

## Some Characteristics of Calcareous soils. A review

A.S. Taalab<sup>1</sup>, G.W. Ageeb<sup>2</sup>, Hanan S. Siam<sup>1</sup> and Safaa A. Mahmoud<sup>1</sup>

<sup>1</sup>Plant Nutrition Dept. and <sup>2</sup>Soil and Water Resource Dept., Agriculture and Biological Division, National Research Centre, 33 El Buhouth St., 12622, Dokki, Giza, Egypt.

Received: 20 Dec. 2018 / Accepted 24 Jan. 2019 / Publication date: 30 Jan. 2019

### ABSTRACT

Calcareous soils are widely spread in arid and semiarid regions. It has been estimated that these soils comprise over one-third of the world's land surface area. In Egypt, the calcareous soils constitute about 25-30% of the total area according to Ministry of Agriculture estimation. The highly calcareous soils in the North Western Coastal zone (about 3 million acres) offer great possibilities for land reclamation and development to help in solving the shortage of food production taking into consideration the available rain fall in that area. Calcareous soils are identified by the presence of calcium carbonate ( $\text{CaCO}_3$ ) in the parent material and an accumulation of lime. This is most easily recognized by the effervescence (fizzing) that occurs when these soils are treated with dilute acid. The pH of these soils is usually above 7 and may be as high as 8.5. When these soils contain sodium carbonate, the pH may exceed 9. In some soils,  $\text{CaCO}_3$  can concentrate into very hard layers, termed caliche, that are impermeable to water and plant roots. When P fertilizer is added to calcareous soils, a series of fixation reactions occur that gradually decrease its solubility and eventually its availability to plants. Phosphorus fixation is a combination of surface adsorption on both clay and lime surfaces, and precipitation of various calcium phosphate minerals. While the total lime content of a soil is important for predicting P reactions, the lime particle size (and its effect on reactive surface area) is often a better predictor of P behavior. Although a calcareous soil may be dominated by free lime, it may also contain significant amounts of iron (Fe), aluminum (Al), and manganese (Mn) either as discrete minerals, as coatings on soil particles, or complexed with soil organic matter. These metals provide strong sorption sites for P and are frequently more significant in controlling P solubility in calcareous soils than lime itself.

**Keywords:** Calcareous soils, phosphorus fixation, lime

### Introduction

Calcareous soils cover a large percent from the North Coastal region of Africa. Calcareous soils are defined as soils containing amounts of calcium carbonate affect distinctly the soil properties related to plant growth, whether they are physical, such as soil – water relations, and soil crusting, or chemical such as the availability of plant nutrients. The calcareous soils in Egypt around 0.65 million feddans (Rasha, 2005). The North Western Coastal region of Egypt is considered as one of the important regions for its considerable potentialities and location. Great efforts had been carried out to evaluate the agricultural potentiality to meet the food requirements of the over increasing population of Egypt. In calcareous soils where pH is high and  $\text{CaCO}_3$  is dominated, plants suffer low availability of P and K would cause problems more serious than their deficiencies. Increasing availability of these nutrients is one of the important objectives in plant nutrition (Khalefa, 2007). Calcareous soils cover more than 30% of the earth surface, and their  $\text{CaCO}_3$  content vary widely from a few percent to 95% (Marschner, 1995). Calcareous soils occur naturally in arid and semi-arid regions because of relatively little leaching. They also occur in humid and semi-humid zones if their parent material is rich in  $\text{CaCO}_3$ , such as limestone, shells or calcareous glacial tills, and the parent material is relatively young and has undergone little weathering. Some soils that develop from calcareous parent material can be calcareous throughout their profile. This will generally occur in the arid regions where precipitation is scarce. In other soils, calcium carbonate has been leached from the upper horizons and accumulated in

**Corresponding Author:** A.S. Taalab, Plant Nutrition Dept., Agriculture and Biological Division, National Research Centre, 33 El Buhouth St., 12622, Dokki, Giza, Egypt.  
E-mail: [astaalab@hotmail.com](mailto:astaalab@hotmail.com)

B or C horizons. These lower CaCO<sub>3</sub> layers can be brought to the surface after deep soil cultivation (Brady and Weil, 1999).

Many scientists discussed the definition of Calcareous soils as Elgabaly, (1973) who said that calcareous soils contain high levels of calcium carbonate (CaCO<sub>3</sub>) that affects soil properties related to plant growth, such as soil water relations and the availability of plant nutrients. Calcareous soils are common in the arid areas of the earth (FAO, 2016) occupying >30% of the earth's surface, and their CaCO<sub>3</sub> content varies from just detectable up to 95% (Marschner, 1995). Calcareous soils are the soils in which a high amount of calcium carbonate dominates the problems related to agricultural land use. They are characterized by the presence of calcium carbonate in the parent material and by a calcic horizon, a layer of secondary accumulation of carbonates (usually Ca or Mg) in excess of 15% calcium carbonate equivalent and at least 5% more carbonate than an underlying layer. In the World Reference Base (WRB) soil classification system calcareous soils may mainly occur in the Reference Soil Group of Calcisols (FAO, 2016)

### 1- Characteristics of calcareous soils:

Calcareous soils effervesces when treated with hydrochloric acid. When free carbonates are present, the acid will produce bubbling due to the evolving of CO<sub>2</sub> gas (Loeppert and Suarez, 1996) as  $\text{CaCO}_3 + 2\text{H}^+ \leftrightarrow \text{Ca}^{2+} + \text{CO}_2 + \text{H}_2\text{O}$

In some soils, the calcium carbonate deposits are concentrated into layers that may be very hard and impermeable to water. This is called caliche layer which is a secondary accumulation of carbonates (usually Ca or Mg) in excess of 15 % calcium carbonate equivalent and at least 5 % more carbonate than an underlying layer. In the World Reference Base(WRB) soil classification system calcareous soils may mainly occur in the reference soil group of calcisol (FAO /AGL., 2000). These caliche layers are formed by rainfall leaching the salts to a particular depth in the soil at which water content is so low that carbonates precipitate (Jackson and Erie, 1973).

Soils can also become calcareous through long period of irrigation with water containing CaCO<sub>3</sub> (Hagin and Tucker, 1982). The secondary calcium carbonates are formed under arid and semi-arid climatic conditions when the carbonate concentration in soil solution remains high. Accumulation starts in the fine and medium-sized pores at the surface of contact between the soil particles. This accumulation may be rather concentrated in a narrow zone of the solum or more dispersed, depending upon the quantity and frequency of rainfall, topography, soil texture, and vegetation (FAO, 2016)

Calcareous soils are alkaline because of the presence of CaCO<sub>3</sub>, which dominates their chemistries. Depending on the solubility product of CaCO<sub>3</sub>, the dissolution results in a high solution HCO<sub>3</sub><sup>-</sup> concentration, that buffers the soil in the pH range of 7.5 to 8.5 (Imas, 2000): as  $\text{CaCO}_3 + \text{H}_2\text{O} \leftrightarrow \text{Ca}^{2+} + \text{HCO}_3^- + \text{OH}^-$

As salts dissolve, the cations entering solution are attracted to the exchange sites usually according to valence and mass action. Except for very small amounts of micronutrient cations and some NH<sub>4</sub><sup>+</sup>, it is the Ca, Mg, K and Na ions that dominate the exchange sites. Their abundance parallel the energy of adsorption sequence, with Ca the most abundant and Na the least. The calcareous soils have 100% base saturation and calcium is the dominant cation on the exchange complex and in soil solution (Loeppert and Suarez, 1996). The cation exchange capacity of a calcareous soil (C horizon) developed from loess of Iowa was reported to be saturated 67% by Ca, 30% by Mg, 2% by K, and 1% by Na (Foth and Ellis, 1988).

As a result of calcareous soils development in regions of low rainfall (irrigated areas), one of the main agricultural constraints is the potential of water availability. The quality of irrigation water is the cause of many management problems. Almost, all waters used for irrigation contain inorganic salts in solution. These salts may accumulate in considerable amounts within the soil profile to such concentrations that may modify the soil structure, decrease the soil water permeability and seriously injure plant growth. Crusting of the surface may affect not only infiltration and soil aeration but also the emergence of seedlings. Cemented conditions of the subsoil layers may hamper root development and water movement characteristics.

Particle size distribution, surface area and reactivity are important properties of soil carbonates which influence soil pedogenic, chemical, and rhizosphere processes (Loeppert and Suarez, 1996). Calcium carbonate provides a reactive surface for adsorption and precipitation

reactions, for example, phosphate, micronutrients such as zinc and dissolved organic compounds (Saleh *et al.*, 1998). Carbonate reactivity influences the rate of volatilization of ammonia (Ryan *et al.*, 1981). Carbonate affects also rhizosphere processes, especially those in which acidification is an important factor. For example, the Fe-deficiency response of dicotyledons involves the oxidation of protons and acidification of the rhizosphere.

Reported symptoms of impaired nutrition in calcareous soils are chlorosis and stunted growth. This is attributed to the high pH of soil solution and reduced nutrient availability. Improved nutrition management is required to grow crops successfully on calcareous soils. Fertilizer management on calcareous soils differs from that on non calcareous soils because of the effect of soil pH on soil nutrient availability and chemical reactions that affect the loss or fixation of some nutrients. The presence of CaCO<sub>3</sub> directly or indirectly affects the chemistry and availability of nitrogen, phosphorus, iron, zinc, magnesium, calcium, potassium and copper (Marschner, 1995). The availability of phosphorus is reduced by the level of calcium and magnesium that are associated with carbonates. In addition, iron, zinc and magnesium deficiencies are common in soils that have high CaCO<sub>3</sub> due to reduced solubility at alkaline pH values (Marchner, 1995).

Soil properties control dynamics of P in soil. Calcareous soils strongly retain P and consequently establish low P concentration in soil solution (Sharif *et al.*, 2000). The various climatic conditions have resulted in a variety of forms of calcite precipitated at various depths in the different soil types, as many be observed partly in the field and more completely under the microscope. The semi arid climate removes Ca<sup>2+</sup> ions from the soil solution by precipitating carbonate, and also causes the exchangeable sodium percent and sodium adsorption ratio to increase with depth (Pal *et al.*, 2001). Phosphorus is primary nutrient and it is required to maintain its optimum supply in the soil for better plant nutrition. Therefore, it is most studied element but the least understood due to its complex chemistry is the soil plough layer. However, much of the phosphate in soil is not available to plants. Alkaline calcareous soils retain phosphorus as higher calcium compounds of lower solubility through a chemical reaction with soil constituent especially Ca and free lime and cause severe loss of this nutrient (Prasetyo *et al.*, 2001).

The phosphorus losses are rapid during initial stages but the intensity of P fixation decreased with the increase in time. The higher soluble phosphate fertilizers are more prone to their fixation because they are more active to chemical reaction with the constituent of the soil. The available phosphorus content decreased with the increase in time (Indiati *et al.*, 1999. and McLaughlin *et al.*, 2003). Many definitions of calcareous soils were proposed in the last years. These definitions were mainly depending on the chemical properties and the total CaCO<sub>3</sub> content regardless the active CaCO<sub>3</sub> content and the physical and hydraulic properties of these calcareous soils. (Shawky *et al.*, 2004). The study of phosphorus sorption of calcareous soils is an important factor for development of successful fertilizer and manure management practices (Leytem and Westerman, 2003). The soil characteristics influencing P sorption include: clay content, organic matter, pH, soil texture, Fe, Al and Ca content (Hedley and McLaughlin, 2005). Soil properties that affect the rate of phosphate retention in 28 contrasting calcareous soils from different geographical regions (14 soils from western Azerbaijan in Iran (WAI) and 14 soils from Western Australia in Australia (WAA)). The results showed that the mean apparent recoveries of applied available P (Olsen P based recovery) after 160 days of incubation at field capacity was found to be 7 % for the soils of WAI and 25 % for the soil of WAA. (Samadi., 2006).

## **2- Problems of cultivating calcareous soils:**

### *2. 1. Crust formation:*

Crust formed on the soil's surface is one of the most important component of the soil. This is true in the case of arid, semiarid and the moderate environment as well (Rahmonov, 2006). Gillette proved with his experiments carried out in wind tunnel that surface covered with crust is less vulnerable for wind erosion (Gillette *et al.*, 1982). There are two main types of surface crusts: one of them is formed out in natural way and the other one is formed out by anthropogenic effects. The former one can be divided into two other groups: the one that is formed by moisture (this is called as physical) and the one that has a biological origin (Goossens, 2004). The latter one forms out as a

result of the cementing effect of different algae, lichens and bacteria living in soil. These microplants can bind soil particles and don't let them start to move and protect them from the bombarding effect of other grains. Excretion of organic matter- for example polysaccharides- can increase the strength of such type of crust.

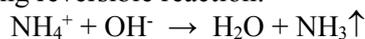
The biological crusts are important in the arid and semiarid regions, because the vegetation cover is not developed enough to provide the stability of surface (Eldridge, 1998). Investigations carried out in desert regions established that the biological crust has more strength and provide better protection than the other one evolved by the effect of precipitation (Rajot *et al.*, 2003, Zhang *et al.*, 2006).

The formation of crusts is a problem in the carbonate-rich soils newly put under cultivation. Crusting which takes place at the soil surface hinders seedling rate of emergence and percentage. The adverse effect of crust depends on their strength and thickness. Hillel (1986) found that emergence of bean seedlings in fine sandy loam soil was reduced from 100 to 0% when crust strength increased from 108 to 273 mbar whereas the emergence of sweet corn was prevented only when crust strength exceeded 1200 mbar.

Lemos and Lutz (1957) showed that increase in the silt or soil fractions less than 0.1mm, the 2:1 type clay mineral, compaction by rainfall and soil puddling increase crust strength. They showed that the calcareous soils they used became severely crusted and compacted after repeated flooding. They stated that the action of water disperses the soil and reorients the soil particles. Thus, a close compact arrangement resulted when the soil was dried.

## 2.2. Ammonia Volatilization

In the soil solution, the ammonia gas is in equilibrium with ammonium ions according to the following reversible reaction:



From the above equation it is obvious that ammonia volatilization will be more pronounced at high pH levels (pH>7.5). On the other hand, ammonia-gas-producing amendments will drive the reaction to the left, raising the pH of the solution in which they are dissolved. When a moist soil dries, the water is moved from the right-hand side of the equation, again driving the equation to the right, encouraging ammonia volatilization. Compared with NH<sub>3</sub> volatilization loss from N fertilizers, NH<sub>3</sub> loss from N mineralized from organic N is relatively small. Urea hydrolysis can increase soil pH thus encourage NH<sub>3</sub> volatilization. Therefore, in neutral and acidic soils, NH<sub>4</sub><sup>+</sup>-N containing fertilizers are less subject to volatilization loss than urea-containing fertilizers. However, in calcareous soils, soil solution pH is buffered at about 7.5, a condition favor volatilization loss for even NH<sub>4</sub><sup>+</sup>-containing fertilizers, for example:



Since CaSO<sub>4</sub> is only slightly soluble, the reaction proceeds to the right and NH<sub>3</sub> volatilization is favored. Similar reactions occur with other NH<sub>4</sub><sup>+</sup>-containing fertilizers that produce insoluble Ca precipitates (e.g., [NH<sub>4</sub>]<sub>2</sub>HPO<sub>4</sub>). In comparison, volatilization losses are not as great if the NH<sub>4</sub><sup>+</sup>-containing fertilizers (e.g., NH<sub>4</sub>NO<sub>3</sub>, NH<sub>4</sub>Cl) produce soluble Ca reaction products.

Ammonia volatilization losses also increase with increasing fertilizer rate and with liquid compared with dry N sources. Volatilization of NH<sub>3</sub> is much greater with broadcast applications compared with subsurface or surface band methods. Immediate incorporation of broadcast N greatly reduces the NH<sub>3</sub> volatilization potential.

Soil colloids, both clay and humus, adsorb ammonia gas, so ammonia losses are greatest where low quantities of these colloids are present or where the ammonia is not in close contact with the soil. For these reasons, ammonia loss can be quite large from sandy soils and from alkaline or calcareous soils, especially when the ammonia-producing materials are left at or near the soil surface and when the soil is drying out. High temperatures, as often occur on the surface of the soil, also favor the volatilization of ammonia. Incorporation of manure and fertilizers into the top few centimeters of soil can reduce ammonia losses by 25-75% from those that occur when the material are left on the soil surface.

By the reverse of the ammonia loss mechanism described above, both soil and plants can absorb ammonia from the atmosphere. Thus the soil-plant system can help cleanse ammonia from the

air, while deriving usable N for plants and soil microbes. Forests may receive a significant proportion of their N requirements as ammonia carried by wind from fertilized cropland or cattle feedlots located many kilometers away.

### 2.3. Precipitation of Soluble Phosphate:

Phosphorus (P) is an essential macronutrient, being required by plants in relatively large quantities (~0.2 to 0.8%). Potassium and nitrogen are the only mineral nutrients required in larger quantities than P. Providing adequate P to plants can be difficult, especially in calcareous soil.

Alkaline soil is defined as soil with pH greater than neutral, typically 7.5 to 8.5. Calcareous soil is defined as having the presence of significant quantities of free excess lime (calcium or magnesium carbonate). Lime dissolves in neutral to acid pH soil, but does not readily dissolve in alkaline soil and, instead, serves as a sink for surface adsorbed calcium phosphate precipitation.

The bioavailability of P is strongly tied to soil pH. The formation of iron and aluminum phosphate minerals results in the reduced solubility of P in strongly acidic soil, improving as pH approaches nearly neutral. This maximum solubility and plant availability of P at pH 6.5 declines again as the pH increases into the alkaline range. This effect of reduced P availability in alkaline soil is driven by the reaction of P with calcium, with the lowest solubility of these calcium phosphate minerals at about pH 8. The presence of lime in alkaline soil further exacerbates the P availability problem. The lime in calcareous soil reacts with soil solution P to form a strong calcium phosphate bond at the surface of the lime. These calcareous soils are common in arid and semi-arid regions with little rainfall.

The resulting effect of low P solubility in calcareous soil is relatively poor fertilizer P efficiency. Plants grown in these conditions can be stunted with shortened internodes and poor root systems due to P deficiency. Deficiency symptoms are sometimes observed as a darkening of the leaf tissue, although it is more common to observe yield loss with no readily seen symptom.

Simply adding fertilizer P at “normal” rates and with conventional methods may not result in optimal yield and crop quality (Stark and Westermann, 2003). Several fertilizer P management strategies have been found to improve P nutrition for plants grown in alkaline and calcareous soil, namely: 1) relatively high P fertilizer rates, 2) concentrated P fertilizer bands, 3) complexed P fertilizer, 4) slow release fertilizer P, 5) cation complexing P fertilizer, and 6) balancing P with other nutrients. These methods may be used alone or in various combinations to effectively supply P to plants growing in calcareous soil.

Adsorption and precipitation of P in calcareous soils take place; it is difficult to distinguish between the two mechanisms. The solid phase of adsorbed P in the soils is very complex (Wandruszka, 2006). Due to the surface adsorption and precipitation process, all the fertilizer P applied to soil is not available to plants. The experiments have shown that application of soluble P and concentration of labile P decreased rapidly with time due to reaction with soil, either due to precipitation or adsorption process by Fe oxides and hydroxides in acidic soils and CaCO<sub>3</sub> in calcareous soils (Pant and Warman, 2000).

Heredia *et al.*, (1997) reported that extractable values were not correlated with adsorption measures. Adsorption and extractions were related to different soil particles that varied according to great group under consideration. Association with different particles was also variable for different great group. Furthermore, coarse texture soil was found to release more P than fine textured soil (Pothuluri *et al.*, 1991). Cumulative release of P had a highly positive relationship with supply parameters irrespective of P level. Soil with slightly lower pH, clay content and CEC did not differ appreciably in respect of adsorption, desorption and supply parameter of P, owing to their similar mineralogical make up. Phosphate reported to be adsorbed on the CaCO<sub>3</sub> surfaces and amorphous or crystalline calcium phosphate precipitate. In addition P in calcareous soils may be adsorbed on the surface of other soil constituent like hydrous oxide, clay and organic matter. The relative importance of these forms of phosphate is contributing to labile P has not been completely defined. Nevertheless, these P forms must provide for the regeneration of solution phase P. Generally, the amount of labile P depends greatly on the amount and the adsorption energy of the P on the soil surfaces and secondly, on the nature and solubility of the dominant compounds occurring in the soil. Although there is no direct proof that NaHCO<sub>3</sub> extracts all the exchangeable P first and then from non-exchangeable

specific surface area, P adsorption was decreased and desorption increased, but varied for a given soil with soil P status.

#### 2.4. Precipitation of Iron Compounds:

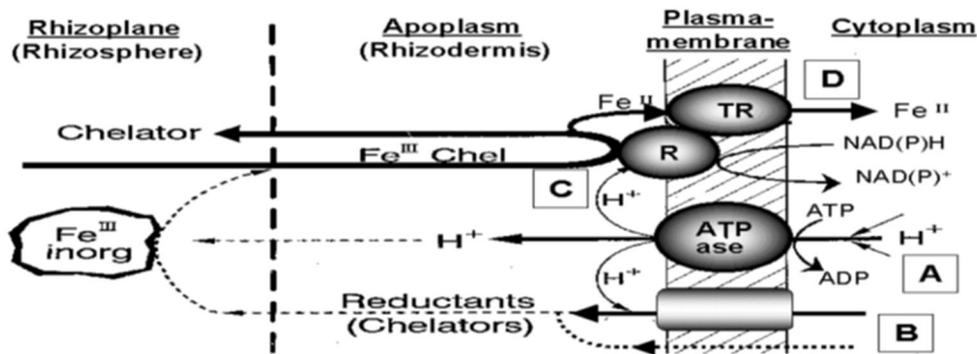
Iron (Fe) is one of the most studied element in mineral nutrition of plants. Although its relatively high abundance in the earth's cultivated soil, plant iron acquisition is often impaired, a fact resulting in severe crop losses (Tagliavini and Rombola, 2001). According to Lindsay (1995) the total Fe in soils is clearly higher than the soluble Fe required for optimal growth, which is at approximately  $10^{-8}$  M in the soil solution. However, he added that the availability of free Fe (III) in soils is basically low: it depends largely on pH and on redox potential and increases with low soil pH and low redox potential. In calcareous soils, the concentration of free Fe (III) is extremely low (about  $10^{-10}$ M). Plants grown in calcareous soils suffer from Fe deficiency chlorosis worldwide, frequently showing yellow leaves and older green leaves. Apart from leaf chlorosis, Fe deficient plant may show depressed leaf formation and growth even when the youngest leaves are green (Kosegarten *et al.*, 1998). The frequent finding of high Fe concentrations in chlorotic leaves (Abadia, 1992) as well as fairly high root Fe concentrations is puzzling.

Both total and active soil carbonates, as a dominant active solid phase in calcareous soil, have a significant effect on iron availability. However, Chen and Barak (1982) showed that olive trees grown in southern Spain, for example, were found without discernible Fe chlorosis with calcium carbonate equivalent content of up to  $800 \text{ g kg}^{-1}$  and active carbonate (the carbonate able to react with ammonium oxalate) content of up to  $300 \text{ g kg}^{-1}$ . These results indicate that olive trees are rather tolerant to Fe deficiency associated with the chemical conditions prevailing in highly calcareous soils. Another study (Loeppen and Haliniark, 1985) found that Fe chlorosis related to properties other than carbonate content and reactivity; the contents of poorly crystalline Fe oxides and silicate clays are among the properties that seem to be related to the occurrence of Fe chlorosis in various plant species. The works carried out by Benitez *et al.* (2002) on the relationships between Fe chlorosis in three olive varieties and soil properties indicated that the leaf chlorophyll content during the growing was poorly correlated with soil carbonate content and reactivity. In contrast, it was significantly correlated with the clay content and with the amounts of Fe extracted with oxalate (Fe<sub>ox</sub>), citrate/ascorbate (Fe<sub>ca</sub>) and diethylenediaminepentaacetic acid (FeDTPA). They suggested that the content and reactivity of poorly crystalline Fe compounds play an important role in Fe nutrition in calcareous soils.

#### Mechanisms of Iron Uptake:

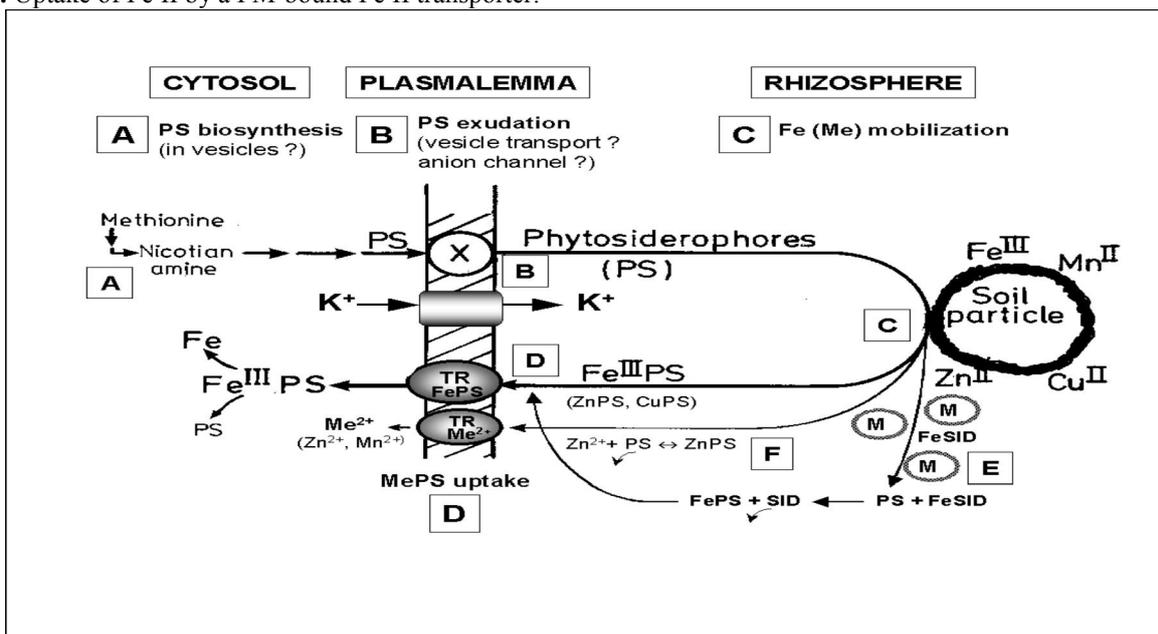
Marschner and Romheld (1995) mentioned that there is general agreement for existing of at least two distinct root response mechanisms (strategies Figures 1 & 2) to iron (Fe) deficiency in higher plants:

Strategy I: exists in dicotyledenous and monocotyledenous species, with the exception of the gramineous species (grasses). This strategy is characterized by three components; First; an increase in the activity of a plasma membrane-bound reductase "turbo". Second; enhanced rates of Fe<sup>3+</sup> reductions by protons and corresponding splitting of Fe<sup>3+</sup> chelates at the plasma membrane. Often, the net rate of H<sup>+</sup> extrusion, i.e. acidification of the rhizosphere, is also increased. This acidification facilitates iron uptake by both enhancement of the reductase activity and solubilization of Fe in the rhizosphere. Third; an additional mobilization of sparingly soluble iron in the rhizosphere may occur by release of reducing and /or chelating substances (e.g. phenolics) from the Fe-deficient root in response to the acidification.



**Fig. 1:** Strategy I for iron (Fe) deficiency-induced changes in root physiology and rhizosphere chemistry associated with Fe acquisition in plants (modified after Marschner, 1995).

- A. Stimulation of proton extrusion by enhanced activity of the plasmalemma ATP Fe III solubilization in the rhizosphere.
- B. Enhanced exudation of reductants and chelators (carboxylates, phenolics) mediated by diffusion or anion channels Fe solubilization by Fe III complexation and Fe III reduction.
- C. Enhanced activity of plasma membrane (PM)-bound FeIII reductase further stimulated by rhizosphere acidification (A). Reduction of FeIII chelates, liberation of Fe II.
- D. Uptake of Fe II by a PM-bound Fe II transporter.



**Fig. 2:** Strategy II for root-induced mobilization of iron and other micronutrients (Zn, Mn, Cu) in the rhizosphere of graminaceous plants (modified after Marschner, 1995). Enhanced biosynthesis of mugineic acids (phytosiderophores, PS) in the root tissue.

- A. Biosynthesis of PS
- B. Exudation of PS anions by vesicle transport or via anion channels, charge- balanced by concomitant release of K+.
- C. PS-induced mobilization of FeIII (MnII, ZnII, CuII) in the rhizosphere by ligand exchange.
- D. Uptake of Metal-PS complexes by specific transporters in the plasma membrane.
- E. Ligand exchange between microbial (M) siderophores (SID) with PS in the rhizosphere.
- F. Alternative uptake of microelements mobilized by PS after chelate splitting.

Strategy II : has been found only in gramineous species. This strategy is characterized by two main components mainly: First; Fe-deficiency induced enhancement of release of phytosiderophores (non-protein amino acids Figure 3) which mobilize sparingly soluble inorganic  $\text{Fe}^{3+}$  compound by complexation of  $\text{Fe}^{3+}$  and formation of Fe-phytosiderophores which are only slightly depressed by high substrate pH and positively correlated to genotypical differences among species in their resistance to "lime induced chlorosis". Second; a highly efficient uptake system for  $\text{Fe}^{3+}$ PS which is further activated under Fe-deficiency. The principal differences between strategy I and II have important ecological implications and also require systematic consideration in the development of screening methods for higher resistance to "lime induced chlorosis".

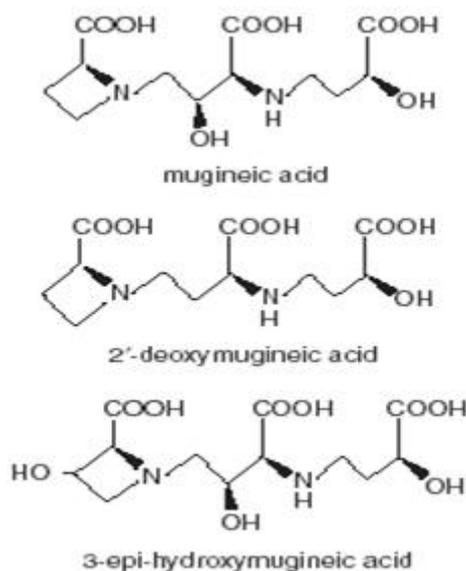


Fig. 3: Structures of some common phytosiderophores

## References

- Abadia, J., 1992. Leaf responses to Fe deficiency: A review. *J. Plant Nutr.* 15: 1699-1713.
- Benitez, M., V. Pedrajas, M. Campillo and J. Torrent, 2002. Iron chlorosis in olive in relation to soil properties. *Nutrient Cycling in Agroecosystems*, 62: 47-52.
- Brady, N. and R. Weil, 1999. *The Nature and Properties of Soils* 12 Edition. Prentice Hall. Upper Saddle River, New Jersey.
- Chen, Y. and P. Barak, 1982. Iron nutrition in calcareous soils. *Adv. Agron.* 35: 217-240.
- Eldridge, D.J., 1998. Trampling of microphytic crusts on calcareous soils and its impact on erosion under rain-impacted flow. *Catena* 33, pp. 221-239.
- Elgabaly, M.M., 1973. Reclamation and management of the calcareous soils of Egypt. In: *FAO Soils Bulletin 21, Calcareous soils: report of the FAO/UNDP Regional Seminar on Reclamation and Management of Calcareous Soils, Cairo, Egypt, 27 Nov - 2 Dec 1972. FAO Soils Bulletin No. 21, pp. 123-127.*
- FAO, 2016. *FAO Soils Portal: Management of Calcareous Soils* (accessed 01.04.16)
- Foth, H., and B. Ellis, 1988. *Soil fertility*. John Wiley & Sons. New York. USA.
- Gillette, D.A., J. Adams, D. Muhs and R. Kihl, 1982. Threshold friction velocities and rupture moduli for crusted desert soils for the input of soil particles into the air. *Journal of Geophysical Research* 87, pp.9003-9015
- Goossens, D., 1998. Effect of soil crusting on the emission and transport of wind-eroded sediment: field measurements on loamy sandy soil. *Geomorphology* 58, 145-160.

- Hedley, M. and M. McLaughlin, 2005. Reactions of phosphate fertilizers and by-products in soils. In: Sims, J. T., Sharpley, A. N. (eds) phosphorus: Agriculture and Environment. American Society of Agronomy, Madison, Wisconsin, 181-252.
- Heredia, O., L. Giuffre and R. Rotondaro, 1997. Adsorbed phosphorus: Relation with Bray and Olsen P in Great Groups of soils in Buenos Aires Province. *Revista-de-la-Facultad-de-Agronomia-Universidad-de-Buenos-Aires*. 17(3): 253 – 262.
- Hillel, P., 1986. Biochemistry of Fern Spore Germination: Protease Activity in Ostrich Fern Spores. *Plant Physiol*. 1986 80: 992-996.
- Imas, P., 2000. Integrated Nutrient Management for Sustaining Crop Yields in Calcareous Soils pp: 1-21. In: GAU-PRII-IPI National Symposium on: Balanced Nutrition of Groundnut and other Field Crops Grown in Calcareous Soils of India. International Potash Institute.
- Indiati, R., E. Coppola, and A. Buondonno, 1999. Changes of soil phosphorus availability in Italian Allisols as estimated by short-term soil phosphorus equilibration procedures using Olsen, Mehlich 3 and paper-strip methods. *Commun Soil Sci. Plant Anal.*, 30: 983-997.
- Jackson, R., and L., Erie. 1973. Soil and Water Management Practices for Calcareous Soils. In: FAO Soils Bulletin 21 - Calcareous Soils. Food and Agriculture Organization of the United Nations, Rome.
- Khalefa, A.M., 2007. Response of maize to application of microbial activator, sulphur and phosphorus to maize grown on a calcareous soil. *J. Biol Chem. Sci.*, vol. 2 (2): 165-188.
- Kosegarten, H., G., Wilson and A. Esch, 1998. The effect of nitrate nutrition on iron chlorosis and leaf growth in sunflower (*Helianthus annuus* L.) *Eur. J.* 8: 283-292.
- Lemos and Lutz, 1957. Soil crusting and some factors affecting it. *Soil Sci. Am. Proc.*, 21, pp.485-491.
- Leytem, A.B. and D.T. Westermann, 2003. Phosphate sorption by Pacific Northwest calcareous soils. *Soil Soci.*, 168: 368-375.
- Lindsay, W., 1995. Chemical reactions in soils that affect iron availability to plants. A quantitative approach. In: J. Abadia (Ed.) *Iron Nutrition in Soils and Plants* Kluwer Academic Publishers, pp 7-14.
- Loeppen, R., and C., Hallmark. 1985. Indigenous soil properties influencing the availability iron in calcareous soils. *Soil Sci. Soc. Am. J.* 49: 597-603
- Loeppert, R., and D., Suarez, 1996. Carbonate and gypsum. In: D.I., Sparks, A. L. Page. F.A. Helmke, R.H. Loeppert, P.N. Soltanpour, M.A. Tabatabai. C.T. Johnson and M.E. Sumner (eds.) *Methods of Soil Analysis. Part 3 Chemical Methods*. SSSA Special Publication No. 5. Madison. WI, pp. 437-474.
- Marschner, H. and V. Romheld, 1995. Strategies of plants for acquisition of iron. *Plant and Soil*. 165: 261-274.
- Marschner, H., 1995. *Mineral Nutrition of Higher Plants*. Academic Press, London
- McLaughlin, M.J., E. Lombi B.Holloway, C. Johnston, D. Brace and R. Armstrong, 2003. Reaction of granular and fluid products in calcareous soils. Fluid from proceeding phoenix, (Fluid Fertilization Foundation).
- Pal, D.K., Balpande, S.S. and P. Srivastava, 2001. Poly-genetic Vertisols of the Purna Valley of central In-dia. *Catena* 43, 231-249.
- Pant, H., and P. Warman, 2000. Phosphorus release from soils upon exposure to ultra-violet light. *Comm. Soil Sci. and Plant Anal.*, 31(3-4): 321-329.
- Pothuluri, J., D. Whitney and D. Kissel, 1991. Residual value of fertilizer phosphorus in selected Kansas's soils. *Soil Sci. Soc. Am. J.*, 55: 399-404.
- Prasetyo, B.H., S. Rituing, and A.B. Siswanto, 2001. Relationships between soil chemical properties and phosphate sorption from some soil types J. *penelitian dan pengembangan pretanian*, 20: 131-137 .
- Rahmonov, O., A. Czylok and R. Simanauskiene, 2006. The significance of biological soil crust in regeneration ecosystems of anthropogenic bare sand. *Anthropogenic aspects of landscape transformations* 4. pp. 88-95.
- Rajot, J.L., S.C. Alfaro and A. Gaudichet, 2003. Soil crusting on sandy soils and its influence on wind erosion. *Catena* 53, pp. 1-16.

- Rasha, E.A., 2005. The relation between active calcium carbonate and some properties of calcareous soils in North Africa. M. Sc. Thesis Cairo, Univ. of Ins. of African Res. and studies Dep. of Natural Resources.
- Saleh, M., M., Saeed, H., Khalid and H. Mostafa, 1998. Affinity of Calcium Carbonate Surfaces to Zinc Sorption. *Alex. J. Agric. Res.*, 43 (3): 303 -315.
- Samadi, A., 2006. Temporal changes in available phosphorus in some calcareous soils, *J. Agric. Sci. Technol.*, 8: 343-349.
- Sharif, M.M., S. Sarir, and F. Rabi, 2000. Biological Phosphorus in some important soil series of NWFP. *Sharhad J. Agri.* 16 (6): 587-592. *Fac. Agric.*, 44 (1): 17-34.
- Shawky, M.E., S.B. El-Amir, H.M. Nasr, A.A. Wahdan and M.A. Bakry, 2004. Calcareous soil definition from the hydraulic and physical point of view. *Egypt J. Soil Sci.*, 44, No. 1, 97-107.
- Tagliavini, M. and A., Rombola, 2001. Iron deficiency and chlorosis in orchard and vineyard ecosystems. *Europ. J. Agron.* 15: 71-92.
- Wandruszka, R., 2006. Phosphorus retention in calcareous soils and the effect of organic matter on its mobility, <http://www.geochemicaltransactions.com/content/7/1/6>.
- Zhang, Y.M., H.L.Wang, X.Q. Wang, W.K. Yang and D.Y. Zhang, 2006. The microstructure of microbiotic crust and its influence on wind erosion for a sandy soil surface in the Gurbantunggut Desert of Northwestern China. *Geoderma* 132, pp. 441-449.