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Legumes: Model Plants for Sustainable Agriculture in Phosphorus and Iron Deficient Soils

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ABSTRACT

Nowadays, the agriculture's target is to reach the amount of crop production that can cover the need to feed growing world population with the crucial challenge of respecting the environment. Several environmental constraints are limiting world agricultural production, mainly the preponderance of calcareous soils suffering from ferric and phosphoric deficiencies. In those soils, legumes were considered as an alternative solution to retrieve a fertile soil without the abusive use of chemical fertilizers. The ability to establish a symbiotic association with nitrogen-fixing soil bacteria is the way used by legumes to restore soil organic matter and to improve soil fertility. Legumes remain a source of healthy food while respecting the environment. This paper describes the importance of legumes for Fe and P deficient soils management through sustainable practices.

Key words: Deficient soils, Legumes, Sustainable agriculture, Tolerance.

According to the United Nations estimation, the human population will be reaching 9.7 billion by mid-century and 11.2 billion by century's end (United Nations, 2015). Unfortunately, the same ascending slope was observed also for the world hunger. In this regard, the Food and Agriculture Organisation marks that hunger is increasing (World Health Organisation, 2019) which has a direct relationship with the depressed agricultural productivity in many countries especially the low-income ones. The agricultural productivity loss is attributed to many environmental factors including soil nutrient deficiencies (Reynolds *et al.*, 2015). In fact, this environmental problem is widespread in calcareous soils that cover more than 30% from the surface of the earth (Taalab *et al.*, 2019). In those soils, plant growth is often restricted by soil physico-chemical conditions (high pH values and bicarbonate concentrations) which causes a decrease in mineral nutrients bioavailability principally Fe (Briat *et al.*, 2015) and P (Houssin *et al.*, 2019). A common approach that is adopted to overcome Fe and P deficiencies of plants on calcareous soils and consequently improve human diet is the fertiliser applications. However, it was noted that the improper use of agro-chemicals causes environmental pollution and decreases the efficiency of nutrient use (Davydov *et al.*, 2018). As an alternative to chemical fertilizers, legumes have a significant role in agriculture providing economic benefits and meeting human demand for protein particularly in developing countries. In fact, legumes have an important role in improving soil health in sustainable agriculture by improving nutritional status of soil. Through symbiosis with rhizobia bacteria, legumes fix atmospheric nitrogen, improve soil fertility and helps to control diseases and pests in cereals by the rotation culture (Naresh *et al.*, 2019). In this short theoretical paper, we have provided an overview of the importance of legumes in overcoming P and Fe deficiencies in calcareous soils.

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Legumes tolerance to soil P deficiency

Soil P deficiency is a crucial limitation for agricultural productivity in developing countries which has led to an important use of chemical fertilizers applications. To avoid the negative impact of those fertilizers on the environment, several researchers have proposed the inclusion of legumes in P-deficient soils as an alternative solution to the application of fertilizers. In this context, research findings have revealed the effectiveness of legumes in calcareous soils suffering from P deficiency (Mitran *et al.*, 2018). Accordingly, this efficiency contributes to the decrease in the use of fertilizers as well as the increase of soil fertility and health. Under P-limited conditions, legumes have evolved various adaptation mechanisms to tolerate P stress (Sulieman and Phan, 2015) that will contribute to a stimulation of the root's extracellular acquisition of rhizosphere soil P or the optimization of its intracellular use efficiency (Vance *et al.*, 2003). Morphological responses are summarized in the modification of the root architecture (root surface area, root length, cluster roots) which increased P uptake (M'sehli *et al.*, 2012).

The most typical root responses of plants in increasing the solubilisation of soil P is the decrease in rhizosphere pH by the release of H^+ and phosphatases acids to the rhizosphere (M'sehli *et al*., 2012). Enhancement of acid phosphatase activity (APases) under P starvation conditions has been demonstrated for N_2- fixing legumes including *Vicia faba* (M'sehli *et al*., 2012), *Lupinus albus* and *Glycine max* (Hinsinger *et al*., 2011; Zogli *et al*., 2017). Studies in *Vicia faba* and *Vicia sativa* showed that P deficient plants increased both extracellular APases, which are involved in hydrolysis of soil's various organic phosphate monoesters and intracellular enzymes acting in the remobilization of P_i from rich P components inside the plant cell (M'sehli *et al*., 2012).

With P deficiency, the concentration of phenols increases to improve the availability of the sparingly soluble soil P for plants (Bargaz *et al.*, 2015). In *Vicia faba*, the exudation of phenolic compounds have been reported a higher concentrations in P-deficient plants (M'sehli *et al*., 2012). Likewise, it has been demonstrated that *Lupines albus* and *Brassica napus* released large amounts of phenolics into the rhizosphere in response to P deficiency (Makoi and Ndakidemi, 2007).

The maintenance of the P-homeostasis in nodules is considered as a main adaptive strategy for rhizobia-legume symbiosis under P starvation by increasing P allocation to nodules, formation of a strong P sink in nodules and direct P acquisition and remobilization (Bargaz *et al.*, 2015).

Legumes tolerance to soil Fe deficiency

In the face of Fe deficiency, legumes have evolved adaptive strategies in order to increase Fe bioavailability (Bargaz *et al.*, 2015). The main adaptive responses are the rhizosphere acidification by the activation of plasma membrane H^+-ATPase, the stimulation of the reduction of Fe^{3+} to Fe^{2+} by a NADPH-dependent Fe (III)-chelate reductase (FCR) and the stimulation of root exudates (M'sehli *et al*., 2009). Several researches have described the genetic variability among legumes regarding their tolerance to Fe starvation. Su *et al.*, (2018) assessed the genetic variability among 12 cultivars of peanut (*Arachishypogaea* L.) in tolerance to iron deficiency based on spectral and photosynthetic parameters. In a complimentary study, M'sehli *et al*., (2011) have studied the tolerance of two lines of *Medicago ciliaris* (TN11.11 and TN8.7) to Fe deficiency and found that TN11.11 line has a potential to enhance revegetation in calcareous soils for pastoral use. In addition, Kallala *et al*. (2019) carried out a study in order to investigate the biodiversity within *Medicago truncatula* plants in response to Fe deficiency, to identify tolerant genotypes and to assess the main tolerance mechanisms. Based on biometric and physiological markers, those authors found a biodiversity among the 20 genotypes studied toward tolerance to iron deficiency. In the same way, M'sehli *et al.* (2012) have reported the higher Fe deficiency tolerance of *Medicago ciliaris* as compared to *Medicago truncatula*.

Legumes are distinguished by their ability to establish symbiotic associations with nitrogen-fixing bacteria and with arbuscular mycorrhizal to facilitate the acquisition of nutrients such as Fe. It has been demonstrated that symbiotic nitrogen fixation and ammonium assimilation induce soil acidification and therefore increase of Fe bioavailability (Pii *et al.*, 2015). Kallala *et al.* (2019) showed that the inoculation of *Medicago truncatula* genotypes with two *Sinorhizobium* strains ameliorates the tolerance of Fe-deficient plants to Fe starvation. Theses authors stated also that both *Sinorhizobium* strains (TII7 and SII4) stimulates the antioxidant enzyme activities in Fe-deficient plants.In addition, rhizobia can also produce strain specific siderophores that can help overcome iron starvation (Bargaz *et al.*, 2015).

CONCLUSION

In arid and semiarid regions, alkalinity is an important environmental constraint for nutrients bioavailability especially Fe and P, which leads to lower crop production. Factors that contribute to Fe and P deficiencies in calcareous soils are high pH values and bicarbonate concentrations. Improving crop production in such soils demand adoption of special management practices which aims to ensure sustainable agriculture that respects the environment.The introduction of legumes in calcareous soils sustain productive agriculture. Hence, it is primordial to select rhizobia strains and legumes genotypes with enhanced tolerance able to thrive under nutrient limiting conditionsand subsequently the use of these selected genotypes in crop rotation.

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