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Research article

The positive effect of phosphogypsum-supplemented composts on potato plant growth in the field and tuber yield

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A B S T R A C T

The production of phosphoric acid from phosphate rock leads to an industrial by-product called phosphogypsum (PG). One ton of phosphoric acid generates 5 tons of PG that is frequently stocked near the production units. Several attempts were made to test PG valorization via soil amendment because of its phosphate, sulphate and calcium content. In this study, the use of PG in composting was envisaged. Composts were produced by mixing olive oil wastes and spent coffee grounds. Two concentrations of PG, 10% (A_{10}) and 30% (A_{30}), were tested in composting substrate in addition to control compost without PG (A_T). After 8 months of fermentation, the resulting composts were used in field experiments using nine different treatments conducted to evaluate the potential use of these PG-containing composts in potato plant (cv. Spunta) cultivation. Plants were grown in the field and the different composts (A_T, A_{10} and A_{30}) were added as fertilizer and compared to commercial compost and cattle manure. During the culture period, a number of physiological (dry weight, chlorophyll content, tuber yield) and biochemical parameters (antioxidant activities, mineral content, starch and protein content) were followed. Similarly, chlorophyll content was measured in plants cultivated on commercial or PG supplemented composts.

An increment of 55.17% in potato yield was recorded with the use of A_{30} the compost.

Collectively, these data reveal the positive impact of the addition of PG in composting which may be adopted as a strategy for PG valorization and its use for the production of high quality edible products.

1. Introduction

In Tunisia, the phosphate industry occupies a crucial position at the economic level. Four industrial units are active in phosphate rock utilization for the production of phosphoric acid and phosphate fertilizers. This phosphoric acid production from wet phosphate industry generates very large quantities of phosphogypsum (PG). Indeed, the wet phosphoric acid process produces about 5 tons of phosphogypsum per ton of phosphoric acid manufactured (USEPA, 2002). PG is mainly composed of gypsum but it also contains phosphates, fluorides and sulphates. Indeed, the activities of ^{226}Ra found in Tunisian PG remained lower than those found for the majority of PGs (Ajam et al., 2009) and was below the critical value of 1 Becquerel/Kg (AFA, 2014).

Tunisian PG has been reported to contain high Cd, Hg and Zn levels (Rutherford et al., 1994; Choura, 2007) but low levels of radionuclides were measured (Tayibi et al., 2009). This waste is accumulated in stock piles near the production units and it can be also discarded in sea water causing several environmental troubles (Zhou et al., 2012).

Much interest has focused on using this by-product as an alternative raw material for many applications, such as building materials and plaster boards (Yang et al., 2013). Another interesting potential use of PG is to improve soil structure and crop yield and to increase the levels of sulphur and phosphorous (Mays and Mortvedt, 1986; Delgado et al., 2002).

Despite the environmental problems regarding phosphogypsum, some countries have made wide-scale use of this by-product as a soil amendment (Al-Hwaiti and Al-Khashman, 2014).

Crop yields and quality of a variety of fruits, vegetables, grains, forage, and oilseeds have generally been found to be higher on

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phosphogypsum-amended soils (AFA, 2014).

Restrictions regarding the agricultural use of this solid waste arose due to its high acidity and the presence of numerous contaminants such as heavy metals (Cd) and natural radionuclides (Abril et al., 2008; Hurtado et al., 2011). Many studies have reported the toxicity of these polluting substances and their damage to plants, animals and humans (Maas et al., 2010).

The high acidity of PG may reduce its use in soil amendment because it can lower soil pH which can negatively affect plant growth and yield (Ayadi et al., 2014). However, to our knowledge the use of PG in the composting process was as yet not tested.

Composts can be an interesting alternative for field fertilization but also for plant protection against phytopathogen infection (Cayuelaa et al., 2008) and plant growth. The composting process frequently uses biodegradable industrial wastes such as olive oil mill wastes (Roig et al., 2004), sweets wastes (Hachicha et al., 2006; Sellami et al., 2007), sewage sludge and green plant wastes (Jouraiphya et al., 2005).

In this context, we have used PG in the composting process by mixing OMW (olive mill waste), spent coffee grounds and 0, 10 and 30% PG. After eight months of composting process, the composts obtained were used for cultivation of potato plants (cv Spunta) under field conditions. The effect of these PG-containing composts on potato plant growth, tuber yield and quality was investigated in this study.

2. Materials and methods

2.1. Compost preparation and chemical composition

Composts (100 kg each) were prepared by mixing olive mill waste water (OMW), spent coffee grounds (G) and olive-pomace (P), using the following proportions:

A_T compost: 25% OMW+ 25% G + 50% P
A_{10} compost: 22.5% OMW + 22.5% G + 45% P + 10% PG
A_{30} compost: 17.5% OMW + 17.5% G + 35% P + 30% PG

Phosphogypsum was provided by the “Groupe Chimique Tunisien” (GCT), the phosphate fertilizer company. The three different composts were tested in two different doses in the field: 1 l/m^2 (0.5X) and 2 l/m^2 (1X).

The composting process was performed for eight months during which, the temperature, pH and humic and fulvic acid contents, were determined every month. At the end of the composting procedure, the chemical composition of the compost was determined (Table 1).

2.2. Field trials and culture conditions

The potato plants cultivation process was performed in a field devoted to this kind of culture by following the current cultivation process used in Tunisia. A plot of about 70 m^2 was exploited to test 9 different amendments distributed in rows of 15 m × 50 cm spaced out between them by 50 cm. Cattle manure and commercial compost (EL kindi) were used as controls. The cultivation process was followed by an engineer and a farmer specialized in potato multiplication. The manure is frequently used by local farmers for potato cultivation. The raw soil containing no amendment was regarded as negative control. Thirty plants were grown per row. The potato seed tubers of the Spunta variety were bought from the market and planted in each row. The dose recommended by the manufacturer of the El Kindi compost, of about 2 L/m^2, was taken as a reference for this study. Standard growth conditions and pesticide treatments were used for plant culture.

The potato culture was performed during the main season recommended for this plant species (Tunisian Technical Center for Potato and Artichock).

2.3. Determination of chlorophyll content

Leaf samples of 0.01 g were harvested and treated with acetone as described by Bouaziz et al. (2012). The mixture was centrifuged at 12000 rpm for 15 min, and then 2 ml acetone 80% were added to the supernatant. The absorbance at 645 and 663 nm were determined and the chlorophyll content (chl) was calculated as follows (Arnon, 1949):

$$\text{Chl a} = 12.7^* \,A663 - 2.69\, ^*A645 \quad (1)$$

$$\text{Chl b} = 22.9^* \,A645 - 4.68\, ^*A663 \quad (2)$$

2.4. Determination of dry matter content

The dry matter was determined by drying leaves and tubers for 72 h at 80 °C. Dry matter content was determined using the following formulae: DW × 100/FW, where FW is fresh weight and DW is dry weight.

2.5. Evaluation of lipid peroxidation

Lipid peroxidation was estimated by measuring the level of MDA (malondialdehyde), a natural product of oxidation of polyunsaturated fatty acids present in the membrane caused by

Table 1
Physico-chemical analysis of different substrates.

		A_T	A_{10}	A_{30}	PG
Organic matter (%)		73.8 ± 0.003	67.5 ± 0.004	45.85 ± 0.007	2.47
pH		8.25 ± 0.083	7.03 ± 0.029	7.04 ± 0.037	1.84
C/N ratio		7.68 ± 1.07	8.44 ± 0.71	7.86 ± 0.44	–
Macro-nutrients (g/Kg)	Mg	3.22 ± 0.27	3.22 ± 0.71	2.7 ± 0.35	0.922
	Ca	26.23 ± 0.75	27.40 ± 1.52	34.74 ± 3.29	265.976
	K	17.75 ± 1.46	20.13 ± 12.16	12.81 ± 1.24	0.158
	P	1.68 ± 0.096	2.235 ± 0.22	2.53 ± 0.17	13.1
Heavy metals	Al (g/Kg)	2.88 ± 0.19	2.96 ± 0.52	2.51 ± 0.25	–
	Zn (ppm)	44.87 ± 3.2	61.17 ± 7.6	68.31 ± 8.021	121.5
	Cr (ppm)	16.2 ± 0.9	11.6 ± 0.3	14.3 ± 0.9	27
	Cd (ppm)	0.4 ± 0.1	1.1 ± 0.4	3.6 ± 0.9	15
Fulvic acid (%)		7.47 ± 0.0062	11.82 ± 0.005	13.31 ± 0.003	–
Humic acid (%)		12.27 ± 0.001	2.59 ± 0.003	1.44 ± 0.004	–