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Salinity and Heavy Metal Stress

REGULAR ARTICLE

Effect of poultry manure on the yield and nutriments uptake of potato under saline conditions of arid regions

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Abstract

In hot arid lands, soil salinity, irrigation with brackish waters and the massive use of mineral fertilizers are major constraints for the development of potato cropping. The current field experiment was conducted in the Sahara Desert of Algeria in order to highlight the effect of organic fertilization on the improvement of potato production and the increase of plant salt-stress tolerance. The variation of yield production parameters and nutritional status of plants were evaluated through a split-plot design including six increasing rates of poultry manure (PM) (0, 20, 30, 40, 50, 60 mt/ha) tested in three experimental sites with increasing salinity levels: low saline soil (electrical conductivity 'EC' = 0.9 dS/m), saline soil (EC = 2.2 dS/m) and high saline soil (EC = 5.9 dS/m). The results revealed a significant and proportional increasing of all studied yield parameters (number, seize and yields of tubers) with the increase of PM rates compared to the control. The effect of the interaction (PM × salinity level) showed that the highest yield (44.55 mt/ha) was recorded in plots treated with 60 mt/ha of PM in high saline soils. The assessment of nutritional status at flowering stage of potato plants demonstrated that concentrations of K+ and N increased while Na+ concentrations decreased, in both leaves and roots, as PM rates increasing, principally beneath high salinity level. Our findings suggest the dose of 60 mt/ha of PM is an optimal amount producing the best tuber yields under saline conditions in arid soils.

Key words: Hot drylands, Nutritional status, Organic fertilization, Potato production, Soil salinity, Tuber yield

Introduction

Salinity is a major environmental constraint facing modern agriculture. Often associated with drought, it leads to a continuous reduction of yields and arable land surface, which threatens global food balance (Munns, 2002; Rafat and Rafiq, 2009). The progressive natural and anthropogenic salinization of arable lands at the rate of three hectares per minute worldwide is a serious concern for agricultural crop production (Parida and Das, 2005; FAO, 2006; Levy and Taib, 2013), particularly in drylands where soils and water resources are too saline for most of the common economic crops (Munns, 2002).

Climatic conditions of these regions are characterized by weak and erratic precipitation associated with important evaporation promoting the accumulation of salts in the soil. However, salinization in arid areas is not due only to climatic conditions, but also to the irrational use of mineral fertilizers and poor-quality water and/or inappropriate irrigation practices (Munns, 2002; Jalali and Merrikhpour, 2008). The excessive salt amounts adversely affect soil physical and chemical properties, as well as the microbiological processes (Lakhdar et al., 2008). The alteration of these properties represents an indirect stress for water and mineral plant nutrition (Levigneron et al., 1995).

Actually, the increase in soil salinity triggers several negative effects on plant growth due to the osmotic stress, ionic stress, nutritional imbalances or a combined effect of all these factors (Ashraf, 1994). The accumulation of Na^+ and Cl^- in tissues

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of plants growing in saline habitats restricts the uptake of essential elements, including mainly NO_3^-, PO_4^{3-}, K^+, N and Ca^{2+} (Kaya et al., 2001; Haouala et al., 2007). However, the negative effect of soil salinity depends on the plant tolerance aptitude and the salinity level (Munns, 2002). Halophytic plants, which grow normally in soils rich in salts, tend to take up and accumulate Na^+ in their vacuoles and use it as an osmoticum (Glenn et al., 1999). On the contrary, glycophytes tend to exclude Na^+ to maintain a high K^+/Na^+ ratio, which seems to be crucial for salt tolerance (Grattan and Grieve, 1999). Like glycophytic plants, potatoes (*Solanum tuberosum* L.) are considered moderately salt-sensitive compared to other cultivated species, since moderately soil salinity levels of 2.0–3.0 dS/m decrease up to 50% of plant growth and yield (Maas and Hoffman, 1977; Katerji et al., 2003).

According to the FAO (2006), this strategic plant is one of the most important crops worldwide; it is indeed ranked fourth behind wheat, rice, and maize. Therefore, it is important to maintain high potato production yield and mitigating the negative effect of salt stress, specifically in arid regions where the scarcity of freshwaters makes the use of salt water for crop production often unavoidable. The harmful effects of salinity on potato plant may be related to the negative effect of some specific ions such as Na^+ and Cl^- that inhibit the production of pigments in leaves; and the influence of high sodium concentration that induce calcium and magnesium nutritional deficiencies (Levy and Veilleux, 2007).

Unfortunately, in Algeria, potato production faces many constraints that affect both the yield and tuber quality. Salinity is ranked among the main factors limiting the performance of this plant, especially in hot arid areas where average yields are low (~22 mt/ha) (DSA, 2009). Thus, enhancing the salt tolerance of potato is a key breeding objective to improve production in these regions. The main challenge facing potato farmers in drylands is to find the best way to combat adverse effects of soil and water salinities in crop fields and minimize their associated environmental and economic impacts in these areas, which are known by the fragility of ecosystems. In fact, several studies reported different strategies in order to reduce salinity effects (Turkan and Demiral, 2009; Ould Ahmed et al., 2010). In this context, organic fertilization seems to be one of the best-suited solutions for this problem (Walker and Bernal, 2008; Ould Ahmed et al., 2010). Besides the ameliorative action that brings the supply of organic fertilizers to soil, the latters can amend in restoring degraded soils through the improvement of organic matter status, physical characteristics and increasing nutrient availability and thus plant growth (Lax et al., 1994; Al-Moshileh and Motawei, 2007; El-Tantawy et al., 2009).

Accordingly, developing a good understanding about how the interactions between salinity and the application of biofertilizers are affecting crop productivity is imperative. In fact, addition of organic matter can accelerate the leaching of Na^+, increase water-holding capacity and aggregate stability, and decrease all of the exchangeable sodium percentage (ESP), the sodium adsorption ratio (SAR), pH, and the electrical conductivity (EC) (Lax et al., 1994).

In addition, by supplying major nutrients particularly N, P and K, the biofertilizers improve the mineral nutrient status and growth of plants grown in salt-affected soils (Qadir et al., 2008). In the same sense, organic matter can improve the microbiological activity of soil that plays a pivotal role in carbon mineralization and nutrient cycling. Thus indirectly affect the transformation and availability of essential nutrients of plants (Wichern et al., 2006). This biofertilization is particularly important for improving nay restoring saline sandy soils, which are critically deficient in organic matter (OM), such as soils of the Sahara Desert where OM is below 1% (Halitim, 1988).

The mechanisms involved in salinity tolerance primarily include the maintaining of balanced selectivity between sodium and potassium absorption, which represents one of the necessary conditions for the improvement of plant production. In this case, the substitution of ions responsible for the salinity (mainly Na) through adding organic manures is a viable strategy to improving salt-affected soils (Garcia et al., 2000). Actually, OM mineralization releases and enriches the soil solution with K^+ and Ca^{2+}, which can prevent, through the ionic antagonism effect, the absorption of the excess of toxic ions that are often required in small quantities such as Na^+ and Cl^- (Lesaint and Coïc, 1983). However, all these benefits of organic substances are reached only under specific doses of biofertilization under saline conditions. Consequently, the determination of the treatment dose is crucial because biofertilization must be optimized, reasoned and balanced to avoid the risk of deficiency and/or toxicity by mineral elements associated with excess salts on the one hand; and to ensure the availability of all necessary elements for plants nutrition during periods of high needs and without compromising the environment quality on the other hand.

Several organic materials such as manures, mulch and composts have been used as soil fertilizers in order to mitigate adverse effects of soil salinity and improve plant productivity (Walker and Bernal, 2008; Mahdy, 2011). Since potato crops have short growth cycle, the application of a rapid-mineralization biofertilizer highly rich in nutrients such as poultry manure (PM) seems to be crucial because PM can cover all plant nutritional needs without the use of mineral fertilizers provided it is applied with sufficient quantity. However, PM application rates were very little studied particularly under field conditions of saline soils where potato plants are subjected to the combined effect of the interaction of several salts. Therefore, the objectives of this study are the following: (i) evaluate the response of potato plant and yield to different rates of poultry manure, (ii) study the role of this organic fertilizer in increasing the salt tolerance of potato crop, and (iii) determine the optimal dose of biofertilization under saline conditions in sandy soils of a hyperarid environment.

Material and Methods

Study area

The present study was conducted at the farm Babaziz (32°52'N, 05°26'E, and 157 m above sea level) located in Hassi Ben Abdallah, 26 km from the city of Ouargla (Sahara Desert of Algeria). The climate is hot arid with mild winters and hot dry summers. The dry season extends throughout the year where rainfall is very low and erratic. The mean of annual precipitation (2000–2010) was 37.29 mm with 41.68% of mean relative humidity. Annual mean of maximum temperatures is 43.71°C recorded in July, and that of minimum temperature is 3.89°C noted in January (NOM, 2011).

The selection of this region was based on its representativeness of the arid regions in terms of degradation and low fertility of soils, especially with regard to low content of organic matter, high salt contents in irrigation water and variable levels of salts in soil. These soil features allow us to conduct the experimental design to investigate the joint effect organic fertilization and soil salinity on potato cultivation under field conditions of hot drylands.

Soil sampling and analysis

Soil samples were collected separately from the arable horizon (max depth 50 cm) of the three sites in study area on February 2010. For each site, an average soil sample was obtained from pooling ten samples, and then it was air-dried, ground and passed through a 2-mm mesh sieve. All physical and chemical soil analyses were carried out on the obtained fine earth using standard methods and protocols (for details see: Sparks, 1996; Mathieu and Pieltan, 2003; Pansu and Gautheyrou, 2006), namely: particles size of soil grains was determined using the pipette method; soil pH and electrical conductivity (EC) were measured on a 1:2.5 and 1:5 soil:water (w/v) ratio, respectively; Calcium carbonate content was determined using a volumetric calcimeter; total organic carbon content (TOCC) was determined by oxidation with potassium dichromate in an acid medium and measurement of the excess dichromate using Mohr's salt (Yeomans and Bremner, 1989); organic matter (OM) content was assessed as: OM = TOCC × 1.72; total nitrogen was determined using micro-Kjeldahl method (Brermer and Mulvaney, 1982); cation exchange capacity (CEC) was determined by saturated method using neutral ammonium acetate (pH = 7.0) (Sparks, 1996); Exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) were extracted by ammonium acetate solution, then Ca^{2+} and Mg^{2+} were quantified using atomic absorption spectrophotometer whereas K^+ and Na^+ were measured with the help of flame photometer.

Results of soil physical and chemical parameters (Table 1A) revealed soils of all the study sites have sandy texture, with a low OM content (<1%), relatively high pH values and low exchange capacity (CEC). In addition, soil analysis indicated also that the three sites have different levels of soil salinity. Indeed, the EC measured in the 1:5 soil extract was 0.9, 2.2 and 5.9 dS/m in site 1, 2 and 3, respectively. Based to the scale of soil salinity (Mathieu and Pieltan, 2003), the surveyed sites were classified into Low Saline Soil (LSS): $EC_{(1/5)}$ = 0.9 dS/m, Saline Soil (SS): $EC_{(1/5)}$ = 2.2 dS/m and High Saline Soil (HSS): $EC_{(1/5)}$ = 5.9 dS/m, respectively.

Table 1. Physicochemical properties of soils of the study sites (A), poultry manure used as fertilizer (B), and the irrigation water (C) used in potato cultivation in Ouargla (Sahara Desert of Algeria).

A. Soil characteristics of study sites				B. Poultry manure properties		C. Irrigation water traits	
Parameter	LSS	HSS	HSS	Parameter	Value	Parameter	Value
Coarse Sand (%)	40.30	42.77	29.60	pH $_{(1/2.5)}$	8.37	EC (dS/m)	5.75
Fine Sand (%)	53.18	50.21	60.58	$EC_{(1/5)}$ (dS/m)	10.20	pH	7.52
Clay and Silt (%)	6.52	7.02	9.82	Total $CaCO_3$ (%)	9.85	SAR	6.20
pH $_{(1/2.5)}$	8.24	8.30	8.43	OM (%)	71.55	Class	C_5-S_1
EC $_{(1/5)}$ (dS/m)	0.90	2.20	5.90	Organic *Carbon* (%)	41.59	Soluble cations (meq/L)	
Total $CaCO_3$ (%)	1.52	2.94	3.83	Total N (%)	3.60	Ca^{2+}	19.70
OM (%)	0.47	0.51	0.65	C/N ratio	11.55	Mg^{2+}	8.28
TOCC (%)	0.27	0.29	0.37	Cellulose (%)	6.18	Na^{+}	23.19
Total N (%)	0.02	0.01	0.02	Ca^{2+} (%)	2.70	K^{+}	1.17
C/N ratio	13.5	29.0	18.5	Mg^{2+} (%)	0.37	Soluble anions (meq/L)	
Ca^{2+} (cmol/kg)	5.01	5.34	9.01	K^{+} (%)	1.90	HCO_3^{-}	1.31
Mg^{2+} (cmol/kg)	0.55	0.80	0.92	Na^{+} (%)	0.26	Cl^{-}	36.0
K^{+} (cmol/kg)	0.25	0.49	1.05	P (%)	1.60	SO_4^{2-}	27.8
Na^{+} (cmol/kg)	0.25	0.62	1.15	Mn (ppm)	265.0	CO_3^{2-}	00
CEC (%)	4.12	8.40	9.48	Zn (ppm)	223.0		
Cl^{-} (meq/L)	8.0	27.0	43.0	Cu (ppm)	57.0		

(LSS: low saline soil, SS: saline soil, HSS: high saline soil, EC: electrical conductivity, SAR: Sodium Absorption Ratio, *OM*: *organic matter*, TOCC: total organic carbon content, Class: diagram of water irrigation classification (Richards, 1954).

Poultry manure analysis

Ten samples of poultry manure were collected randomly from a private farm, packed in polythene bags and transported to the laboratory. Before analysis, the average manure samples was air-dried, ground and sieved to 2 mm. The pH and EC were measured in a 1:2.5 and 1:5 mixtures (v/v) of manure and water, respectively. Organic matter (OM) was determined after the sample was ashed at 550°C (Method of calcination). Organic Carbon (%) was quantified as follow: Organic Carbon = MO/1.72. Total nitrogen was determined by micro-Kjeldahl method (Bremer and Mulvaney, 1982). Moreover, the oven-dried samples of poultry manure (70°C) were ground to 0.5 mm mesh size and digested using the method described by Yoger et al. (2006) then Ca^{2+}, Mg^{+} and K^{+} were measured with the help of atomic absorption spectrophotometer. Phosphorus (P) was determined by Olsen's method (Olsen et al., 1954). Available Zn, Cu, Mn in manure were measured in the DTPA extract (Lindsay and Norvell, 1978) using atomic absorption spectrometry. Content of cellulose (%) was measured by the acid-detergent-fibre (ADF) (Goering and Soest, 1970). The physicochemical properties of sampled PM (Table 1B) showed high values of C, N, P, K in this organic fertilizer. The value of C/N ratio was about 11, indicating adequate stabilization of this type of manure.

Irrigation water

Soils of the three sampled sites were irrigated using waters extracted from deep fossil underground aquifer (the Continental Terminal water-table). According to USSL classification of irrigation water (Richards, 1954; USSL, 1954) that includes electrical conductivity (EC) and Sodium absorption ratio (SAR), the quality of water used in irrigation belongs to the class C_5-S_1, revealing unsuitable water for irrigation under ordinary conditions. However, it can be used where soils are permeable with adequate drainage system (Daoud and Halitim, 1994), which is the case of these sandy soils. It is noteworthy that NaCl is the dominant salt in these irrigation waters. Values of chemical parameters of the irrigation water are reported in Table 1C; these water traits were obtained according to the analytical procedures described by Richards (1954).

Plant growth conditions and experimental design

Field experiment was conducted from February to June 2010, in three different sites based on soil salinity. The experiment was carried out using potato (*Solanum tuberosum* cv. Spunta) as a test plant. The treatments consisted of three levels of soil salinity: LSS (EC = 0.9 dS/m), SS (EC = 2.2 dS/m) and HSS (EC = 5.9 dS/m) factorial combined with six rates of poultry manure (PM): 0, 20, 30, 40, 50 and 60 mt/ha. The experiment consisted of 18 treatments, replicated four times and conducted as a split-plot design with level of soil salinity in the main plots and the rates of PM in the sub plots. The whole experiment thus included a total of 72-elementary plots dispatched over four blocks of 235 m^2 for each. The surface covered by each elementary plot was 12 m^2 (3m × 4m), and the space between plots and blocks was 1 and 2 m, respectively.

After soil preparation, the poultry manure was incorporated superficially using a scarifier according to proportions of each plot treatment. Amounts of PM were fractionated according to the needs of each plant phenological stage: 2/3 of the selected rate of manure were added two weeks before planting the potato crop, and 1/3 was applied at the time of flowering (early tuber growth). At each elementary plot, uniformed tuber seeds (weight of 75 ± 5 g) were planted at a density of 4 plants m^{-2}. The spacing was 75 cm between rows and 40 cm between plants. There were no precipitations during the entire growth cycle, thus the plantation was fully dependent on irrigation using the localized irrigation systems (drip irrigation). Irrigation was applied daily from February to June. It was stopped at the maturity of potato tubers, seven days before harvest. Furthermore, weed control and phytosanitary treatments (fungicide and insecticides) were performed whenever needed. At all study sites, the crop was harvested on June 2010 and yield was measured only for plants growing in the central rows while the outer rows were serving as borders.

Data recorded

Measurements of growth parameters

Random samples of five plants were taken from every experimental plot at the harvest time (about 120 days after planting date) in order to measuring reproductive parameters, including: (i) the number of tubers per plant;(ii) size of tubers per plant: assessed using a vernier calliper (± 0.01 mm) as the average widths of plant tubers; (iii) tuber yield per plant: measured using an electrical balance (± 0.1g) as the total weights of plant tubers; and (iv) total yield (mt/ha): estimated as the average production per plant multiplied by number of potato plants rounded to 1-ha.

Mineral analysis

The nutritional status of potato plants was assessed by analyzing mineral contents of both leaves and roots, including contents of N, K, Na and the ratio K/Na, which are linked to the yield of the plant. Sodium concentration was analyzed in order to test the ability of selectivity of the K^+ absorption.

Therefore, in each elementary plot, samples of leaves (4^{th} leaf from the point of growth) and roots were randomly collected from five plants for each treatment during early flowering state. These samples were dried at 60°C until constant weight (dry weight: DW) and ground with a porcelain grinder. Analysis of Na^+ and K^+ by Flame Photometer (Jenway PFP7) was carried out on ashes and digested leaves and roots in 2N HCl (Chapman and Pratt, 1982). Total nitrogen was determined by micro-Kjeldahl method (Brermer and Mulvaney, 1982).

Statistical analysis

All results were expressed as means and standard deviations (SD). The analysis of variance (Two-way ANOVA) was used to test the variation of field experimental data (for both yield parameters and mineral contents) according to variation sources of the split-plot design including mainly the effects of poultry manure rates (PM), soil salinity levels (SL) and their interaction (PM × SL). When the result of the ANOVA is significant (P <0.05), the least significant difference (LSD) test was applied to evaluate the significance of differences between means of treatments.

Results

Yield parameters

Effects of poultry manure rates

Based on the analysis of variance, the overall effects of PM were highly significant on yield parameters including number of tubers per plant, tuber size per plant, tuber yield per plant, and total tuber yield. Results, indicated that the application of PM in graded doses (20, 30, 40, 50 and 60 mt/ha) had significantly (P <0.01) increased all measured growth yield parameters as compared with the control. In addition, the application of 60 mt/ha of manure produced the highest averages in all yield parameters. Under this rate of fertilization potato produced 9.7 ± 1.8 tubers per plant, with a size of 6.5 ± 0.8 cm per tuber, and tuber yield estimated at 1.3 ± 0.2 kg per plant, and a total tuber yield of 32.8 ± 8.4 mt/ha (Table 2). In this case, application of 60 mt/ha of PM to soils had significantly increased the previous parameters compared to the control (0 mt/ha) by 49.53%, 39.35%, 96.92% and 66.1%, respectively.

Effects of salinity levels

Regarding to the effect of soil salinity levels on potato yield parameters, results revealed clearly that soil salinity significantly influenced (P <0.05) the number of produced tubers per plant, tuber size, tuber yield per plant and the total yield in all study sites. ANOVA showed a significant variation of study parameter values between the three soil salinity levels. The LSD demonstrated that the results of potato growth parameters noted in HSS ‘group A’ significantly differed of those of both LSS and SS ‘group B’. Besides, the highest values of all study yield parameters were recorded in HSS site with an average of 9.4 ± 1.5 tubers per plant, and average diameter of tuber of 6.1 ± 0.7 cm, with a mean tuber production per plant estimated to 1.0 ± 0.3 kg and a total tuber yield of 32.5 ± 8.8 mt/ha (Table 2). These parameters increased in HSS with 26.66%, 12.77%, 21% and 31.45% compared to LSS site; and with 31.64%, 15.1%, 23.8% and 46.52% compared to SS site, for the number of tubers, tuber size, tuber yield per plant and total yield, respectively. However, the lowest values of tuber numbers, seizes, and tuber yield per plant as well as the total tuber yield were reported in SS site. The production results obtained in LSS site had intermediate position between HSS and SS, but the LSD test showed no significant difference between LSS and SS.

Table 2. Effect of different rates of Poultry manure (PM) (0, 20, 30, 40, 50 and 60 mt/ha) on values (mean ± SD) of potato yield parameters including number of tubers per plant, tuber size per plant, tuber yield per plant, and total yield (mt/ha), under different salinity levels (SL) of soils.

PM rate (mt/ha)	Soil salinity levels (SL)			Mean
	LSS	SS	HSS	
Number of tubers per plant				
0 (control)	5.50 ± 0.50	5.89 ± 0.51	8.05 ± 0.58	6.48 ± 1.28^{d}
20	5.66 ± 0.34	6.17 ± 0.76	8.11 ± 0.39	6.65 ± 1.21^{d}
30	5.94 ± 0.42	6.61 ± 0.35	8.11 ± 0.51	6.89 ± 1.03^{c}
40	9.00 ± 0.50	7.78 ± 0.48	10.50 ± 0.50	9.09 ± 1.26^{ab}
50	8.33 ± 0.33	7.78 ± 0.48	10.65 ± 0.42	9.05 ± 1.56^{ab}
60	9.92 ± 0.95	8.44 ± 0.42	10.72 ± 0.81	9.69 ± 1.20^{a}
Mean	7.39 ± 1.86^{B}	7.11 ± 1.06^{B}	9.36 ± 1.46^{A}	7.98 ± 1.80
SL: $LSD_{(0.05)}$ = 2.32, PM: $LSD_{(0.01)}$ = 2.27, SL × PM: $LSD_{(0.05)}$ = 1.40				
Size of tuber per plant (cm)				
0 (control)	4.77 ± 0.20	4.31 ± 0.30	4.87 ± 0.38	4.65 ± 0.37^{e}
20	4.79 ± 0.40	4.64 ± 0.36	5.74 ± 0.27	5.06 ± 0.60^{d}
30	5.06 ± 0.24	5.14 ± 0.38	6.09 ± 0.27	5.43 ± 0.56^{c}
40	5.55 ± 0.33	5.49 ± 0.24	6.51 ± 0.29	5.85 ± 0.56^{b}
50	5.83 ± 0.26	6.02 ± 0.19	6.48 ± 0.22	6.11 ± 0.35^{ab}
60	6.41 ± 0.17	6.15 ± 0.15	6.89 ± 0.49	6.48 ± 0.42^{a}
Mean	5.40 ± 0.65^{B}	5.29 ± 0.73^{B}	6.09 ± 0.73^{A}	5.60 ± 0.78
SL: $LSD_{(0.05)}$ = 2.16, PM: $LSD_{(0.01)}$ = 2.20, SL × PM: $LSD_{(0.05)}$ = 1.82				
Tuber yield (kg/plant)				
0 (control)	0.64 ± 0.08	0.63 ± 0.09	0.68 ± 0.05	0.65 ± 0.07^{d}
20	0.73 ± 0.09	0.69 ± 0.06	0.80 ± 0.03	0.74 ± 0.07^{c}
30	0.70 ± 0.09	0.79 ± 0.08	0.87 ± 0.07	0.79 ± 0.10^{c}
40	0.90 ± 0.05	0.81 ± 0.07	0.99 ± 0.07	0.90 ± 0.09^{b}
50	0.98 ± 0.06	0.97 ± 0.03	1.38 ± 0.04	1.11 ± 0.21^{ab}
60	1.19 ± 0.04	1.14 ± 0.04	1.52 ± 0.03	1.28 ± 0.18^{a}
Mean	0.86 ± 0.20^{B}	0.84 ± 0.18^{B}	1.04 ± 0.32^{A}	0.91 ± 0.26
SL: $LSD_{(0.05)}$ = 0.92 , PM: $LSD_{(0.01)}$ = 0.82, SL × PM: $LSD_{(0.05)}$ = 0.12				
Total yield (mt/ha)				
0 (control)	19.43 ± 1.35	19.34 ± 1.33	20.50 ± 2.14	19.76 ± 1.53^{e}
20	21.05 ± 1.90	20.42 ± 1.87	24.56 ± 1.28	22.01 ± 2.43^{d}
30	24.66 ± 1.84	21.38 ± 1.50	29.72 ± 1.77	25.26 ± 3.93^{c}
40	25.86 ± 1.93	22.56 ± 1.90	34.87 ± 1.11	27.76 ± 5.71^{c}
50	27.26 ± 1.86	24.26 ± 1.90	41.63 ± 0.94	31.05 ± 8.16^{ab}
60	29.95 ± 1.03	24.96 ± 1.11	43.55 ± 1.05	32.82 ± 8.38^{a}
Mean	24.70 ± 3.94^{B}	22.16 ± 2.47^{B}	32.47 ± 8.75^{A}	26.44 ± 7.15
SL: $LSD_{(0.05)}$ = 5.49, PM: $LSD_{(0.01)}$ = 5.53, SL × PM: $LSD_{(0.05)}$ = 1.30				

(LSS: Low Saline Soil, SS: Saline Soil, HSS: High Saline Soil). Observed values of LSD test are given for the effect of SL (α = 0.05), PM (α = 0.01), and SL × PM (α = 0.05). Superscript small letters indicate differences between levels of PM, while capital letters between levels of SL. Values with the same letters are significantly not different.

Effect of the interaction 'Poultry manure rates × salinity levels' on yield parameters

The interaction between both surveyed factors 'PM × SL' had statistically a significant effect (*P* <0.01) on all studied potato production traits. In this respect, results showed that the highest yield parameters were obtained in plots treated by the combined effect of high rate of PM (i.e. 60 mt/ha) and high level of soil salinity (HSS). The corresponding data combined treatment were 10.7 ± 0.8 tuber per plant, with a tuber size of 6.9 ± 0.5 cm, and tuber production of 1.5 ± 0.1 kg per plant and a total tuber yield reached 43.5 ± 1.1 mt/ha (Table 2).

Nutritional status of potato plants

Effect of poultry manure rates

The variation of nutrient contents (N, K^+, Na^+, and K^+/Na^+ ratio) of potato plant leaves and roots according to the combined effects of PM rates and levels of soil salinity are represented in Figure 1. Results revealed that increasing the PM rates increased significantly (*P* <0.01) the contents of potato plants with N, K^+ as well as K/Na ratio, in both green leaves and roots. ANOVAs showed that PM rates have very high significant effect (*P* <0.0001) on the variation of values of all nutritional parameters (Figure 1).

In plant leaves, nutrient contents N and K^+ increased from 17.3 and 15.8 mg/g of dry weight **(**DW) to 58.9 and 55.5 mg/g DW as the PM level was raised from 0 to 60 mt/ha, respectively. Besides, the K^+/Na^+ ratio experienced an increase from 0.8 to reach up 2.6 according to PM augmentation (Figure 1A, 1B and 1D). In same order, these contents (N, K^+ and K^+/Na^+ ratio) increased in plant roots from 15.2, 14.4 mg/g DW and 0.6 to 54.4, 37.2 mg/g DW and 1.68, respectively as the PM level was raised from 0 to 60 mt/ha, respectively (Figure 1E, 1F and 1H).

Accordingly, the best foliar and root contents on N, K and K/Na ratio were recorded at PM rate of 60 mt/ha. Nevertheless, our results demonstrated that values of K^+/Na^+ ratio was obviously higher in potato leaves compared to roots.

Whereas a reverse trend was observed for Na^+ content. Results indicated that the average of Na^+ contents measured in both potato leaves and roots proportionally and significantly decreased with the increase of PM rates, while K^+ uptake increased (Figure 1B, 1C, 1F and 1G) This induced the increase of K^+/Na^+ ratio in plants treated with PM compared to control, in both plant leaves (Figure 1D), and roots (Figure 1H). However, the highest values of root Na^+ contents were recorded in controls with an average content of 25.83 mg/g DW for the thee study sites (LSS, SS, HSS); whilst the lowest values were recorded in plant roots treated with 60 mt/ha of PM with an average of 22.44 mg/g DW (Figure 1G).

Effect salinity levels

According to ANOVAs values of N, K^+, Na^+ contents and K^+/Na^+ ratio varied very highly significantly according to salinity levels (*P* <0.0001) (Figure 1). The highest averages of N and K^+ contents were obtained in potato plants of HSS site, for both leaves (average N content = 44.6, average K^+ content = 46.7 mg/g DW) and roots (N content = 43.8, K^+ content = 32.6 mg/g DW). Whereas, the lowest average contents of both nutriments were recorded in SS site with 41.1 and 35.0 mg/g DW in leaves, respectively; and with 41.1 and 23.6 mg/g DW in roots, respectively. The study site with LSS (EC = 0.9 dS/m) was classified on intermediate position between HSS and SS with 41.7 and 35.5 mg/g DW for N and K^+ contents in leaves, respectively; and with 41.4 and 24.9 mg/g DW for N and K^+ contents in roots, respectively (Figure 1A, 1B, 1E, 1F).

In the same trend, the highest average of K^+/Na^+ ratio was recorded in leaves of plants growing in HSS site with a value of 2.0, while the lowest ratio value was noted in SS site with an average K^+/Na^+ = 1.3. Overall, LSS site occupied an intermediate position between HSS and SS with K^+/Na^+ = 1.9. However, in plant roots, the highest average K^+/Na^+ ratio was recorded in LSS site with 1.32 (Figure 1D, 1H).

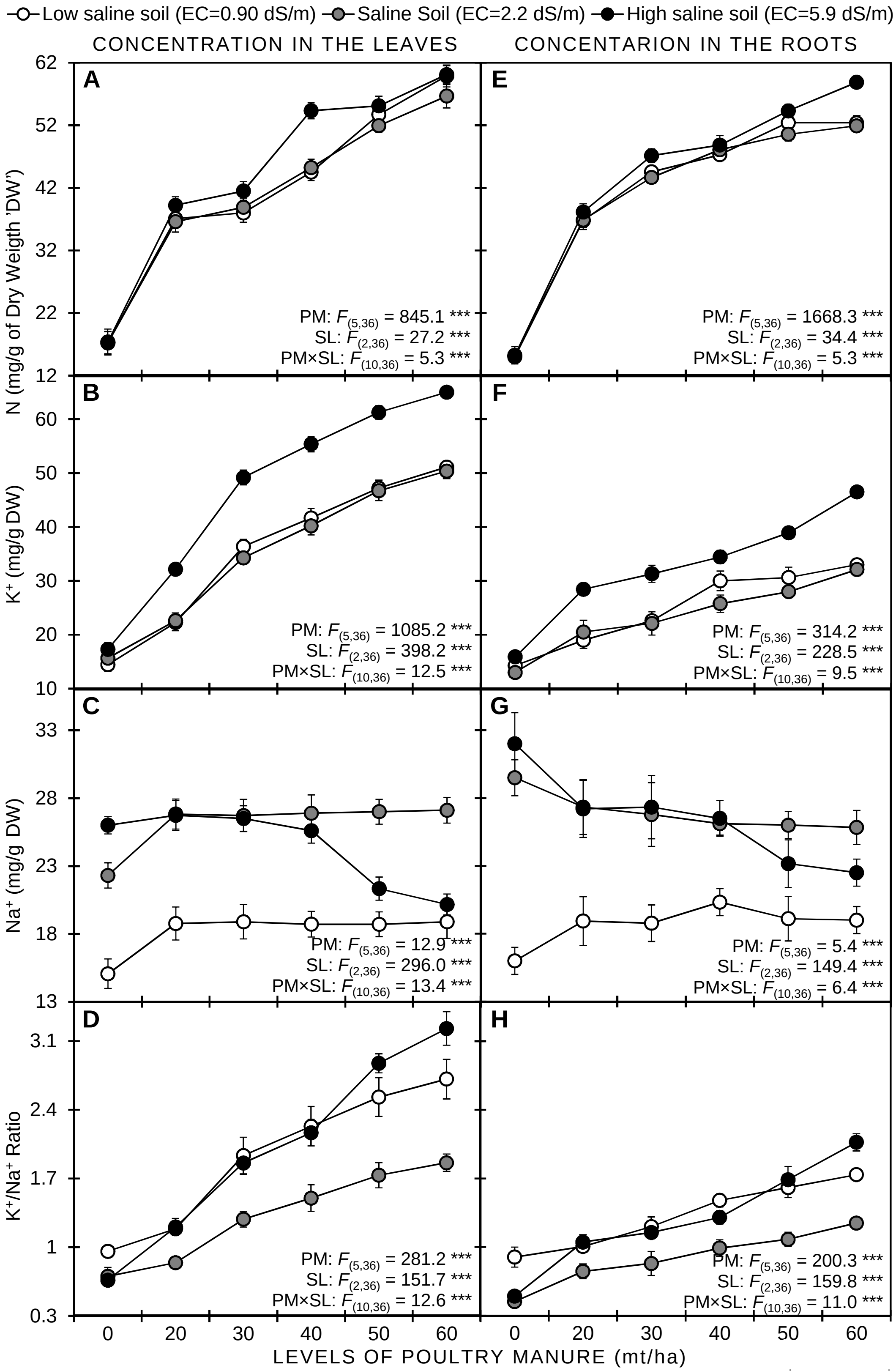

Figure 1. Effect of different levels of poultry manure (PM) on concentrations of Nitrogen (A, E), K^+ (B, F), Na^+ (C, D), and K^+/Na^+ ratio (D, G) in leaves and roots of potato plants grown under different soil salinity levels (SL). Test statistics (*F* (*df* numerator, *df* denominator) and *P*-values (***: $P < 0.0001$) are ANOVA Type II for the effects of PM, SL and PM × SL.

Effect of interaction (Poultry manure × Soil salinity levels) on uptake of some minerals

Regarding the variation of mineral nutritional parameters, the ANOVA revealed a highly significant effect (P <0.0001) by the interaction between salinity levels and PM rates. The highest values of N, K^+ contents and K^+/Na^+ ratio were recorded in plots where potato plants were treated with 60 mt/ha of PM in HSS site. The corresponding data for these parameters respectively were 60.1, 65.0 mg/g DW and 3.2 in leaves and 58.9, 46.5 and 2.1 mg/g DW in roots (Figure 1).

Moreover, the interaction between levels of soil salinity and PM reflected different trends in variation of leaves and roots Na^+ concentrations in all study sites. The results showed that Na^+ content experienced a steep decrease in HSS plots enriched with high rates of PM (50 and 60 mt/ha) compared to the other PM rates, in both leaves and roots. However, opposite effect was observed for SS site, where the Na^+ content of leaves did not decreased with the increasing application of PM rates; while in roots, Na^+ concentration followed the same trend as that observed in HSS. Concerning LSS site, records of Na^+ contents in both leaves and roots were slight compared to SS and HSS sites, and experienced very little change with the application of PM, whatever the amounts of the latter (Figure 1C, 1G).

Discussion

Tuber yield parameters

Under hyperarid conditions of the Sahara Desert, the introduction of poultry manures to the soil induced a high improvement of potato yield parameters compared to the control, regardless of soil salinity levels of the experimental sites. Our findings are in accordance with those reported by Lemaga and Caesar (1990) demonstrating that yield parameters of potato were significantly higher in plots having received PM, compared with other types of manures. These results can be explained by the favorable effect of PM on the whole of physical, chemical and biological properties of the soil (Jalali and Ranjbar, 2009; Demir et al., 2010).

The improvement of yield parameters of potato following fertilization with poultry manure under our experimental conditions could be attributed to the improvement of both soil moisture retention and potentials of nutrient supply (with macro and micronutrients) of the sandy soils that characterize the study sites. Therefore, the improvement of yield parameters may be explained by the rapid and continuous release of nitrogen, potassium and phosphorus from this manure, which satisfied nutritional needs of potato during all stages for its development cycle. Especially since these nutriments are present in the poultry manure under a readily available form for plant uptake (El-Tantawy et al., 2009; Delgado et al., 2012).

These findings are in close agreement with the finding stating that poultry manure is very rich animal manure that boosts soil productivity better than other organic manures and gives considerable increase in organic C, available P and exchangeable cations (Gupta et al., 1997; Jinadasa et al., 1997). In fact, it is important to note that the positive effects of organic manures on plant growth are not only due to temporal availability of essential minerals but also attributable to the improvement of soil physical, chemical and biological characteristics (Lakhdar et al., 2008).

The high effect of the rate 60 mt/ha of PM on potato yield parameters may be attributed to its high content of macro and micronutrients than the other used rates. Indeed, similar patterns of potato growth increase under arid conditions have been reported in response of using increasing rates of PM (Al-Moshileh and Motawei, 2007). These results are also consistent with those of Pannikov and Mineev (1977), which showed that increasing organic fertilizer amounts applied to potato crops leads to a significant increase of yield parameters until a threshold of 100 mt/ha.

Unlike several studies stating that water and/or soil salinity retards plant growth and significantly reduces potato tuber yield (Maas and Hoffman, 1977; Levy, 1992; Levy and Veilleux, 2007); in our investigation the best potato yield parameters were all recorded in HSS site despite its high salinity levels in soil and irrigation water. However these findings are in harmony with those of study investigated potato salinity tolerance (Hannachi et al., 2004), where it was exposed that potato plants adapted to high soil salinity and saline irrigation water (NaCl = 4 g/L) can have almost similar agronomic performance (number of tubers and yield per plant) or even above of those obtained from plants not subjected to salt stress and irrigated with unsalted water. Similar trend of potato production under desert conditions vs. salinity was reported in the study of Amnon et al. (2004), in which it was demonstrated that high potato yields can be produced even when soils and irrigation water contain high concentrations of salt.

According to Patel et al. (2001), under saline conditions, potato yields remained unaffected by soil salinities as high as 3.5–7.6 dS/m and/or by saline irrigation water with EC = 6.2 dS/m. In fact, irrigation with saline water can be problematic in heavy and poorly structured soils with low infiltration capacity; because it often leads to increased soil salinization (Shainberg and Singer, 1990). Actually, when the water table is high, saline irrigation water aggravates the pre-existing salinity problems.

Furthermore, our experiment was conducted under field conditions where the potato plant is simultaneously influenced by other salts besides NaCl. Under such conditions, the negative effect of Na^+ is offset by the antagonistic effect of K^+ and Ca^{2+} existing in soil and/or provided by the irrigation water (Tejada et al., 2006; Jalali and Ranjbar, 2009). This assumption is acceptable insofar as both soils of HSS site and water used for irrigation are rich in Ca^{2+} and K^+ ions. In other words, the plant can withstand the effect of several salts instead of a single salt. Therefore, antagonism between the combinations of different types of cations can exerts a protective effect for plants against salinity. Thus, the more the biofertilization brings nutrients, the more the plant will benefit, not only for its nutrition, but also for its ionic and osmotic homeostasis and fitness (Niu et al., 1995). This is even more pronounced with large amounts of manure amendment releasing more salts in terms of quality and quantity. In fact, plants seem tolerate the effect of several types of salts applied simultaneously than the effect of each salt considered separately (Lesaint and Coïc, 1983).

Obviously, our results revealed that application of organic manures decreased the adverse effects of salinity on the potato yield. Besides, the greater the amount of manure increases, the effect on potato yield is obvious. These results are in accordance with findings under saline conditions in sandy soils of the Sahara of Saudi Arabia, where it was revealed that high level of salinity significantly increased both vegetative growth and potato yield (Al-Moshileh and Motawei, 2007). Additionally, the observed increase in potato yield under our conditions was very consistent with the study of Hannachi et al. (2004), who reported that organic fertilization increased salt tolerance of potato crops under saline conditions.

According to Jalali and Ranjbar (2009), the application of OM in saline soils reduce the main parameters of salinity i.e. pH, SAR and ESP. In fact, organic manures result a greater adsorption of Ca^{2+}, Mg^{2+} and K^+ than Na^+ which leads to lower soil ESP (Murtaza et al., 2009). Moreover, Qadir et al. (2008) and Walker and Bernal (2008) reported that an acceleration of Na^+ leaching considerably decreases the ESP and EC.

Moreover, it is clear from out results that SS and LSS plots give low potato yields even treated with high amounts of PM, as it was reported in hot arid desert of the Middle East (Levy, 1992; Levy and Veilleux, 2007), but tuber yields increase in HSS along with the increase of PM rates.

These findings are similar to those reported by Skiredj (2007), who determined that under saline conditions, the application of organic fertilization led to increase potato yield parameters, and this increase was proportional to rates of biofertilizers. Still, in response to high doses of manure, potato yields are not reduced more than 50% of its value in non-saline conditions, but, unlike the theory of Ayers and Westcot (1976), it seems to be comparable with the yield obtained in non-saline conditions. Thus, potato plant can tolerate high levels of salinity of both soil and water, particularly when manures were applied with high quantity.

Nutritional traits of plants

Regarding the variations of mineral nutriments in plant tissues, using the poultry manure as a soil conditioner resulted in a significant increase in the plant uptake nutriment compared to the control. These results are supported by several studies reporting that PM markedly increases K^+ and N concentrations in leaves and roots of potato (Demir et al., 2010; Delgado et al., 2012).

Unlike to the studies of Maas and Hoffman (1977) and Alhagdow et al. (1999), who reported that soil salinity reduces potato foliar contents with N and K^+ and increased their contents in Na^+; the present survey reported that high concentration of N and K^+ contents and high K^+/Na^+ ratio of potato leaves were recorded in site of high level of soil salinity (HSS: EC = 5.9 dS/m). These results can be explained by the initial high calcium contents in both the soil and irrigation water. This cation is known to increase nitrogen and potassium absorption, in reverse compared to Na^+ (Fenn et al., 1991; Niu et al., 1995).

The selective uptake of K^+ against Na^+ is considered one of the important physiological mechanisms contributing to salt tolerance in many plant species (Yamaguchi and Blumwald, 2005). Indeed, Mengel and Kirkby (2001) reported that potassium is a major osmoticum that contributes to osmotic adjustment, stomatal movement and Na^+–restriction–uptake under saline conditions. Moreover, most glycophytes respond to salinity by ion exclusion (Slama, 1982). Actually, this exclusion occurs in leaves of most of these plant species, so they could accumulate high levels of Na in their roots and stems. In addition, the maintenance of a high tissue K^+/Na^+ ratio by plants under saline condition may serve as replicable mechanism of salt-tolerance (Chow et al., 1990; Ashraf and Ali, 2008).

Our findings highlight that soil salinity does not seem reduces foliar contents of potassium and nitrogen in the presence of high PM levels. Indeed, it is under high level of soil salinity the highest contents of these important nutrients have been recorded. According to Clark et al. (2007) and Walker and Bernal (2004, 2008), PM improves the mineral nutrient status of plants in saline soils through supply with abundant nutrients, particularly N and K^+. Moreover, out results evidence that potato plants accumulate more K^+ in their leaves than Na^+ in response to PM application and under our field conditions of soil salinity (up to EC = 5.9 dS/m). This is perhaps associated with an improvement in selective absorption of K^+ against Na^+ in response to PM fertilization, which supplies soil with a set of mineral nutriments in both quantity and quality.

This result is in close agreement with findings of Alburquerque et al. (2007) that pointed out the positive impact of PM fertilization on the improvement of K^+ absorption strategy in plants. In this context, PM application enriches further the rhizosphere with Ca^{2+}, which tends to replace exchangeable Na^+ on the adsorption sites, and thus decreases salinity (Garcia et al., 2000; Tejada et al., 2006).

Calcium intake through PM fertilization is essential for both K^+ vs. Na^+ ion selectivity and membrane integrity (Hanson, 1984). According Fenn et al. (1991), elevated concentrations of Ca^{2+} in the nutrient solution mitigate the adverse effects of salinity by inhibiting the uptake of Na^+. Moreover, Walker and Bernal (2008) reported that application of PM at a rate of 20–30 g/kg significantly increased the CEC by three to five units; however, as the exchange sites are mostly saturated with Ca^{2+}, Mg^{2+} and K^+, Na^+ ions are prevented from entering the exchange complex.

Furthermore, the content of PM on humic substances, which are generally associated with natural organic compounds, thereby induce an improvement of the chelation ability of K^+, Ca^{2+} in soil solution. Thus, these substances effectively replace Na^+ from the cation exchange complex particularly at alkaline pH value, and reduce the SAR of soil solution of saline soils (Gaffar et al., 1992). Likewise, under saline conditions, humic substances may induce anti-stress influences on plants by augmenting the uptake of nutriments and diminishing the assimilation of some toxic elements (Masciandaro et al., 2001).

The high performance of potato plants subjected to the combination of high rate of PM (60 mt/ha) and high level of soil salinity is due to the significant reduction of Na^+ content in leaves and roots; this treatment generated more antagonistic effects against the harmful effects of Na^+ ions. These results can be explicated by the fact that the use of organic fertilizers releases a huge amount of Ca^{2+} and K^+, which tend to replace exchangeable Na^+ (Garcia et al., 2000). The analysis of irrigation water (Table 1B) also revealed its richness with these cations (Ca^{2+}, Mg^{2+}, K^+), which play the equivalent role as those supplied from PM. Indeed, the irrigation of saline soils with waters rich in divalent cations represents a relevant strategy for the remediation of saline soils (Jalali and Ranjbar, 2009).

The combined and additional effect of Ca^{2+} and K^+ provided from PM beside the initial richness of both irrigation water (Ca^{2+}, K^+) and soil in HSS site (Ca^{2+}) has probably increased the concentrations of K^+ and Ca^{2+}, which therefore had improved absorption of these cations compared to decreased Na^+ uptake. The predominance of these cations causes the decrease in osmotic pressure and associated sodium toxicity. This ascertainment confirms one of the main rules of mineral nutrition in plants about the effect of ionic related to the strategy of nutrient uptake by the plant. According to Tunstall (2005), the relative concentrations of cations in the soil solution determine their degree of absorption. In fact, increasing the concentration of these two cations has probably changed dynamics of ion balance, and has influenced potato plants to limit the Na^+ absorption. The ionic antagonism established under our experimental conditions helped to improve the ionic absorption strategy in favor of these useful cations for plant (Ca^{2+}, K^+) at the expense of toxic cations especially Na^+, which is normally found in excess in salt-laden soil solution.

Conclusion

The interaction between soil salinity and increasing poultry manure (PM) fertilization significantly affected tuber yield parameters and chemical contents of potato plants. Out findings suggest that supplementing of organic fertilizers can effectively be used as a restoration strategy to alleviate adverse effects of salinity and to support plant growth of crops under saline conditions of sandy soils. In addition, our results allow assuming that biofertilization using PM efficiently overcomes the inhibitory effect of salinity and thus improves growth, yield and nutritional status of potato plants. Under crop conditions similar to ours, i.e. when both soil and irrigation water contains high salinity levels including in the hot arid climate, potato plants yield further if PM were applied with of 60 mt/ha. This PM rate can be considered as an optimal dose under saline conditions of arid soils, which represents an exclusive fertilizer formula free of mineral composts. Therefore, PM fertilization with that dose seems to be one of the appropriate agronomic solutions, not only to mitigate the physiological effects related to osmotic disturbances of salt stress, but also to exploit the brackish waters of these areas. However, since PM compounds are rapidly mineralizable into the soil, the released mineral elements can be leached and cause groundwater pollution. This is often observed in overdose biofertilization or when PM is applied out of growth period; in both cases, the plants cannot use all the available nutrients and the surplus will be a serious concern. Hence, optimizing the management of PM use as organic fertilizer is important to increase potato production and decrease nutrient losses below the root zone, particularly in sandy soil of deserts. Finally, to exploit these results and to maximize the profitability of PM fertilization in potato crop, the determination of an economically optimal-dose of the manure is imperative in each region.

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Author contribution

M. O. and M. T. H. conceived and designed research. M. O. performed the field experiments and lab work. H. C. and M. O. analysed data and prepared the figures and tables. M. O. and H. C. wrote the manuscript and reviewed drafts of the paper. All authors read and approved the manuscript.

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