

Effect of Some Soil Mineral Levels on Their Contents in Different Plant Parts and on the Yield of Chickpea-Rhizobium Symbioses

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Abstract: Chickpea is a legume with high nutritional value. It is mainly grown in arid and semi-arid areas soils, which are characterized by a deficiency in mineral elements, a severe water deficit and a poor soil quality. Our work aims to evaluate the effect of different mineral elements in the soil on nodular biomass, growth and yield of chickpea. The physico-chemical analyses of the soil and the agronomical and physiological parameters showed that the level of available phosphorus in the soil positively affected the growth parameters in the chickpea studied plants. Our results also confirmed the positive effect of adequate plant P nutrition on yield. Indeed, among the studied fields, agricultural soil 7 presented the highest potassium content and seeds yield (12.87 mg/g DM and 62 seeds per plant, respectively). In parallel, soil 7 recorded the highest value of available phosphorus 23.52 ppm. On the contrary, soil 5 was the least rich in P content (6.73 ppm). A positive correlation was recorded between the sodium concentration in the soil and in the aerial parts ($r=0.73$). The results also showed that the aerial part was richer in calcium than the root part and the nodules. Moreover, other positive correlations were recorded between the calcium concentration in the soil and in the aerial part and in the root part ($r=0.76$ and $r=0.54$; respectively).

Keywords: Chickpea, Mineral Nutrition, Soil, Symbiosis

1. Introduction

Chickpea is an important crop that provides the main components of the human diet to a growing global population. Chickpea is an important source of protein, fiber, and micronutrients and plays an essential role in sustainable agriculture [1, 2]. The chickpea crop in terms of production ranks third after beans with an annual production of over 11.5 million tons. The largest producing country is India. Australia, Canada and Argentina are the main exporters. The current chickpea area is estimated at 14.56 million hectares with a global production of 2.3 million tons [3]. In Morocco, chickpea is a species mainly grown under rainfed conditions

and generally in areas with a semi-arid climate. Frequent droughts, poor distribution of rainfall and lack of nutrients in soil are the major abiotic constraints on production [4, 5]. Plants must draw significant amounts of certain mineral elements from the soil for optimal growth and development such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and other elements [6]. Legumes are primarily dependent on symbiotic nitrogen. In addition, phosphorus deficiency can also lead to nitrogen deficiency. For legumes, potassium affects osmoadaptation during growth under stress conditions. Boron (B) and calcium are minerals that have an important impact on the symbiosis of legumes. Calcium is needed at the beginning of the rhizobia-legume association and boron during nodule maturation [7]. Plants require the macronutrients

nitrogen (N), phosphorus (P) and potassium (K) for growth and development. These nutrients strongly affect crop yields and the quality of agricultural production. Improving nutrient use efficiency provides an opportunity for plants to overcome the effects of essential mineral element deficiencies [8]. Calcium (Ca) is also a macronutrient with different physiological roles especially in plant signaling for biotic and abiotic stresses [9]. It is an essential nutrient for plants. Indeed, its deficiency in plants can lead to poor tolerance to various stresses, decreased quality and yield of plants [10].

The content of Pi (Inorganic phosphate) in the soil is generally less than 0.01 mmol/L [11]. In addition, Pi has very low mobility in soil. In parallel, plants can only acquire free Pi from the soil solution and thus often suffer from Pi deprivation. To avoid this Pi deficiency, plants have developed a set of transporters involved in the efficient uptake of Pi from the soil solution to the root cells. Indeed, inorganic phosphate is acquired by roots and sent to the stems through the xylem [8].

Potassium content in soils is generally low. While potassium (K^+) plays a key role in several physiological processes during plant growth and development. Indeed, K^+ is involved in many physiological processes, such as maintenance of membrane potential, enzyme activation and osmoregulation [12]. However, K^+ deficiency in most agricultural soils limits yield [13]. In addition, several works have shown that potassium accumulation in the plant contributes to abiotic stress tolerance by lowering the ROS status of plants [14, 15]. Accumulation of harmful amounts of Na^+ in living plant cells negatively affects plant growth and development. Indeed its accumulation induces cytosolic efflux of K^+ and thus leads to imbalance in cellular homeostasis, ROS (reactive oxygen species) accumulation, and disruption of Ca^{2+} and K^+ functions, nutrient deficiency and poor growth [16].

Calcium is an essential element for plant development under various conditions and especially during biotic and abiotic stresses [17]. Thus, it serves a dual function, being not only an important factor for cell wall and membrane stability, but also serving as a second messenger in many developmental and physiological processes, including plant response to biotic stress [18]. Calcium improves vigor, plant stiffness, and seed formation [19]. Some calcium is associated with the cell wall, while some is exchangeable at the plasma membrane. Furthermore, Ca^{2+} can represent more than 10% of dry weight and does not show any negative effect on plant development [20]. Plants need Calcium to fortify cell walls and thus counteract various stresses. Calcium stabilizes cell membranes by connecting various proteins and lipids to their surfaces. In addition, Ca^{2+} can be exchanged with other cations such as potassium and sodium in response to stress. Calcium-deficient soils can lead to cell wall deterioration and thus tissue weakening [18]. In addition, calcium is involved in several processes such as root and pollen tube growth. The aim of our work was to study the influence of essential mineral elements present in the soil on the yield but also their accumulation in the different parts of chickpea plants.

2. Material and Methods

2.1. Study Area

The assessment focused on ten farms located in the Douar Timgret region of El Oualidia province of Sidi Bennour. It is an agricultural region with the following geographical coordinates 32°36'06.8"N 8°55'35.0"W.

2.2. Soil and Plant Sampling

Soil sampling was carried out in 4 well-spaced points for each agricultural soil at a depth of 0 – 20 cm. concerning the sampling of the plants, ten plants are taken at random on the diagonal of each field. For plants: the fresh weight of the root part and the aerial part is estimated. After 48 hours in the oven, the two parts are dried to determine the dry weight (DM). The powder obtained after grinding will be used for the determination of phosphorus, potassium, calcium and sodium. After rinsing the roots, we recovered all the nodules on these organs, then after weighing they were separated into two parts: one is kept in the fridge and the other is dried in the oven (80°C for 48 h). After drying for 48 h in an oven, the nodules were weighed a second time and passed to dry grinding. The powder thus obtained will be used for the determination of phosphorus and various mineral elements.

2.3. Physicochemical Analysis of the Soils Sampled from the Agricultural Soils

2.3.1. Determination of Soil pH

To 10 g of soil, we added 20 ml of distilled water, after 30 min of agitation; we determine the pH value with a pH meter.

2.3.2. Electrical Conductivity

Electrical conductivity was determined according to Smith J. L., Doran J. W. [21]. After weighing 10 g of soil in a flask, we added 40 ml of distilled water. After 30 minutes of agitation at 25°C, the electrical conductivity was determined by a conductivity meter (HI8820N, Hanna Instruments, Woonsocket, Rhode Island, USA).

2.3.3. Assay of Available Phosphorus

The determination of P was determined according to Murphy J., Riley J. P. [22]. To 2.5 g of soil, we added 50 ml of 0.5M $NaHCO_3$. After one hour of stirring, the solutions were filtered through Whatman paper. The reaction medium used for the phosphorus determination consisted of 1 ml of the filtrate obtained, 5 ml of reagent AB and 4 ml of distilled water. After stirring, the whole was boiled for 20 min. After cooling, the optical density was measured at 820 nm. The phosphorus content was determined by reference to a standard range prepared from a KH_2PO_4 solution.

2.3.4. Determination of Mineral Elements (K, Na and Ca)

The determination of potassium, sodium and calcium in plants was carried out with a Jenway flame spectrophotometer using the same filtrate used for the determination of phosphorus.

3. Results and Discussion

3.1. Physicochemical Characteristics of the Soils of Different Plots

The soils from the plots sampled in this study cover a wide range of properties with respect to their chemical composition and their available phosphorus content. These results show that the pH of the soils studied show variations from one soil to another [2]. pHs are generally neutral to alkaline. The electrical conductivity (extract 1/5) of the soils studied is low (less than 4 decisiemens/m) which reflects that there is no problem of salinity or sodicity since the Na⁺ contents are also low (ESP less than 15%). We note that soil 7 presented the lowest pH (6.9) but the highest levels of nutrients such as available phosphorus and calcium (23.5 ppm and 27.96 mg/g of soil, respectively). On the contrary, soil 5 had the lowest concentration of Pa (6.7 ppm) and average contents of potassium and calcium (3 and 10 mg/g of soil). The results of assays of soil mineral elements showed that there is a relationship between the assimilable phosphorus content and soil parameters such as pH. Indeed,

the maximum uptake of P by plants occurs at a pH between 6.5 and 7 [23]. Agricultural soil 7 has a pH that is in the maximum P absorption zone (pH=6.9) while soil 5 has the highest pH (pH=8.3) which resulted in maximum yield in soil 7 and on the contrary the lowest yield was observed in agricultural soil 5. The results obtained also showed the positive effect of P in the soil on yield. Agricultural soil 7 presented the highest available phosphorus concentration in soils, the opposite of soil 5 [2]. Indeed, phosphorus plays an important role in root development, nutrient uptake, plant growth and yield of legumes [24, 25].

3.2. Potassium Content in Chickpea Plants

Potassium content in the aerial part of chickpea plants varied significantly ($p < 0.05$, table 1) between 2.74 and 12.87 mg/g of Dry Matter (DM) in soils 1 and 7 respectively (figure 1). For the root, the potassium concentration varied between 2.16 and 13.71 mg/g of DM in plots 8 and 3 respectively. For the nodules, the plants in soil 2 showed the highest potassium content (16.07 mg/g of DM) while those of soil 8 showed the lowest content (1.44 mg/g of DM).

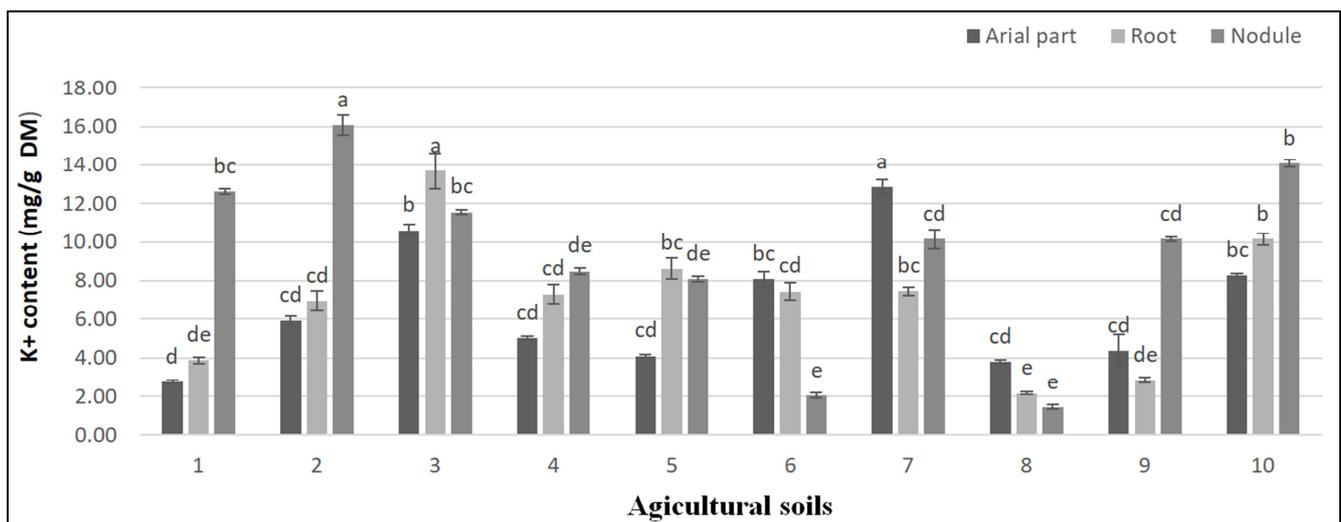


Figure 1. Potassium content in aerial parts, roots and nodules of the chickpea plant in the different agricultural soils.

The highest potassium content in the aerial part of chickpea plants was observed in agricultural soil 7. This is in agreement with the work of Oram N. J., *et al.* [26] who showed that the concentration of potassium in soil significantly increased biomass in forage plants. Potassium concentration in soil significantly increased the biomass. Potassium is involved in several physiological and biochemical processes, such as the activation of enzymes among others nitrogen metabolizing enzymes, protein synthesis, photosynthesis and carbohydrate metabolism [27] which leads to improved biomass and crop yield [28, 29]. A positive correlation was rated between yield and potassium concentration in the aerial part.

3.3. Sodium Content in Chickpea Plants

For sodium, the concentration in the aerial part varied

($p < 0.001$, Table 1) between 1.79 and 5.35 mg/g of DM in agricultural soils 1 and 10 respectively (figure 2). Root levels of this element varied from 6.87 to 9.99 mg/g of DM in soils 6 and 9 respectively. For nodules, plants from soil 9 showed the highest Na⁺ content (9.2 mg/g DM) while those from soil 10 showed the lowest content (1.82 mg/g DM). Roots recorded the highest sodium concentrations compared to the other organs. A positive correlation was recorded between the sodium concentration in the soil and in the aerial part ($r = 0.73$).

Our results also showed a relationship between the concentration of sodium and calcium in the soil and their accumulations in the plants. In order to avoid the toxicity of Na in the tissues and in the different parts of the plant, changes in the accumulation patterns of the mineral elements have been demonstrated in different works [30]. It was recorded that the roots presented the highest sodium

concentrations compared to the other organs. The reduction of the negative impact of sodium in the soil and its toxicity for plants is controlled by the absorption of Na^+ by the roots of plants. Indeed, the plants accumulated sodium in the roots and were able to regulate the transfer of Na^+ ions to the leaves. Stem tissues acted as a barrier for Na^+ translocation from the root to the leaves [31]. A positive correlation was recorded between the sodium concentration in the soil and in the aerial parts; this can be explained by the fact that plants have the ability to accumulate large amounts of sodium in

their shoots when adequate amounts of sodium are present in the soil [32].

Table 1. Results of two-way analysis of variance (ANOVA II) of the considered parameters (phosphore (P), Calcium (Ca^{2+}), Sodium (Na^+), Potassium (K) and Yield).

Soils	Ca^{2+}	K	Na^+	P aerial	P nodule	Yield
dF	F	F	F	F	F	F
9	7.59***	3.23*	8.96***	11.96***	12.78***	56.40***

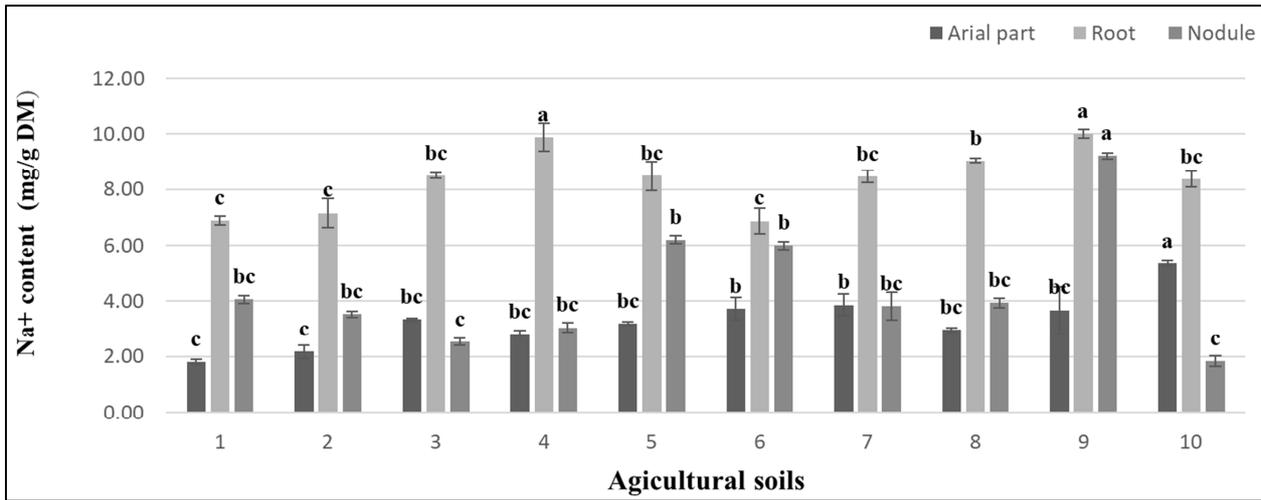


Figure 2. Sodium content in aerial parts, roots and nodules of chickpea plants in the different agricultural soils.

3.4. Calcium Content in Chickpea Plants

The calcium content in the aerial part of the chickpea plants varied significantly ($p < 0.001$, Table 1) between 7.6 and 18.7 mg/g of DM in agricultural soils 3 and 2 respectively (figure 3). For the root, the calcium concentration varied between 1.1 and 1.8 mg/g of DM in soils 6 and 7 respectively. For the nodules, the plants in soil 2 showed the highest calcium content (3.7 mg/g of DM) while those of soil 8 showed the lowest content (0.8 mg/g of DM).

Note that the aerial part is richer in calcium than the other organs. A positive correlation was recorded between the calcium concentration in the soil and in the aerial part and in the root ($r = 0.76$ and $r = 0.54$; respectively). It has also been noticed that the aerial part is richer in calcium than the other organs. Indeed, potassium and calcium also play an important role in plant growth [33]. Authors noticed that the calcium concentration increased in the leaves as the soil salinity increased to avoid sodium toxicity in the tissues [34].

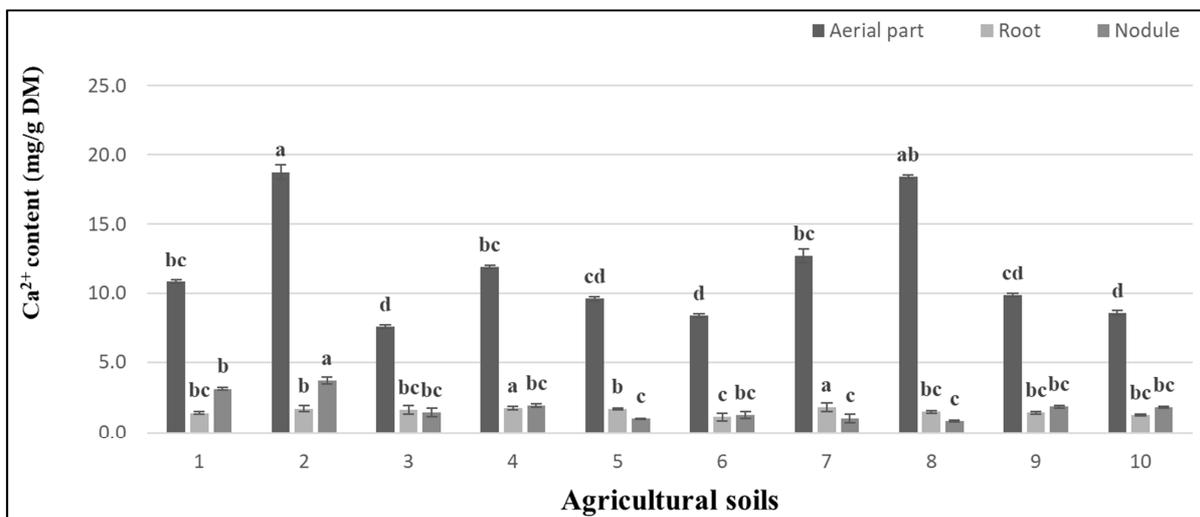


Figure 3. Calcium content in aerial parts, roots and nodules of chickpea plants in the different agricultural soils.

3.5. Yield Per Plant

The yield of chickpea plants in the different agricultural soils varied significantly ($p < 0.001$, Table 1) between 11 and 62 seeds per plant. The highest yield was observed in plants from soil 7, while the lowest yield was noted in plants from

soil 5 (Figure 4). In parallel, soil 7 recorded the highest value of phosphorus 23.52 ppm. On the contrary, soil 5 was the least rich in this element (6.73 ppm). A positive correlation was recorded between yield and potassium concentration in the aerial part.

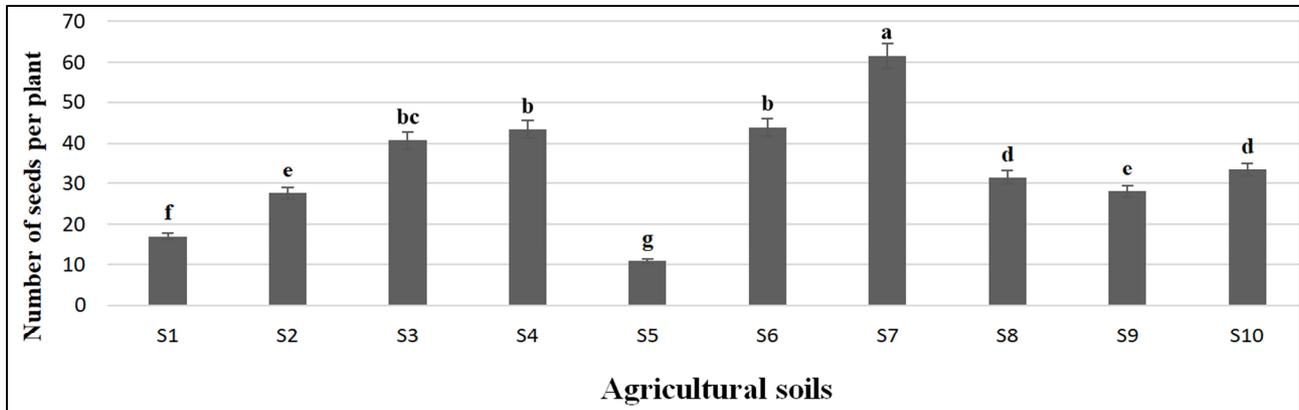


Figure 4. Yield of chickpea plants in the different agricultural soils.

The results obtained showed that the mineral element that most influenced the yield was the available P in the soil with a correlation of 0.94. The yield was also positively correlated with nodular P and aerial P ($r=0.63$ and $r=0.57$). This is in agreement with the work of Latati M., *et al.* [35] who found that P availability in the rhizosphere and nodule dry weight were positively correlated. This availability has also improved aerial dry weight and grain yield in legumes. Indeed, phosphorus (P) is a major mineral nutrient for plants and enters in several metabolism components that are essential for plant growth and development [36]. Potassium concentration in the soil significantly increased the biomass which is in agreement with the work of Ruthrof K. X., *et al.* [37]. A positive correlation was recorded between yield and potassium concentration in the aerial part. This is in agreement with the results of the study by Gashti A. H., Vishekaei M. N. S., Hosseinzadeh M. H. [38]; which showed that potassium with calcium increased the growth and yield of peanuts.

4. Conclusion

Like all plants, chickpea needs nutrients in the soil for its growth and development. Our results showed that after sampling the soil for mineral elements, the highest concentration of potassium was observed in the aerial part and nodules of chickpea plants. For calcium, the aerial part was richer in calcium than the other organs. Roots recorded the highest concentration of sodium compared to other organs.

Conflicts of Interest

All the authors do not have any possible conflicts of interest.

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