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Study of Phosphogypsum Amendment in Arid Zone Soil El Fja Region (Mednine, Tunisia)

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Abstract – An arid zone is characterized as an area of low precipitation, high temperature, and high rate of evaporation. The soil in this zone is characterized by neutral, high salt content, and low organic matter. Therefore its agronomic potential can be easily deteriorated by erosion or over cultivation and consequently amendments are added to enhance physic-chemical properties of soil. This work is a trial to recover soil in El Fja region (Mednine, Tunisia) by adding various amounts of phosphogypsum (PG) a byproduct issued by fertilizers industry. Phosphogypsum-soil mixtures were prepared in pots, with different percentages: 10%, 20%, 30%, 40% and tested under broad bean cultivation (*Vicia faba L*). Physical and chemical properties of these mixtures were investigated. Water reserve and water retention capacity increased, which led to an augmentation in agricultural yields, its maximum was reached at a percentage of 10% of PG amended.

Keywords : Amendement, arid zone, phosphogypsum (PG), soil.

1. Introduction

In Tunisia considerable attention has been focused on phosphogypsum which is a byproduct of the phosphate fertilizer industry and emanates from the production of phosphoric acid from rock phosphate, in order to reduce the volumes to be disposed in landfill, and to provide new soil conditioners to balance the use of industrial fertilizers in agriculture especially in poor soil like those in arid zone.

In fact, Tunisian South Est is an arid zone characterized as an area of low precipitation, high temperature, and high rate of evaporation (You 2016). The soil in this zone is characterized by neutral to basic, high salt content, and low organic matter (Kayouli 2006; Jeddi 2010). Therefore, its agronomic potential can be easily deteriorated by erosion overgrazing or agriculture activity. Consequently, amendments are added to enhance physic-chemical properties of soil (Cherifa 2009). Several trials have been performed using soil conditioners such as farmyard manure, compost, biochar (Cherifa 2009; Uchimiya 2010).

This work deals with the use of PG as an amendment in the arid zone soil. In fact, the production of PG in Tunisia is estimated to be 10.5 million tons annually (Ben Amor 2012). That constitutes a real environmental problem as only a small amount of this production is converted, while only 15% of world PG production is recycled as building materials, agricultural fertilizers or soil stabilization amendments and asset controller in the manufacture of Portland cement as reported by Tayibi (2009).

Numerous works studied the effect of adding PG to soil. Carvalho (1997) proved that PG can be considered as a good amendment for acidic subsoils that present toxic levels of aluminum and/or calcium deficiency. Alva (1990) showed the amelioration of soil infertility due to PG. Garrido (2006) found that gypsum-rich industrial by-products could regulate the mobility of Cd, Cu and Pb in acid soils. Kumpiene (2008) revealed a success in immobilizing As, Cr, Cu, Pb and Zn in soil by phosphorus amendments and clays. Recently Hentati (2015) studied the eco-toxicity of amended soil with PG and its impact on bacteria, invertebrates, algae and plants, emphasizing the necessity of setting limits for PG application in soils.

This research is an investigation of the physico-chemical properties of sand-PG mixtures in the arid zone and consequences on an example of agricultural yields.

2. Materials and methods

2.1. Site description and soil mixtures

Soil phosphogypsum mixtures were put in pots in a greenhouse at the Institute of Arid Regions in Medenine, at 33° 21"16 ' North latitude and 10° 30"19 East longitude. This area is characterized by hot dry climate. In fact, Temperature can exceed 40 °C in August and the annual rainfall average doses not surpass150mm/year. El Fje soil has a sandy texture with small amounts of silt (4.92%) and clay (2.17%) which were determined by Robinson pipette (Robinson1922).

Experiments were realized on PG-sand mixtures with different percentages in weight: 10%, 20%, 30%, and 40%.

Posphogypsum samples were furnished by the Tunisian Chemical Groupe in Gabès. The composition of PG varies depending upon the source of rock phosphate and the process for manufacturing phosphoric acid (Wright 1998). The common composition (Zairi 1999) of PG is: calcium sulfate dihydrate, orthophosphoric acid various salts and trace metals.

2.2. Characterization of PG by XRD

Powdered samples were analyzed by X-ray diffraction (Figure 1), PG seems to be mainly formed by calcium sulfate dihydrate polymorphs and some minor impurities like Mg $(OH)_2$, SiO_2, $MgSiO_3$ and Na_2SiF_6.

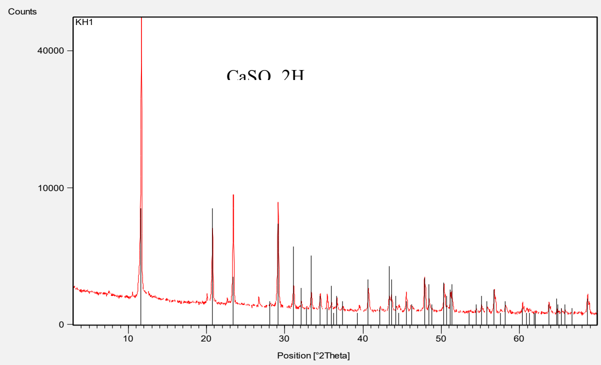

Figure 1. X-Ray Diffractogram of powdered PG (□□Cu=1.54 Å)

2.3. Physical and chemical analysis of PG-sand mixtures and cultivation yield determination

Soil and soil-PG mixtures characterization was performed according to Dugain methods (Dugain 1961). A summary of the soil, PG and PG-soil characteristics is reported in Tables 1, 2 and 3. After maturation, board bean plants and pods were collected measured then weighed. Values are gathered in table 4.

2.4. Statistical analysis

All experiments were made in triplicate. Analysis of variance (ANOVA) followed by Tukey's testwas carried out using SAS/STAT(R) 9.2 software, statistical grouping where then deduced (Table 3).

3. Results and Discussion

3.1. Soil and PG characterization

From the data collected and gathered in Table 1 related to soil, pH is about 7.5 and the electrical conductivity is (2.33 mS/cm) indicating a moderately saline soil (Wong 2009) with a limited cation exchange capacity, low organic carbon and active carbonate percentages respectively.

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Table 1. Soil characterization

Physico-chemical characterization of El Fje Zone soil	Carbonate (%)		Total N (%)	S.O.C. (%)	CEC (meq/ 100g)	pH	EC mS/cm	Phosphates(P_2O_5ppm)	Gypsum (%)	Ca+Mg meq/l	Anions (meq/l)			Exchangeable Bases (ppm)	
	Active	Total									HCO_3^-	Cl^-	CO_3^{2-}	K^+	Na^+
	1.17	15.97	0.18	0.58	4.30	7.5	2.33	901	1.36	33.5	5.7	15	0	133.3	108.2

EC : Electrical Conductivity of a saturated soil paste extract ,S.O.C. Soil Organic Carbon, CEC: Cation Exchange Capacity

In the other side as shown in Table 2, PG has low pH due to the acid remaining from fertilizer manufacture (Zairi1999). Moreover, it has important cation exchange capacity and gypsum percentage. In addition, PG has high ion concentrations due to its mineral composition previously described and to potential crystalline and non crystalline impurities like chlorate, phosphate and carbonate known to be present in the phosphate mineral generating PG (Drouet 2015; Zairi 1999). All these facts go with the important EC measured.

Table 2. PG characterization

Physico-chemical characterization ofphosphogypsum	Total N (%)	S.O.C. (%)	CEC (meq/ 100g)	pH	EC mS/cm	**Phosphates (P_2O_5ppm)**	Gypsum (%)	Ca+Mg meq/l	Anions (meq/l)			Exchangeable Bases (ppm)	
									HCO_3^-	Cl^-	CO_3^{2-}	K^+	Na^+
	0.3	1	7.1	2.3	18	1209	97.5	52	380	75	0	237.3	377.3

3.2. Effect of PG amendment on soil in pre and post cultivation

The physicochemical properties (Table 3) of PG-soil mixtures in pre-cultivation assessed regularly with the amount of amendment involved, except for pH, decreasing as PG has an acidic one. In post cultivation samples, for all percentages studied EC, CEC and the ionic concentrations increased significantly this is explained by the partial solubilization of PG and its impurities in addition to the carbonates and chlorates brought by irrigation tape water (SONEDE 2017). This later lixiviated PG-soil mixtures that led to the stabilization of pH near 7. The vegetal development of broad bean enhanced S.O.C and total N concentrations. Legumes are commonly known to enrich poor soil (Vågen 2005; Graham 2003).

In this work we found that PG amendment increased water retention in soil (Table 4) as Field Capacity, Wilting point and Moisture retention increased with the percentage of PG added to soil, this fact was also reported by A. Batool (2015).

Table 3. Physicochemical properties of PG-soil mixtures

		Pre-cultivation					Post-cultivation				
		0	10%	20%	30%	40%	0%	10%	20%	30%	40%
pH		7.5 c	5.4b	5.2b	5.1b	4.5a	6.7a	6.8a	6.8a	6.9a	7.0a
EC (mS/cm)		2.3 a	5.2b	8.9c	10.0c	12.3d	7.1a	11.1b	17.6c	22.9d	25.13d
CEC(meq/ 100g)		4.3 a	5.8a	6b	6.5b	6.9b	7.1a	11.1b	17.6c	22.9d	25 .1d
S.O.C.(%)		0.58 a	0.64ab	0.68ab	0.75bc	0.87c	0.8a	1.10b	1.10b	1.18b	1.22b
TotalN (%)		0.18 a	0.26b	0.29c	0.31c	0.35d	0.28a	0.29ab	0.30ab	0.31b	0.32b
Carbonate (%)	Active	1.2 a	2.3a	4.0b	4.8c	5.0c	3.5a	4.3a	5.2a	5.3a	5.5a
	Total	5.6 a	5.6a	6.9a	8.3a	15.19 b	7.6a	8.3b	10.4c	11.1d	12.8e
Gypsum(%)		1 .4 a	6.2b	20.3c	27.1d	33.1e	1.8a	7.9b	20.3c	23.4c	31.2d
Ca+Mg (meq/l)		33.5 a	39.3a	42.3a	43.5b	45.3b	20.3a	21.2a	21.9a	24.1b	24.8b
Anions (meq/l)	HCO_3^-	5.7 a	10.3b	12.0c	13.3cd	14.0d	4.3a	5.7ab	6.0b	6.3b	6.7b
	CO_3^{2-}	0	0	0	0	0	0	0	0	0	0
	Cl^-	15.0 a	16 .7b	18.3c	20.0cd	23.3d	43.3a	90b	150c	168cd	178d
	SO_4^{2-}	13.3 a	18.0b	21.0c	21.5c	24 .1d	20.3a	20.4a	21.0ab	21.3b	21.4b
Exchangeable Bases (ppm)	K^+	341 a	388a	717b	787b	873c	315.3 a	462.7a	629.6a	1004.4 b	1282.9 b
	Na^+	85 a	1111b	2274c	2322c	3634d	837.6 a	1545.1b	3501.1 c	3609.6 c	4036.1 c
P_2O_5 ppm		901 a	954b	978bc	995c	1029d	609.2 a	1323 .2 a	3988.6 a	4014.1 b	4467.8 b

Table 4. Water retention characteristics of soil

Field Capacity	8.4a	11.2b	15.9c	17.4d	20.9e
Wilting point	3.3a	4.7b	6.9c	8.4c	10.6d
Moisture retention	5.1a	6.4b	8.9c	8.9c	10.4d

3.3. Effect of PG amendment on broad bean (*Vicia faba L*) cultivation

PG influenced the majority of soil physicochemical properties after amendment. When it comes to the vegetal development of broad bean, PG decelerates the development of the plant after seeding. Besides, this amendment is fatal when added to arid zone soil in high percentages. No beans were obtained with 20%, 30%, and 40%, as displayed in Table 5. The productivity of the 10% PG-soil mixture is better than that of bare soil. Moreover, plant, root and shoot, mensurations which are length and weight, are the most valuable for the 10% PG-soil mixture.

Table 5. PG effect on vegetal development

		0% PG	10% PG	20% PG	30% PG	40% PG
Vegetal development after seeding (days)		17	19	24	27	27
Plant	length (cm)	49	52	42	27	26
	weight (g)	11.8	13.0	11.6	9.9	5.4
Root	length (cm)	7	9	6	6	5
	weight (g)	3.0	3.5	2.7	2.0	1.9
Shoot	length (cm)	42	43	36	21	21
	weight (g)	7.1	9.5	8.9	7.8	3.5
Mineral matter after calcinations	root	15.0%	18.0%	15.4%	15.2%	14.8%
	shoot	18.0%	19.2 %	17.0%	16.0%	14.0%
Pod board bean	number	6	8	0	0	0
	length (cm)	2.7	6.2	-	-	-
	weight (g)	0.9	3.7	-	-	-

4. Conclusion

This work is a trial for the valorization of PG in agriculture as an amendment in arid zone soil. Different percentages of phosphogypsum-soil mixtures 10%, 20%, 30% and 40% were prepared in pots, Physical and chemical properties of these mixtures were then studied; these properties are directly affected by those of the amendment. Therefore, broad bean cultivation (*Vicia faba L*) was experienced in the chosen mixtures. An increase in agricultural yields was noticed with a maximum at a percentage of 10% of PG amended; besides plantation affected the physico-chemical properties of the soil.

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