

Proceeding Paper

Study of the Sodidity of Phosphate By-Products and Sludge Mixture for Large-Scale Application in Mine Site Reclamation [†]

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Abstract: Morocco has a very long mining tradition, and is threatened by ground salinization. The objective of this study was to evaluate the salinity level in the mixture of phosphate mining by-products and sludge prior to its use to reclaim a mine site or for soil remediation. The experiment was conducted with Italian ryegrass in 4 months under greenhouse. The design was a randomized complete block with 10 treatments and 4 replications. The results revealed that treatments containing phosphogypsum helped to reduce the effect of sodicity on soil. Thus, phosphogypsum associated with sludges can be used as an amendment to reclaim mine soil affected by sodicity.

Keywords: salinity; substrates; phosphate by-products; sludge

1. Introduction

Morocco, a Mediterranean country located in arid and semi-arid climate zones with a very long mining tradition, is threatened by ground salinization. More than 5% of Moroccan areas are already affected by salinity to various degrees [1]. Thus, on a global scale, after erosion in Morocco, salinity is ranked as the second threat to crop production [2]. Faced with the degradation and scarcity of land and the difficulties of management, it is becoming urgent to implement cost-effective, efficient, and less expensive techniques through the valorization of by-products of the phosphate industry and sewage sludge by revegetation of mining sites. This new approach has been performed through the recent study [3]. These studies showed that phosphate and sewage sludge by-products could be used as substrates for mine site reclamation, but no study has evaluated the effect of phosphogypsum on the mixture before large-scale application.

The objective of the study was to evaluate the sodicity level in the mixture of phosphate mining by-products and sludge prior to its use to reclaim a mine site or for soil remediation.

2. Materials and Methods

2.1. Substrates

The substrates used for this study constituted the by-products from phosphate mining and wastewater treatment plants. The by-products from phosphate mining were topsoil (TS) from the overburden, gathered and put aside prior to mining; phosphogypsum (PG); ground phosphate waste rocks (PWR); and phosphate sludge (PS). The by-product from wastewater treatment plants is sewage sludge (SS). The different substrates from phosphate mining were from the complexes El Jadida and Youssoufia, whereas the substrate from wastewater treatment plants was from Ben Guérir. Control (TS) used corresponds to topsoil. Samples (PG, PWR and TS) were sieved through 2 mm mesh sieve before the experiment.

2.2. Pot Preparation and Experimental Layout

The experiment was conducted with Italian ryegrass (*Lolium multiflorum*) in 4 months under greenhouse conditions at the Agriculture Innovation Transfer Technology Center-Ben Guérir (AITTC) of the University Mohammed 6 polytechnic at Ben Guérir, Morocco. The pots used for the experiment had a volume of 12 L. The experimental layout was a randomized complete block design with 5 substrates defined in different proportions, 10 treatments and 4 replications. Fertilizers were applied in treatments not receiving sludge as described by Guéablé et al., (2021) (Table 1). Water from the well of the experimental farm of AITTC was used for irrigation, and the seedlings were watered daily.

Table 1. Treatments and substrate composition and additions.

Treatments	PG	PWR	TS	SS	PS	Texture	Bulk Density (g/cm ³)	EC (dS/cm ³)	SAR (Cmol(+)/kg)
T1	-	100%	-	-	-	Sandy silt	1.20 ± 0.08	1.31 ± 0.03	0.23 ± 0.03
T2	-		100%	-	-	Clay	1.38 ± 0.80	3.19 ± 0.04	0.33 ± 0.02
T3	65%	30%	-	5%	-		1.02 ± 0.22	3.36 ± 0.33	0.26 ± 0.03
T4	65%		-	5%	30%	Sandy silt	1.02 ± 0.06	3.36 ± 0.17	0.30 ± 0.02
T5	65%		35%	-	-		1.05 ± 0.08	3.12 ± 0.75	0.24 ± 0.04
T6	65%	35%	-	-	-	Sandy silt clay	1.01 ± 0.08	3.13 ± 0.47	0.20 ± 0.18
T7	65% *	35% *	-	-	-	Sandy silt	1.02 ± 0.82	3.13 ± 1.43	0.24 ± 0.02
T8	-	95%	-	5%	-		1.22 ± 0.82	1.63 ± 0.09	0.24 ± 0.14
T9	-	65%	35%	-	-	Sandy silt clay	1.26 ± 0.28	1.37 ± 0.09	0.21 ± 0.04
T10	-	-	-	5%	95%		1.22 ± 0.04	1.18 ± 0.55	0.45 ± 0.42

* Addition of phosphorus in DAP (Diammonium phosphate) form at a rate of 1.08 g/pot (50 ppm), and potassium in the form of potassium sulphate at a rate of 8.3 g/pot (400 ppm). PG: phosphogypsum; PWR: phosphate waste rock; TS: topsoil; SS: sewage sludge; PS: phosphate sludge.

2.3. Data Collection

The experiment was conducted under greenhouse at AITTC for 4 months using Italian ryegrass. Samples of the different substrate components and water irrigation were analyzed at the soil, plant, and water laboratory of AITTC, and the data analyzed were obtained after the experiment. Thus, pH measurements, the electrical conductivity (EC) and the cation exchange capacity (CEC) were analyzed as described by [3].

2.4. Sodium Adsorption Ratio (SAR)

One of the criteria currently recognized in the scientific literature as indices of soil and substrate sodicity is the Sodium Adsorption Ratio (SAR) with a reported threshold of 13 cmol(+)/kg. For irrigation water, SAR represent the hazard of soil sodicity following the use of the water for irrigation. [4]. It is defined by Equation (1).

$$\text{SAR} = \text{millimoles of Na}^+ / [\text{millimoles of } 0.5(\text{Ca}^{2+} + \text{Mg}^{2+}) / 2]^{-1/2} \quad (1)$$

where: SAR = Sodium adsorption ratio, (Cmol(+)/kg).

Na^+ , Ca^{2+} , Mg^{2+} = Exchangeable cations (Cmol(+)/kg).

2.5. Characteristics of the Water Irrigation

Water irrigation used in this study was from the experimental farm of AITTC (Table 2). The irrigation rate used for each pot was 500 mL. According to [3], this water had moderately saline water. Thus, this water could have negative effects on many crops, but it could be utilized with careful management practices [4]. Furthermore, the mean value SAR value of 3.63 cmol(+)/kg indicated a low risk of sodalisation with a sodicity class S1. A similar result was obtained by [5], where SAR was 8.69 cmol(+)/kg.

Table 2. Characteristics of the water irrigation used.

Parameters	Values
EC (dS/m)	2.58
pH	7.35
SAR (Cmol(+)/kg)	3.63

3. Results

The mean pH values of the different treatments varied between 7.77 and 8.20; therefore, the pH was alkaline (Table 3). However, the lowest pH values were for treatments (T3, T4, T5, T6 and T7) containing PG. Furthermore, the mean EC values of all treatments ranged 1.30 to 3.50 dS/m. Thus, these treatments were lower than 4 dS/m. In addition, the SAR values of different treatments ranged from 0.21 to 1.51 cmol(+)/kg, and were less than 13 cmol(+)/kg. The SAR values containing PG (T3, T4, T5, T6 and T7 treatments) were lowest, ranging from 0.21 to 0.29 cmol(+)/kg. However, for the treatments (T1, T2, T8, T9 and T10) without PG, the SAR values were greater, ranging from 0.95 to 1.51 cmol(+)/kg.

Table 3. Selected chemical properties of different treatments.

Treatments	pH	EC (dS/m)	SAR (Cmol(+)/kg)
T1	8.2 ± 0.16	1.41 ± 0.44	1.17 ± 0.15
T2	7.77 ± 0.08	3.05 ± 0.82	1.51 ± 0.19
T3	7.46 ± 0.06	3.5 ± 0.58	0.29 ± 0.09
T4	7.46 ± 0.02	3.32 ± 0.69	0.28 ± 0.05
T5	7.06 ± 0.02	3.31 ± 0.55	0.23 ± 0.04
T6	7.37 ± 0.02	3.21 ± 0.60	0.21 ± 0.04
T7	7.47 ± 0.12	3.11 ± 0.42	0.23 ± 0.02
T8	7.88 ± 0.02	2.38 ± 0.41	1.39 ± 0.20
T9	7.94 ± 0.03	1.38 ± 0.09	0.95 ± 0.48
T10	7.96 ± 0.02	1.30 ± 0.47	1.06 ± 0.14

4. Discussion

The mean EC values of all treatments lower than 4 dS/m. In addition, the SAR values of different treatments less than 13 cmol(+)/kg. According to [4,6], these treatments are classified as sodics because their EC are lower than 4 dS/m and their SAR are less than 13 cmol(+)/kg. However, the treatments (T3, T4, T5, T6 and T7) containing PG had a very low sodicity compared with the treatments (T1, T2, T8, T9 and T10) without PG. Thus, PG associated with PS and/or SS helped to reduce the effect of sodicity in soil. PS and SS can be considered as amendments, and according to several authors, PG associated with amendments was more effective than that with simple gypsum [6,7]. This combination can decrease the sodicity of the soils or substrates. Indeed, PG has a very variable composition which depends to a large extent on the composition of the natural phosphates from which it is obtained. However, it is mainly a source of calcium (CaO) and sulfur (S). PG, thanks to the addition of calcium, allows to fight against the harmful effects of sodium on the soil structure and infiltration capacity. The calcium (Ca²⁺) brought to the soil is then fixed on the soil colloids, and each time a calcium ion is fixed, there is a sodium ion (Na⁺) which is progressively evacuated from the soil into solution. This allows for the removal of sodium

during drainage. The presence of significant amounts of calcium will allow the evacuation of sodium ions to continue over time and restructure the soil [6]. However, in the absence of drainage, sodium sulfate could cause a drop in pH. Therefore, water management is essential in the reclamation of soils in order to maintain the soil pH in neutrality.

5. Conclusions

The results showed that the soils were sodics. However, the treatments containing PG helped to reduce the effect of sodicity on soil. Thus, phosphogypsum associated with sludges can be used as an amendment to reclaim mine soil affected by sodicity.

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