^{+2} uptake by plants.

3.1 Manganese Deficiency in Plants

Symptoms of manganese deficiency include interveinal chlorosis (dark-green veins), the most sensitive species being bean, lettuce, onions, peas, potato, sorghum, soybean, wheat [18]. In soybean, deficiency appeared when manganese level was below 20 ppm [31].

Hawson [32] stated that deficiency symptoms in most species are associated with leaf levels less than 20 ppm with particularly severe symptoms at less than 10 ppm, meanwhile healthy plants normally contain 50 to 200 ppm of manganese. Some studies regarding strawberry quality indicated that except for a decrease in fruit size, manganese deficiency has no appreciable effect on fruit appearance or quality [33].

Some researches indicated that crops quality and quantity decreased due to manganese deficiency, and this is due to low fertility of pollen and low in carbohydrates during grain filling [28].

Manganese deficiency in crops can be prevented and corrected by band applying manganese fertilizer to the soil, spraying it on the foliage or increasing the acidity of soil (with sulphur and aluminum sulphate).

3.2 Manganese Toxicity in Plants

Manganese toxicity occurs in well-drained soils with pH below 5.5 [18]. In addition, tropical, subtropical and temperate soils represent sources of high manganese concentrations that could produce visible symptoms of toxicity [18]. Toxicity may appear after excessive manganese application (soil or foliar). Toxicity symptoms include marginal chlorosis and necrosis of leaves, leaf puckering. There are crops considered more sensitive to excess manganese: alfalfa, cabbage, cauliflower, clover, potato, sugar beet, tomato [18].

High content of manganese was found in leaves of beetroot and leguminous plants in comparison with cereals (corn) where the content is lower. The level of manganese in plants usually increases with the progress of vegetation period, high levels being found in plant organs where the metabolism is more intensive [34].

Some researches [31] indicated that toxicity levels in soybean occurred when tissue concentration was above 250 ppm. Low quantity of other available elements as Ca, Mg, K, Fe and Si intensifies manganese toxicity [35]. Some studies revealed that after application of manganese based-fungicides (Mancozeb), levels of manganese were up to 1500 ppm [32]. Literature studies indicate that some species (*Pytolacca Americana L.*, *Polygonum perfoliatum L.*, *Polygonum hydropiper L*, *Phytolacca acinosa*) can tolerate and accumulate high concentrations of manganese and are suitable for bioremediation of manganese-polluted environments [36,37].

4. MANGANESE FERTILIZERS

Manganese fertilizers fulfill correction or prevention of manganese deficiency in plants. Fertilizer sources are both organic (animal wastes, but are low manganese content) and inorganic materials. Manganese compounds used as fertilizers are manganese carbonate, manganese chloride, manganese dioxide, manganese oxide, manganese sulphate, chelates (Mn-EDTA) (Table 3). Manganese oxides' solubility in water is very low and the recommendation is to be grinded and used for acidic soils [28]. Broadcast application of chelates is not recommended because manganese may be converted in unavailable forms, calcium and iron displacing manganese in the chelate.

For horticultural crops, it is strongly indicated to apply manganese fertilizers as foliar spray as well as in the case of calcareous soils [28].

Table 3. The main sources of manganese fertilizer [24, 28, 38, 39]

Manganese fertilizer	Chemical formula	Mn content, %
Manganese carbonate	$MnCO_3$	31
Manganese chelate	Mn-EDTA	12
Manganese chloride	$MnCl_2$	17
Manganese dioxide	MnO_2	63
Manganese oxide	MnO	41-68
Manganese sulphate	$MnSO_4 \cdot 3H_2O$	26-28

Brennan and coworkers [40] developed an experiment, which revealed that application of manganese sulphate, and manganese oxide on two different alkaline soils from Australia increased the yield of 45-day-old lentil (*Lens culinaris* Medik).

An important issue is that all manganese fertilizers interact with glyphosate in a tank mix, resulting in reduced herbicide efficacy and lower manganese availability. Anyway, it is recommended the use of Mn-EDTA because is the least antagonistic Mn fertilizer to glyphosate and it is preferred for tank mixing [41].

5. MANGANESE IN LIVING ORGANISMS

5.1 Role of Manganese in Living Organisms

Manganese is an essential trace element found in all tissues. The role of manganese as co-factor for enzymes represents one of the most important functions of this element in biochemistry. Mn-dependent enzymes are oxidoreductases, transferases, hydrolases, lyases, isomerases, meanwhile manganese metalloenzymes include arginase, glutamine-synthetase, phosphoenolpyruvate decarboxylase, Mn-superoxide dismutase (Mn-SOD) [42]. Some manganese-activated enzymes (pyruvate carboxylase) are also activated by other ions (Mg^{+2}).

Manganese is involved in cholesterol synthesis; a deficiency may be related to a lack of this precursor for hormones synthesis [43]. Manganese an antagonist of iron, can replace magnesium in certain enzymes, and may interfere with the metabolism of calcium due to the similarity regarding ion radius [42].

Absorption of manganese occurs in its divalent and tetravalent forms, with an intake of 2–9 mg/day [44]. A small proportion of manganese is oxidized to Mn^{3+} and enters the systemic circulation, possibly by binding to transferrin, an iron-carrying protein [42] due to similar characteristics of manganese and iron (transition metals with +2 and +3 oxidation states in physiological conditions and similar ionic radius) [44].

5.2 Manganese Dietary Sources

Diet represent main source of manganese intake for humans and no case of manganese deficiency in human have ever observed [45]. Recommended dietary intake for manganese is 2-5 mg/day [46].

An important consideration for assessment of human exposure to manganese in food is bioavailability. Some factors may influence the level of manganese absorption upon ingestion: oxalic acid, fibers, tannins and phytic acids, which tend to decrease manganese absorption [47].

Fruits and vegetables contain lower concentrations of manganese; the main sources are grains and rice (Table 4). Recent researches revealed that tea represent a great source of manganese [48]. Manganese intake after tea drinking commonly exceeds proposed adequate intake values of 1.8-2.3 mg Mn/day and occasionally exceeds upper limits of 10-11 mg Mn/day [49].

Al-Oud's researches [50] indicated that tea plant could accumulate large quantities of manganese (390-900 mg/kg); the highest value was found for Chinese green tea. Kumar et al. [51] found that Indian tea contain Mn between 371-758 mg /kg, with an average value of 575±96 mg/kg. Subramanian and coworkers [52] analyzed Indian medicinal plants and found manganese average levels between 85.72-101.50 mg/kg. Ismail et al. [53] conducted a study that revealed that leafy vegetables accumulate more manganese that fruit vegetables.

Table 4. Dietary sources of manganese [54, 55]

Dietary sources	Mn (mg/100g)	Dietary sources	Mn (mg/100g)
wheat germ	13.3	sunflower seeds	2.0
wheat bran, crude	11.5	sweet potato, cooked, baked in skin	0.6
rice, brown	3.7	peas, green, canned, drained	0.3
oats	4.9	kale, cooked, boiled, drained	0.4
flour, soybean, defatted	3.0	corn, sweet, cooked, boiled, drained	0.2
soybeans, dry	2.5	lettuce, iceberg, raw	0.2
beans, lima, dry	1.2	banana	0.2
peanuts roasted/salted	2.1	prunes, dried	0.2

Othman [56] analyzed composition of fresh fruit juice made up from Mbezi pineapple (*Ananas comosus* L.) and found a great manganese content 5.70 ±0.89 mg/100g fresh weight. This indicated that 100 grams of Mbezi pineapple juice was sufficient to provide 2-5 mg Mn/day.

According to Rubio et al. [57] milk and yogurt contain small levels of manganese (around 0.003 mg/100g), meanwhile nuts are a great source of manganese (1.89 mg/kg). Same group of researchers did not detect manganese in alcoholic and non-alcoholic drinks [57]. Some researches carried out in Nigeria [58] with the aim to find out if canned and non-canned beverages could present high content of iron, manganese and nickel, indicated that 42% from analyzed canned beverages contain manganese over 0.05 mg/L, meanwhile 51.72% of the non-canned beverages had manganese level greater than 0.05 mg/L. The range of the manganese in the canned beverages was 0.001-0.730 mg/L and 0.001-0.209 mg/L for non-canned beverages.

There are many studies concerning manganese content in wines, due to its importance regarding wine oxidation, formation of acetaldehyde during oxidation and from toxicological perspective. The manganese content in wines could reach accidentally the value 10 mg/L, this being a consequence of fungicide contamination (Maneb, for example) or to fraudulent treatments with potassium permanganate (to intensify the color of red wines or to desulfitation of white wines) [59]. According to Ribereau-Gayon et al. [60] usually small quantities of manganese are present in all wines (1-3 mg/L). Higher concentration may come from vineyard soil, equipments and phytosanitary treatments [60].

According to researches regarding manganese content in Romanian wines [61], manganese average concentrations are below 1 mg/L in white wines meanwhile rośe and red wines contain more than 1.2 mg/L (as mean value).

Manganese is a common natural constituent of ground water and elevated levels of manganese may appear in some ground water due to certain bedrock formations or pollution sources. Manganese is not considered a health hazard. Main responsible factor that may lead to increased values of manganese concentration in water is human activities. According to European legislation [62] manganese content in drinking water is 0.05 mg/L. Anyway, manganese intake from drinking water is substantially lower than intake from food products. Studies carried out on bottled drinking water from different countries [63] revealed high manganese levels that exceeded limit imposed by European legislation. Four bottled waters from Germany (two with 0.093 mg/L, 0.290 mg/L, 0.310 mg/L) and one from Slovenia (0,240 mg/L) distinctly exceeded this concentration.

Chemical analysis on drinking waters from Yozcat, Turkey [64] revealed values below limits set by World Health Organization drinking water quality guidelines. According to WHO [65] a value of 0.5 mg/L should be adequate to protect public health. Concentrations below 0.1 mg/L are usually acceptable to consumers.

Wang and coworkers [66] found in August 2009 that manganese content of the drinking water source in Yancheng was 0.15 mg/L. The cause of this pollution was the wastewater and waste slag discharged by the stainless steel factories nearby.

Other studies [67] carried out on Scottish ground waters indicated elevated manganese concentrations; 30% of the Scottish sites sampled (475 sites totally) contain more than 0.05 mg/L. The principal controls on Mn concentrations in groundwater in Scotland are redox conditions that exercise the strongest control and pH, with influences on Fe behavior. Roccaro and coworkers [68] developed some researches in order to purify the groundwater from Volcano Etna area (Sicily), because manganese concentration reach the value of 1.87 mg/L, much more than 0.05 mg/L proposed by European legislation.

5.3 Manganese Deficiency

Manganese deficiency at humans is uncommon. Literature studies indicate that no cases of manganese deficiency have been reported [45]. Subjects that adopted a manganese deficient diet developed fine, scaly skin and presented increases of serum calcium, phosphorus and alkaline phosphatase levels [45].

5.4 Manganese Toxicity

Excessive exposure to manganese mainly via occupational inhalation may cause symptoms of central nervous system (aberrant behavior, hallucination, Parkinson's like symptoms) known as "manganism" [45]. Manganese can enter into human body by inhalation or ingestion. Absorption of inorganic manganese through the skin it seems to be negligible. Subjects with manganism resemble patients with Parkinson's disease. Although these manifestations are similar in many respects, there are distinct differences between them.

Similarities between Parkinson's disease and manganism include the presence of generalized bradykinesia and widespread rigidity. There are also dissimilarities between Parkinson disease and manganism, notably the following in manganism: a less frequent resting tremor, more frequent dystonia, a particular propensity to fall backward, failure to achieve a sustained therapeutic response to levodopa. [69].

Unlike idiopathic Parkinson's disease, patients with manganism may have a less frequent resting tremor, more frequent dystonia, easily fall backward and failure to respond to levodopa [70].

Neurotoxic effects that were consequences of excessive manganese exposure were described for the first time by Coupier in 1837 for workers from France that were grinding manganese oxide for obtaining bleaching powder [44].

The neurological impact of manganese poisoning is progressive and passes through three stages:

1) There are no specific signs, but the subjects are whining of tiredness, headaches, irritability, joint pains;
2) Disturbance of posture and excessive salivation; it may appear organic psychosis - "manganic madness";
3) Rigidity, speech disturbances, muscle pains [71] .

Many cases of manganism have been reported particularly in miners, smelters and workers involved in the battery and alloy industry [72]. One case of manganism was reported in Taiwan in 1985 [73] when a man working in a ferro-manganese alloy factory presented the symptoms of manganese-induced parkinsonism. Then, investigations lead to other six patients from the same factory that presented symptoms that were associated with chronic manganese intoxication: rigidity, impaired dexterity, micrographia, hypophonia, "cock-walk gait" (high-stepping gait, strutting on the toes with flexed elbows and erect spine) [73].

One interesting study that describe the clinical manifestations of a fatal acute accidental manganese intoxication [74] present the case of a 50-year-old man that presented to the emergency department with muscle weakness, dizziness, abdominal pain, nausea, diarrhea after ingested "Epsom salt" ($MgSO_4 \cdot 7H_2O$) during a "liver cleansing diet". In reality, the man was poisoned with manganese sulphate, $MnSO_4$, because the supplier had mistakenly prepared the salts with hydrated manganese sulphate instead of magnesium sulphate heptahydrate. The patient died but the results on investigations into this case enabled 33 other patients to be successfully treated after they ingested the same compound.

Manganism treatment usually consists on chelation therapy with $CaNa_2$ EDTA. This manner of treatment indicated that manganese excretion in the urine increased meanwhile the manganese level in blood decreased even if the clinical symptoms did not present any improvement [75]. Other studies [76] present the beneficial effects of para-amino-salicylic acid therapy for few patients but the therapeutic responses should be investigated further.

6. ANALYTICAL METHODS USED TO QUANTIFY MANGANESE

Analytic techniques used for manganese low levels assessment from environmental, food, biological samples are various and include atomic absorption spectrometry (AAS), mass-spectrometry (ICP-MS), inductively coupled plasma mass spectrometry with quadrupole mass analyzers (ICP-QMS), polarography, neutron activation analysis, fluorescence analysis, flow injection analysis [77-81].

Low concentrations, insufficient sensitivity of the methods and matrix effects often complicates the assessment of manganese traces. Using preconcentration and separation methods, these problems are often removed.

Spectrophotometric method for manganese determination is very easy and advantageous, in routine analysis being versatile and economically. Periodate [82], persulphate [83], bismuthate [84] oxidation of Mn^{+2} to MnO_4^- in acidic medium and the measurement of the absorption of the charge-transfer band of permanganate at appreciatively 520 nm are widely used as methods for manganese determination from various samples. Intensity of the purple color of the permanganate ion is correlated with amount of manganese in analyzed sample. The 1-(2-pyridylazo)-2-naphtol (PAN) method is sensitive, rapid and is suitable for low levels of manganese [85]. This method supposes using an alkaline-cyanide reagent and after PAN addition, appears an orange-red colored complex of manganese. Formaldoxime method, similar to PAN, is based on the formation of reddish-brown manganese complex. This method is usually used to determine the level of manganese from waters, but the main drawback of the method is the interference caused by trivalent iron that forward to a violet colored complex [86]. Addition of hydroxylamine and EDTA or ascorbic acid [87] in the sample solved this inconvenient.

Numerous kinetic methods have been reported regarding catalytic effect of Mn^{+2} on the oxidation of organic compounds with suitable oxidants [88]. These methods presented good sensitivity and received considerable attention because of the significant advantages in the determination of many analytes at trace levels.

7. CONCLUSIONS

Manganese is an essential element present in all living organisms and is required for growth, development and maintenance of health. It is present in soil, plants or in human body and accomplishes important tasks: activates a large number of enzymes or is constituent of metalloenzymes.

Deficiency in plants is determined mainly by the characteristics of the soil (pH, organic matter content, moisture and aeration), meanwhile deficiency at humans is not common. Unlike deficiency, the toxicity appears in plants due to acidic reaction of the soil or after excessive soil or foliar applications, and in human body mainly by occupational means.

Manganese and its compounds have numerous applications that influence our daily lives as consumers. The main use of manganese is in metallurgical processes, as a deoxidizing and desulfurizing additive. Also, is essential to steel production and plays an important role in the development of various steelmaking processes (about 90% of all manganese uses every year goes into steel as an alloying element). After steel, the second most important role of manganese is represented by dioxide form in dry cell batteries.

The uses of manganese and of its compounds are various and include manufacture of glass, textile bleaching, matches and fireworks, “anti-knock” agents (MMT), antifungal compounds, antibacterial agents.

Manganese is an important element with major implications for life.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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