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Effect of Phosphogypsum on Faba Bean Yield and Heavy Metals Content under Saline Conditions †

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Abstract: Salinity is one of the most severe abiotic stresses which causes significant losses to agricultural production, especially in arid and semi-arid areas. In the present study, we conducted a pots experiment to evaluate Phosphogypsum (PG) and Gypsum (G) as amendments and their effect on faba bean shoot and grain yield under saline conditions (soil ECe = 11.17 mS/cm, water EC = 1.5 mS/cm and water SAR = 4.2 meq/L). In addition, we investigated the safety of their application based on heavy metals content in the harvested grain. Our findings demonstrate that the use of PG as amendment for saline soil reclamation improved faba bean grain and biomass yield without affecting grain quality regarding heavy metal content.

Keywords: salinity; phosphogypsum; yield parameters; heavy metals

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1. Introduction

Salinity is one of the main challenges facing agricultural production systems in arid and semi-arid regions. Currently, the total land area impacted by high salt levels is about 1 billion hectares, and the area of affected land is significantly increasing [1]. In Morocco, the total soil affected by salinity is about 1.148 Mha [2].

Salt-affected soils usually generate physical and chemical disorders in soil–plant water systems. The reclamation of salt-affected soils can be done using several amendments, such as phosphogypsum, a byproduct of the phosphate industry. It was reported that PG effectively mitigates soil salinity and enhances crop yields [3].

The phosphate industry in Morocco, a major phosphate-based fertilizer producer, generates around 25 Mt of PG annually [4]. However, studies on the valorization of PG as a soil amendment in salt-affected soils in Morocco are scarce. The objectives of this study were to investigate the effect of the PG on faba bean shoot and grain yield and to investigate the safety of its application based on heavy metals content in the harvested grain under saline conditions.

2. Material and Methods

2.1. Soil Sampling and Analysis

Soil from the Sidi Elmokhtar region of Morocco was identified from a soil database and then sampled, air-dried and ground to pass through a 2 mm mesh sieve. Soil pH was measured in 1:5 soil:water extract. ECe is the electrical conductivity of saturated paste which was prepared by hand mixing [5]. The available phosphorus was determined using the Olsen method [6]. Spectrophotometry (Cary 60 UV–Vis, Agilent Technologies, Santa Clara, CA, USA) was used to determine sulfate, ammonium, chlorine and nitrate contents. The exchangeable sodium, potassium, calcium and magnesium were determined by atomic absorption spectroscopy (200 Series AA, Agilent Technologies, Santa Clara, CA, USA). The soil is saline, Table 1 shows the chemical properties of the soil.

Table 1. Soil chemical properties.

Property/Element	pH	Ece (mS/cm)	P_2O_5 (mg/kg)	K_2O (mg/kg)	CaO (mg/kg)	Na_2O (mg/kg)	MgO (mg/kg)	SO_4 (mg/kg)	NO_3 (mg/kg)	NH_4 (mg/kg)
Value	8.1	11.17	67	308	7984	759	1067	3211	40.2	6.05

2.2. Irrigation Water

pH and Ec were measured directly by a pH meter (InoLab pH 7310) and a conductometer (Mettler Toledo. SevenCompact). The sulfate, ammonium, chlorine and nitrate contents were quantified by spectrophotometry (Agilent Technologies. Cary 60 UV–Vis). The phosphorus, sodium, potassium, calcium and magnesium were determined by ICP (Agilent Technologies. 5110 ICP-OES). The water had a moderate salinity (Table 2).

Table 2. Chemical properties of irrigation water.

Property/Element	pH	Ec (mS/cm)	SAR (meq/l)	K (mg/L)	Na (mg/L)	Ca (mg/L)	Mg (mg/)	NH_4 (mg/L)	Cl (mg/L)	SO_4 (mg/L)	NO_3 (mg/L)	P_2O_5 (mg/L)
Value	7.8	1.5	4.2	28.6	214.6	84.9	66.8	0.04	252.2	64.0	24.8	0.05

2.3. PG and G Analysis and Pot Preparation

The experiment was conducted in pots in a greenhouse at Mohammed VI Polytechnic University in Benguerir, Morocco. Each pot was filled with 10 kg of soil. The PG used is that of Jorf Lasfar Phosphate, situated near the city of El Jadida. The second amendment was natural gypsum for agricultural use. PG and G were incorporated with the top 9 cm. The treatments consisted of: Control, 15 t/h of G, 15, 30 and 45 t/ha of PG. pH and EC were measured in a ratio of 1:5 PG or G:water extract. The rest of the elements were quantified by ICP-OES. PG is more acidic than G, and it is richer in nutrients (Ca, S and P). The chemical compositions of PG and G are presented in Table 3.

Table 3. Chemical composition of PG and G.

Property/Element	pH	EC (mS/cm)	Ca (%)	S (%)	P (%)	K (ppm)	Mg (ppm)	Cd (ppm)	Zn (ppm)	Cu (ppm)	Fe (ppm)	Ni (ppm)	Pb (ppm)
Phosphogypsum	5.8	2.4	26.0	23.7	0.8	869.0	259.0	4.7	8.5	2.6	126.7	1.8	1.9
Gypsum	8.12	2.3	22.8	13.1	0.02	969.0	7587.0	<0.003	9.9	2.4	2606.4	4.2	1.4

2.4. Statistical Analysis

Data were subjected to statistical analyses using IMB SPSS 20 software. One-way ANOVA tests were performed to test the difference between treatments. When ANOVA was significant, Tukey's test was used to compare the means.

3. Results and Discussion

3.1. Yield Parameters

The amendments (G and PG) were associated with an increased number of grains and shoot yield. In pots, compared to the control, 30 t/ha and 45 t/ha of PG increased shoot dry matter by 52% and 54%, respectively (Table 4). Similar results were reported by [7] in maize trials where 20 t/ha and 40 t/ha of PG increased dry matter by 45% and 69%, respectively. Fresh biomass, fresh grain and dry weight were improved only with the highest rates of PG (30 and 45 t/ha) (Figure 1 and Table 4). The application of 30 and 45 t/ha increased grain dry weight by 52% and 62%, respectively, when compared to the control. In previous works, 10t/ha of G was enough to significantly increase faba bean grain yield [8]. PG application increased the yield of spring chickpeas by 50% and lentils by 27% [9]. The application of 30 and 45 t/ha also significantly increased thousand grain weight. However, neither PG nor G had a significant effect on the harvest index (Table 4).

Table 4. Yield parameters of faba bean (mean ± standard deviation). Means followed by the same letter within the same column are not significantly different.

Treatments	Number of Grains (m^2)	Plant Fresh Weight (g/m^2)	Plant Dry Weight (g/m^2)	Thousand Grain Weight (g)	Harvest Index (%)
Control	106 ± 7 c	464 ± 34 b	198 ± 14 c	1073 ± 71 b	37% ± 1% a
15 t/h of Gypsum	118 ± 7 bc	504 ± 23 b	227 ± 7 b	1070 ± 50 b	36% ± 2% a
15 t/h of Phosphogypsum	118 ± 7 bc	506 ± 13 b	225 ± 8 b	1152 ± 68 ab	38% ± 2% a
30 t/h of Phosphogypsum	140 ± 13 ab	628 ± 24 a	300 ± 11 a	1236 ± 38 a	37% ± 2% a
45 t/h of Phosphogypsum	153 ± 18 a	634 ± 14 a	305 ± 12 a	1215 ± 62 a	38% ± 1% a

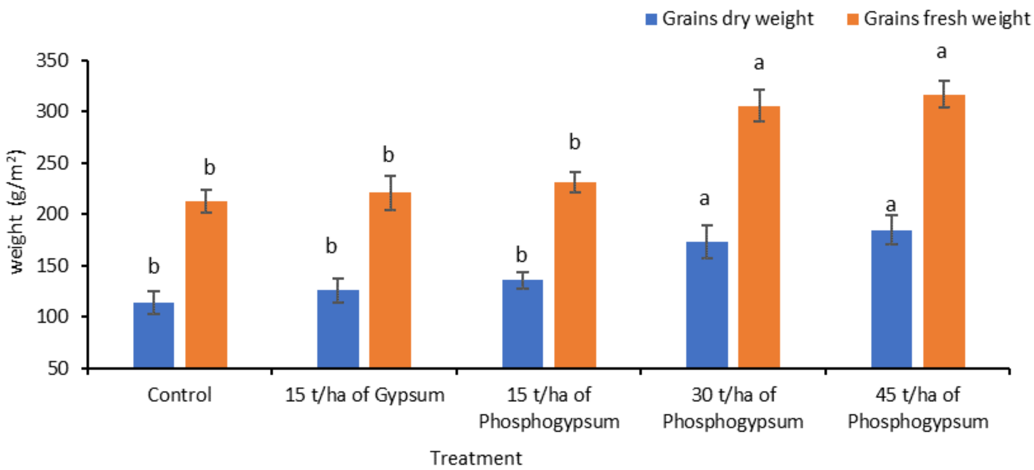

Figure 1. Dry and fresh grain weight of faba bean (mean ± standard deviation). Same letters in a column series indicate no significant differences among treatments.

Yield increases observed with PG compared to G may have been due to PG acidity and its calcium, sulfur and phosphor contents. In addition, PG was reported to dissolve faster and produce an acidic reaction in the rhizosphere, thus positively influencing nutrient availability [10].

3.2. Heavy Metals Content

This study showed that the application of the PG did not affect the grain quality. The grain heavy metals contents were below the recommended levels (Table 5) and were not affected by the application of PG and G. This finding is in agreement with a previous study where PG did not have an accumulative impact on plant heavy metal content [11]. This result can be explained by the alkaline soil pH as reported by [12] who indicated that transfer of heavy metals from soil to plants was negatively correlated with soil pH.

Table 5. Grain heavy metals content (mean ± standard deviation). Means followed by the same letter within the same column are not significantly different.

Treatments	Cu	Fe	Zn	Ni	Pb	Cd
	ppm					
Control	12.7 ± 1.5 a	62.7 ± 16.3 a	72.7 ± 12 a	3.4 ± 0.3 a	<0.01	<0.003
15 t/h of Gypsum	11.2 ± 1.7 a	85.2 ± 19.9 a	67.2 ± 7.8 a	3.6 ± 0.9 a	<0.01	<0.003
15 t/h of Phosphogypsum	11.3 ± 2.3 a	74.2 ± 28.8 a	69.2 ± 8.5 a	3.0 ± 0.3 a	<0.01	<0.003
30 t/h of Phosphogypsum	12.0 ± 1.5 a	78.7 ± 26.0 a	82.2 ± 21.7 a	3.0 ± 0.3 a	<0.01	<0.003
45 t/h of Phosphogypsum	11.2 ± 1.7 a	79.7 ± 20.8 a	70.2 ± 6.6 a	3.0 ± 0.2 a	<0.01	<0.003
Recommended Limits [13]	73.3	425.5	99.4	67.9	0.3	0.2

4. Conclusions

Results from this study have shown that the effectiveness of the treatments, on shoot and grain yield, was in the order of: 45 t/ha of PG > 30 t/ha of PG >15 t/ha of PG >15 t/ha of G > control. The application of 30 and 45 t/ha of PG increased grain dry weight by 52% and 62%, respectively, when compared to the control. Grain heavy metal contents were below the recommended limits and similar across treatments. Our findings suggest that the application of PG increased faba bean yield and can be considered as a safe amendment for reclaiming salt-affected soils.

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