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Foliar Calcium and Magnesium Application Effect on Potato Crop Grown in Clay Loam Soils

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ABSTRACT

Calcium (Ca) and magnesium (Mg) are of the secondary nutrients that required by plants for healthy growth. So, two field experiments were conducted at Kafr Bosat Village, Talkha District, Dakahlia Governorate, Egypt (Latitude 30° 43' 22.01" N, Longitude 30° 16' 44.50" E) during the winter growing seasons of 2014/2015 and 2015/2016 to investigate the effect of foliar Ca and Mg application and their interactions on the growth, yield, quality, nutrient concentration and uptake of potato crop (*Solanum tuberosum, L.* - c.v. salany) that grown in clay loam soil. The experiment was designed as a spilt plot design with three replicates; the main plots were assigned for three levels of foliar application of Mg; Mg_0, Mg_1 and Mg_2 (control, 0.2 and 0.4 % Mg as magnesium sulfate), and the sub plots were devoted to three levels of foliar Ca; Ca_0, Ca_1 and Ca_2 (control, 0.6 and 0.8 % Ca as calcium nitrate). Results showed the importance of Ca and Mg supplies, where they illustrated that foliar application of Ca and Mg levels significantly increased plant growth parameters at 90 days as plant fresh weight, leaf area and chlorophyll a, b and total concentrations; tubers yield and its quality as % of dry matter, starch and protein contents, and uptake of N, P, K, Ca and Mg (kg fed^{-1}) in shoots and tubers at harvest. Plant tuber yield and average tuber weight increased with increasing foliar application of Ca, whereas number of tubers $plant^{-1}$ was decreased. Also, results at 90 days, demonstrated that foliar application of Ca and Mg levels significantly increased N, Ca and Mg concentrations in leaves, but K concentration was decreased. At harvest, tubers content of N, P, K, Ca and Mg increased significantly with foliar application of Ca up to Ca_2 (0.8 % Ca) and spraying with Mg up to level Mg_1 (0.2 % Mg). Interaction between foliar application of Ca and Mg levels had a significant effects on plant growth parameters, tubers yield and its quality and nutrients uptake in dry shoots and tubers yield. The highest values of tubers yield (17.251 ton fed^{-1}), dry matter % of tuber (24.78 %), starch % (18.24 %) and contents of N, P, K, Ca and Mg in shoots and tubers were recorded by the interaction of $Ca_2 \times Mg_1$. It could be concluded that foliar applications of Ca and Mg at 0.8 % Ca as calcium nitrate and 0.2 % Mg as magnesium sulphate were more important to improve plants growth and increase tubers yield and their quality under this conditions.

Keywords: calcium, magnesium, clay loam soil, potato growth and yield nutrient uptake.

INTRODUCTION

Potato (Solanum tuberosum L.) is one of the most important vegetable crops in Egypt. It requires high amounts of nitrogen, phosphorus and potassium fertilizers for optimum growth, production and tuber quality, which requires high needs of other essential nutrients (secondary and micronutrients) for balance. The secondary nutrients such as calcium and magnesium are essential for healthy plant growth, but are needed in lesser amounts than the primary nutrients.

Calcium (Ca) is one of the three secondary nutrients, along with magnesium (Mg) and sulfur (S), it is required by plants for healthy growth. Calcium has many roles in plant: participates in metabolic processes of other nutrients uptake; promotes proper plant cell elongation; strengthen cell wall structure- calcium is an essential part of plant cell wall; it forms calcium bectate compounds which give stability to cell walls and bind cells together; participates in enzymatic and hormonal processes; helps in protecting the plant against heat stress- calcium improves stomata function and participates in induction of heat shock proteins; helps in protecting the plant against diseases; affects fruit quality; has a role in the regulation of the stomata (Marschner, 1995 and Mengel and Kirkby, 2001). Arvin *et al.,* (2005) revealed that increasing calcium in plant enhances plant tissue resistance to bacterial phytopathogens, and also enhances the structural of cell walls and membranes.

Calcium is one of the most important elements in soil and it is also a very important factor of plant growth and production such as potato (Kleinhenz and Palta, 2002). In this respect, Ozgen *et al.,* (2003) showed that Ca content in the soil can influence both potato tubers number and tuber size by increasing soil Ca, one may increase average tuber size and decrease tubers number. Hirschi, (2004) reported that Ca is transported to the tuber along with water via the roots on stolons and tubers, and added that Ca application can increase tuber Ca concentration and reduce storage rot and internal defects such as hollow heart, brown center, and internal brown spot. Ozgen *et al.,* (2006) found that the application of soluble sources of Ca (calcium nitrate and calcium chloride) without gypsum increased tuber Ca concentration and decreased the incidence of internal brown spot. Modisane (2007) revealed that increasing levels of calcium from 44 (control) to 176, 352 and 704 mg L^{-1} of calcium sulphate had a significant impact on the potato crop growth and quality. Gunter and Palta, (2008) indicated that overall for potato production, Ca applications are recommended only if pre-plant soil exchangeable Ca is below 300 mg kg^{-1}, and the increase in tuber Ca concentration occurred even when exchangeable Ca tested at over 1000 mg kg^{-1}. Moreover, Palta (2010) demonstrated that fertilization with calcium increases tuber calcium and lowers incidence of physiological disorders such as internal brown spot, hollow heart and bruising, as well as tuber calcium is important for the health of the sprout and of the tuber skin. Under conditions of isohumic soils, Hamdi, *et al.,* (2015) showed that applying additional of calcium nitrate levels (0, 20, 40, 60, 80, 100 and 120 kg ha^{-1}) had affected potato plant growth parameters such as tuber weight and dry matter, as well as increased tuber size significantly and Ca level in leaf and tuber, but reduced the number of tubers $plant^{-1}$. Whereas, under Nile Delta region-Egypt, Helal and AbdElhady, (2015) illustrated that the Ca-levels (10 and 20 kg Ca fed^{-1}) significantly improved plant growth and chemical content of potato in both seasons, and also concluded that calcium fertilization may enhance potato tuber yield and quality.

Magnesium is a component of the chlorophyll molecule. It serves as a cofactor in most enzymes that activate phosphorylation processes as a bridge between pyrophosphate structures of ATP or ADP and the enzyme molecule. Also, magnesium stabilizes the ribosome particles in the configuration for protein synthesis (Mengel and Kirkby, 2001). It is known that the 1.93% of the earth's crust is composed of magnesium, while in spite of the high amount of magnesium in the earth's crust, today there is often a lack of magnesium in several agriculture fields. Hongwei *et al.,* (2000) revealed that Mg deficiency reduced the effectiveness of other applied plant nutrients. Thus, the positive effects on yield and farmer income from balanced NPK fertilizer use cannot be brought into full play. Guneş *et al.,* (2002) stated that Mg deficiencies reason was the lowest amount of Mg found in soil, but the amount of other cations such as H^+, K^+, NH_4^+, Ca^{++} and Mn^{++} were also the reason of Mg deficiencies. Kacar and Katkat, (2007) reported that chemical fertilizers which are produced with developing technology do not include Mg, with more products are harvested with recently developed varieties of plants and more nutritional elements are extracted from the soil increase the Mg requirements. In addition, Excess nitrogen and potassium fertilizers is applied to soil solution comprising a high concentration with K^+ and NH_4^+ ions with Mg^{++} ions by competing plants that inhibit the uptake of Mg^{++}.

Talukder *et al.,* (2009) studied the effect of five levels of Mg viz., 0, 5, 10, 15, and 20 kg ha^{-1} on growth and yield of potato and also to find out the optimum and economic dose of Mg for potato under Tista Meander Floodplain Highland soils. They revealed that Mg had significant effects on tuber yield of potato, and higher tuber yield was obtained from 10 kg Mg ha^{-1}. Moreover, after optimum level of Mg (13 kg ha^{-1}) tuber yield reduced by 3.83 kg for additional use of one kg Mg ha^{-1}. Orlovius and McHoul, (2015) studied the impacts of magnesium fertilizers at rate of 60 kg Mg ha^{-1} (25 kg Mg fed^{-1}) on yield, quality and leaf concentrations of magnesium in potatoes and sugar beet. They found that there were clear increases in leaf Mg concentration and yield resulting from application of Mg fertilizers. Use of Mg fertilizers with higher solubility helps to avoid the risk of Mg deficiency and subsequent losses in yield and economic returns.

Therefore, this investigation aims to study the effect of foliar calcium, magnesium application and their interactions on growth, yield and its quality as well as nutrients concentrations and uptakes of potato crop that grown in clay loam soil under the environmental conditions of Dakahlia Governorate, Egypt.

MATERIALS AND METHODS

Two field experiments were conducted during the winter growing seasons of 2014/2015 and 2015/2016 at Kafr Bosat Village, Talkha district, Dakahlia Governorate, Egypt (Latitude 30° 43' 22.01" N, Longitude 30° 16' 44.50" E) to investigate the effect of foliar application of calcium and magnesium and their interactions on the growth, yield and its quality, nutrients concentrations and uptakes of potato crop (Solanum tuberosum, L.) grown in clay loam soil.

Soil samples were taken from the surface layer (0–30 cm) before soil preparation; some physical and chemical properties of soil were analyzed according to Jackson, (1967) and Hesse, (1971) as shown in Table (1). Available calcium and magnesium were extracted by ammonium acetate solution (1 N at pH 7) and determined using atomic absorption-Sens AA (model 2016) at Fertilizers Development Center- Delta Company for Fertilizers-Dakahlia Governorate-Egypt.

Table 1. Some physical and chemical properties of the field experimental soil before planting potato.

Properties		Values	Properties		Values
	Sand %	38.40	**EC (dSm^{-1})		3.21
particles	Silt %	28.33		Ca^{++}	12.4
size distribution	Clay %	33.27	Soluble Cations	Mg^{++}	11.3
	Texture	Clay Loam	(meq L^{-1})	Na^+	6.4
SP %		65.1		K^+	1.0
O.M %		2.3		CO_3^{--}	--
$CaCO_3$ %		2.9	Soluble anions	HCO_3^-	6.9
*pH		7.61	(meq L^{-1})	Cl^-	12.0
Bulk density (Mg cm^{-3})		1.25		SO_4^{--}	12.2
Available N, P, K Ca, Mg and B (mg kg^{-1})					
N		46	Ca		540
P		16	Mg		250
K		340	B		0.6

***pH: in 1:2.5 soil : water suspension, ** EC: in soil water extract 1:5.**

The experiment was designed as a split plot with three replicates. The main plots were assigned for three levels of foliar Mg application (Mg_0: control, Mg_1: 0.2 % Mg and Mg_2: 0.4 % Mg as magnesium sulfate contains 10 % Mg), and the sub plots were devoted to three levels of foliar Ca application (Ca_0: control, Ca_1: 0.6 % Ca and Ca_2: 0.8 % Ca as calcium nitrate contains 17 % Ca).

Potatoes (c.v. salany) were planted in 25 October, 2014 and harvested in 5 March, 2015 in 1st season, and planted in 20 October, 2015 and harvested in 1 March, 2016 in 2nd season.

Application of fertilizers: Nitrogen fertilizer was applied at rate of 150 kg N fed^{-1} (as ammonium nitrate, 33.5 % N) at three doses (20 % with planting and 80 % at two equal doses before the first and second irrigations). Phosphate fertilizer was applied at rate of 75 kg P_2O_5 fed^{-1} as single calcium superphosphate (15.5 % P_2O_5) at one dose with soil preparation. Potassium fertilizer was applied at rate of 48 kg K_2O fed^{-1} as potassium sulphate (48 % K_2O) at two doses with planting and before second irrigation. The other cultural practices were carried out according to the potato extension guide - Ministry of Agriculture, Egypt. Concerning the irrigation, potato plants were irrigated 6 irrigations after planting as surface irrigation in furrow.

Application of treatments: Ca-levels were sprayed at twice, one after complete emergence and other one after 10 days (at rate of 200 L fed^{-1}). Also, Mg-levels were applied as foliar twice after the last spray time of Ca by 10 days and after 15 days later (at rate of 200 L fed^{-1}).

Plant Measurements: after 90 days from planting date, five plants from each plot were taken randomly to measure and determined the following parameters of plant growth: plant height, number of leaves, plant fresh weight, plant dry weight, leaf area and chlorophyll A, B and total. Leaf area (m^2 $plant^{-1}$) was calculated using the following equation according to Koller, (1972):

$$\text{Leaf area} = \frac{\text{Dry weight of leaves x disk area x No .of disks}}{\text{Dry weight of disks}}$$

- Total chlorophyll was determined according to the method that described by Holder (1965), where 0.2 g of fresh leaf samples were ground and extracted with 5 ml acetone (80%) in the dark, and the absorbance was measured on spectrophotometer at wave length 663 and 645 nm (Ouzounidou and Strasser, 1977).

1. Chlorophyll a (mg kg^{-1}) = {(16.5×reading at 663) - (8.3×reading at 645)}
2. Chlorophyll b (mg kg^{-1}) = {(33.8×reading at 645) - (12.5× reading at 663)}
3. Total chlorophyll (mg kg^{-1}) ={Chlorophylla+Chlorophyll b}

At harvest: after 130 days from planting date, the following parameters were recorded: tuber weight (g $plant^{-1}$), number of tubers $plant^{-1}$, fresh tuber yield (t. fed^{-1}), and tubers quality parameters (dry matter %, specific gravity, starch % and protein %) as follows: Specific gravity was determined according to the method of Smith, (1975).

- Specific gravity (S. G) = weight in air/ (weight in air-weight in water).
- Starch % was calculated according to the formula of Burton, (1948) as follows: Starch % = 17.547+ {0.89 x (dry matter -24)}
- Protein%was calculated according to Ranganna,(1977) using conversion factor as follows:{Protein%=Nitrogen%x 6.25}.

Analysis of plant: Samples of leaves and tubers that taken at 90 days and at harvest were oven dried at 70^0C till constant weight, then ground to a fine powder and sub samples of 0.5 g were digested using a mixture of sulfuric and perchloric acids (Piper, 1950) to determine the concentrations of nitrogen, phosphorus, potassium, calcium and magnesium according to A.O.A.C. (1990). Nitrogen was determined by Kjeldahl method, phosphorus using spectrophotometrically method and potassium by flame photometer. Calcium and magnesium were determined using atomic absorption-Sens AA (model 2016) at Fertilizers Development Center-Delta Company for Fertilizers-Dakahlia Governorate , Egypt.

The statistical analysis of the obtained data was done according to the methods described by Gomez and Gomez, (1984) using LSD at 5 %.

RESULTS AND DISCUSSION

The following results that shown in Tables 2, 3, 4 and 5 demonstrate the effects of nutrition with Ca and Mg as a foliar application on the growth, yield, quality and nutrients concentrations and uptakes of potato crop grown in clay loam soil.

1-Plant growth:

Data in Table 2 show the effect of foliar application of Ca and Mg levels and their interactions on potato growth parameters after 90 days from planting. It is clear from results that foliar application of Ca-levels increased significantly vegetative growth parameters as number of leaves $plant^{-1}$, plant fresh and dry weight, leaf area and chlorophyll content (a, b and total) up to level Ca_2. While foliar Ca-levels had insignificant effect on plant height. So, these results appear the importance of Ca supplies for improving potato growth under these conditions, which may be attributed to calcium role in plant such as; promotes proper plant cell elongation; strengthen cell wall structure; it forms calcium bectate compounds which give stability to cell walls and bind cells together; participates in enzymatic and hormonal processes (Marschner, 1995 and Mengel and Kirkby, 2001). Also in this respect, Helal and AbdElhady, (2015) found that Ca levels; 10 and 20 kg Ca fed^{-1} were more significant for improving potato plant growth under Nile Delta region.

Also, data in the same previous Table illustrate that foliar application of Mg levels had significant effects on plant fresh weight, number of leaves $plant^{-1}$ and chlorophyll a, b and total contents, but had insignificant effect on plant height, leaf area and plant dry weight after 90 days from planting. It is obvious that foliar feeding by Mg levels significantly increased the contents of chlorophyll a, b and total up to level Mg_2, and this response is related to the role of Mg in structure chlorophyll molecule, as well as its role as a cofactor in most enzymes that activate phosphorylation (Mengel and Kirkby, 2001), which reflected on leaf area per plant and consequently on plant weight.

As for the effect of interaction on plant growth after 90 days, data also in Table 2 show that interaction among Ca and Mg levels had significant effects on plant height, leaves number $plant^{-1}$, plant dry weight and chlorophyll a concentration, but had insignificant effects on plant fresh weight, leaf area and chlorophyll b and total concentrations. The highest values of leaves number $plant^{-1}$ (23.8) and chlorophyll a concentration (31.33 mg kg^{-1}) were recorded at the interactions of $Mg_2×Ca_1$, whereas the highest values of plant height (58.3 cm), plant fresh weight (211 g) and plant dry weight (26.64 g) were recorded at the interaction of $Mg_1×Ca_2$. These results illustrate that plant growth increased with interaction between Ca and Mg, and this reflects the importance of Ca and Mg supplies. In this respect, Nookaraju *et al.,* (2012) showed that calcium is a major essential nutrient required for normal growth and development of plants as well as potato tuberization.

Table 2. influence of foliar calcium and magnesium application and their interactions on potato growth parameters after 90 days form planting (averages of the two growing seasons).

Treatments		Plant height (cm)	Leaves number $plant^{-1}$	Plant fresh weight (g)	Plant dry weight (g)	Leaf area (m^2 $plant^{-1}$)	Chlorophyll a (mg kg^{-1})	Chlorophyll b (mg kg^{-1})	Total chlorophyll (mg kg^{-1})
	Ca_0	55.7	18.5	185	21.11	0.280	26.79	22.73	49.52
Mg_0	Ca_1	57.7	20.3	201	23.88	0.293	29.62	24.93	54.55
	Ca_2	55.5	21.7	209	25.23	0.293	30.32	25.43	55.75
Mean		56.3	20.2	198	23.40	0.289	28.91	24.36	53.27
	Ca_0	54.2	19.5	184	21.89	0.284	28.99	24.74	53.73
Mg_1	Ca_1	56.0	22.3	204	23.69	0.299	30.43	26.95	57.38
	Ca_2	58.3	23.0	211	26.64	0.300	30.68	27.34	58.02
Mean		56.2	21.6	200	24.07	0.294	30.03	26.34	56.37
	Ca_0	56.0	20.0	176	23.06	0.283	28.49	24.94	53.43
Mg_2	Ca_1	57.3	23.8	178	25.83	0.294	31.33	26.96	58.29
	Ca_2	54.5	23.0	194	24.47	0.295	31.28	28.03	59.31
Mean		55.6	21.9	190	24.46	0.288	30.37	26.65	57.02
Means of Ca:									
Ca_0		55.3	19.3	182	22.02	0.282	28.09	24.14	52.23
Ca_1		57.0	22.2	194	24.46	0.295	30.46	26.28	56.75
Ca_2		56.1	22.6	205	25.45	0.296	30.76	26.93	57.70
L.S.D. at 5 % for:									
Mg		Ns	0.92	8.1	NS	Ns	0.66	0.56	0.88
Ca		NS	0.57	5.4	0.47	0.006	0.46	0.71	0.87
Ca*Mg		2.74	0.99	NS	0.82	NS	0.80	NS	NS

2- N, P, K, Ca and Mg concentrations at 90 days:

Data shown in Table 3 show the impact of foliar Ca, Mg application and their interactions on N, P, K, Ca and Mg concentrations as % in leaves and tubers after 90 days from planting. It is obvious from results that foliar application of Ca levels significantly increased the concentrations of N, Ca and Mg in leaves and tubers, while it had insignificant effect on the concentrations of P and K in leaves. The concentration of K in leaves decreased with foliar Ca-levels, whereas P concentration slightly increased. In contrast, P and K concentrations in tubers increased significantly with foliar Ca applied up to Ca_1. It is clear from mentioned results that foliar Ca have a positive effects on the most of nutrients concentrations in leaves and tuber at 90 days except K, and this may be attributed to the antagonistic effect of Ca on K absorption by roots at higher levels. These results are in agreement with those obtained by Ozgen, et al. (2006), Hamdi, et al. (2015) and Helal and AbdElhady (2015).

Regarding the effect of foliar Mg application, data in Table 3 show that foliar application of Mg levels had significant effects on the concentrations of N, P, Ca and Mg in leaves and tubers at 90 days, but had an insignificant effect on the concentration of K in leaves. N and Ca concentrations in leaves increased significantly with foliar spraying by Mg up to level Mg_1, whereas the increase in Mg concentration was significantly up to level Mg_2. Moreover, N, P, Ca and Mg concentrations as % in tuber increased significantly with foliar Mg application up to level Mg_2 for N and P concentrations and up to level Mg_1 for Ca and Mg concentrations. In contrast, K concentration in tubers slightly decreased with foliar Mg at 90 days. It can be concluded from previous results, that there is a positive correlation (as synergetic effect) between foliar application of Mg and N, P and Ca concentrations in plant, while there is a negative correlation (as antagonism relationship) between foliar applied of Mg and K concentrations in plant which may be returned to the competition between K and Mg. In this respect, Gunes *et al.,* (2002) and Kacar and Katkat, (2007) showed that excess the applied amounts of K, NH_4, Ca and Mn in soil solution inhibit the uptake of Mg.

Also, data shown in Table 3 clear that interactions among Ca and Mg levels had significant effects on P, K, Ca and Mg concentrations as % in leaves and on Ca concentration in tuber. While, the interaction between Ca and Mg levels had insignificant effect on N % in leaves and on N, P, K and Mg % in tubers after 90 days from planting. In general, N, Ca and Mg concentrations in leaves and tubers increased with interactions among Ca and Mg levels.

3- Potato Yield and Its Components:

Data in Table 4 illustrate that foliar fertilization with calcium nitrate as a source of Ca at 0.6 and 0.8 % Ca (Ca_1 and Ca_2) increased plant tuber yield, total tubers yield (t. fed^{-1}), average weight of tuber (g) and dry shoots weight (kg fed^{-1}) significantly up to level Ca_2. In contrast, tubers number $plant^{-1}$ insignificantly decreased with spraying Ca. Results clear generally, the importance of foliar spraying Ca for improving total fresh tubers yield that increased by 7.9% and 8.9% with spraying Ca-levels Ca_1 and Ca_2, respectively, without significant differences between them (Ca_1 and Ca_2). In this respect, Ozgen *et al.,* (2003) found that tubers number was decreased with increasing soil Ca, and suggested that soil Ca influences tuberization by altering the hormonal balance at the stolon tip. Also, these results are in accordance with Hamdi *et al.,* (2015) who found that applying additional calcium nitrate levels (0, 20, 40, 60, 80, 100 and 120 kg ha^{-1}) increased tuber weight, dry matter, tuber size, but reduced the number of tubers $plant^{-1}$.

Table 3. influence of foliar calcium and magnesium application and their interactions on N, P, K, Ca and Mg concentrations as % in leaves and tubers after 90 days form planting (averages of the two growing seasons).

Treatments		Leaves (%)					Tubers (%)				
		N	P	K	Ca	Mg	N	P	K	Ca	Mg
	Ca_0	3.23	0.227	3.88	1.48	0.87	1.68	0.185	2.62	0.090	0.038
Mg_0	Ca_1	3.36	0.242	3.99	1.52	1.02	1.73	0.197	2.68	0.106	0.032
	Ca_2	3.57	0.207	3.77	1.79	1.06	1.75	0.187	2.66	0.113	0.029
Mean		3.39	0.225	3.88	1.59	0.98	1.72	0.189	2.65	0.003	0.033
	Ca_0	3.30	0.173	3.91	1.79	0.96	1.73	0.187	2.55	0.107	0.040
Mg_1	Ca_1	3.55	0.175	3.66	2.04	1.05	1.75	0.195	2.62	0.116	0.039
	Ca_2	3.57	0.183	4.01	2.05	1.08	1.82	0.192	2.67	0.122	0.036
Mean		3.47	0.177	3.86	1.96	1.03	1.77	0.191	2.61	0.115	0.038
	Ca_0	3.46	0.207	3.94	1.84	1.10	1.80	0.197	2.58	0.115	0.044
Mg_2	Ca_1	3.51	0.202	3.75	1.95	1.13	1.83	0.203	2.57	0.105	0.035
	Ca_2	3.72	0.235	3.63	2.04	1.23	1.87	0.207	2.63	0.106	0.037
Mean		3.56	0.214	3.77	1.94	1.15	1.83	0.202	2.59	0.108	0.038
Means of Ca:											
Ca_0		3.33	0.202	3.91	1.70	0.97	1.74	0.189	2.59	0.104	0.041
Ca_1		3.47	0.206	3.80	1.84	1.07	1.77	0.198	2.62	0.109	0.035
Ca_2		3.62	0.208	3.80	1.96	1.12	1.81	0.195	2.66	0.114	0.034
L.S.D. at 5 % for:											
Mg		0.10	0.010	NS	0.06	0.014	0.04	0.018	0.04	0.006	0.004
Ca		0.09	NS	NS	0.04	0.028	0.03	0.008	0.05	0.005	0.003
Ca*Mg		NS	0.013	0.26	0.07	0.048	NS	NS	NS	0.007	NS

Data shown in Table 4 demonstrate that foliar application of Mg levels increased plant tuber yield (g), total tuber yield (t. fed^{-1}) and dry shoots weight(kg fed^{-1}) significantly up to level Mg_1 (0.2 % Mg), but it had insignificant effect on tubers number per plant and average weight of tuber. Fresh tuber yield (t. fed^{-1}) was increased by 10.9 % with foliar application of 0.2 % Mg as well as dry shoots weight which increased by 7.54 % compared with control (Mg_0). These results correlated with the increases in vegetative growth parameters which may be attributed to the importantance roles of Mg in plant. Foliar application of Mg promotes plant growth as chlorophyll concentration, leaf area, number of leaves $plant^{-1}$ which consequently reflected on whole plant and on its productivity as a tuber yield. In this respect, Talukder *et al.,* (2009) found that magnesium had significant effects on tuber yield of potato, and higher tuber yield was obtained from 10 kg Mg ha^{-1} (soil application).

Table 4. influence of foliar calcium and magnesium application and their interactions on potato yield and its components and quality of tubers at harvest (averages of the two growing seasons).

Treatments		Potato Yield and Its Components					Tuber Quality Parameters			
		Plant tubers yield (g)	Number of tubers $plant^{-1}$	Average weight of tuber (g)	Fresh Tuber yield (t. fed^{-1})	Dry shoots weight (kg fed^{-1})	Dry matter %	Specific gravity	Starch %	Protein %
	Ca_0	676	3.0	237	14.395	788	22.39	1.097	16.11	6.10
Mg_0	Ca_1	725	2.5	301	15.099	851	22.44	1.098	16.16	6.44
	Ca_2	768	2.7	301	15.411	909	22.53	1.125	16.24	6.49
Mean		723	2.7	280	14.969	849	22.45	1.107	16.17	6.34
	Ca_0	686	3.0	238	15.351	860	23.02	1.110	16.68	6.37
Mg_1	Ca_1	793	3.3	242	17.203	931	24.19	1.116	17.72	6.45
	Ca_2	809	3.2	258	17.251	949	24.78	1.108	18.24	6.51
Mean		763	3.2	246	16.602	913	24.00	1.111	17.54	6.44
	Ca_0	740	3.2	237	15.325	885	23.44	1.117	17.05	6.43
Mg_2	Ca_1	783	2.5	325	16.333	860	24.62	1.110	18.10	6.55
	Ca_2	825	2.7	321	16.426	869	24.65	1.114	18.12	6.71
Mean		766	2.8	283	16.028	862	24.11	1.11	17.64	6.56
Means of Ca										
Ca_0		701	3.1	237	15.024	844	22.95	1.108	16.61	6.30
Ca_1		767	2.8	289	16.211	880	23.75	1.108	17.33	6.48
Ca_2		801	2.8	293	16.363	909	23.98	1.116	17.53	6.57
L.S.D. at 5 % for:										
Mg		32.5	Ns	Ns	0.39	29.7	0.45	NS	0.40	0.14
Ca		29.0	Ns	44.9	0.31	24.6	0.34	NS	0.30	0.10
Ca*Mg		NS	NS	NS	0.53	42.7	0.59	0.015	0.52	NS

Concerning the effect of interactions on yield and its components, data in the same previous Table illustrate that interaction between foliar application of Ca and Mg levels significantly increased total fresh tuber yield and dry shoots weight per fed^{-1}, but had insignificant effect on plant; tubers yield, tubers number per plant and average tuber weight. The highest total fresh tubers yield and dry shoots weight fed^{-1} were 17.251 t. fed^{-1} and 949 kg fed^{-1} at the interaction of $Ca_2 \times Mg_1$. So, these results show that the superiority was for foliar application of Ca at 0.8 % Ca and Mg at 0.2 % for obtaining higher potato yield under soil conditions of study.

4- Quality of tubers:

Data in Table (4) illustrate the effect of foliar application of Ca, Mg and their interactions on quality of tubers as the percentages of dry matter, starch and protein and also specific gravity of tuber.

Concerning the effect of Ca, data reveal that foliar application of Ca as calcium nitrate at 0.6 and 0.8 % Ca significantly increased the quality of tubers as the percentages of dry matter, starch and protein, but had insignificant effect on specific gravity of tuber. In additionally, results clear that the superior treatment was for Ca_2 compared with control (Ca_0) and Ca_1. So, these results demonstrate the importance of calcium supplies to improve the quality of tubers which may be attributed to roles of Ca in plant; calcium stronger cell walls, it forms calcium bectate compounds which give stability to cell walls and bind cells together; and also has a role in the regulation of the stomata (Mengel and Kirkby, 2001). These results are in accordance with findings of Modisane, (2007) and Helal and AbdElhady, (2015) who stated that calcium is a major essential nutrient required for potato tuber yield and quality.

As well as, foliar application of Mg levels had a significant effect on the most studied parameters of tubers quality (dry matter, starch and protein %), except specific gravity which was insignificant. Foliar spraying Mg at 0.4 % Mg (Mg_2) recorded the highest values of dry matter (24.11%), starch (17.64 %) and protein (6.56 %) without significant differences with their values that recorded at level Mg_1. This positive effect of foliar spraying Mg on quality of tubers may be attributed to role of magnesium in protein synthesis and phosphorylation processes (Mengel and Kirkby, 2001). In this respect, Talukder *et al.,* (2009) reported that Mg fertilization significantly affected the yield and its quality.

Interactions among Ca and Mg levels had a significant effect on tuber quality at harvest as dry matter %, specific gravity and starch %, but had insignificant effect on protein %. In general, tuber quality was increased with interaction between Ca and Mg; whereas the highest values of dry matter (24.78%) and starch (18.24 %) were recorded at the interaction of $Ca_2 \times Mg_1$, as well as the highest protein % (6.71%) was recorded at the interaction of $Ca_2 \times Mg_2$. These results illustrate the integration between the effect of foliar application of Ca and Mg on quality of tubers which related with their effects on potato growth and yield.

5- N, P, K, Ca and Mg uptake of shoots and tubers at harvest:

Data in Table 5 illustrate the impact of foliar spraying Ca, Mg and their interactions on N, P, K, Ca and Mg uptake of shoots and tubers yield (kg fed^{-1}) at harvest. Data show that foliar application of Ca levels increased significantly N, P, K, Ca and Mg uptake of shoots and tubers. The highest uptake of N, P, K and Ca in tubers and shoots were obtained with foliar spraying level Ca_2, whereas the highest Mg uptake of dry shoots was under Ca_1 level and in tubers was at rate of Ca_2 without significant differences among them (Ca_1 and Ca_2). It is clear from these results the importance of foliar spraying Ca as calcium nitrate for improving the uptake of potato plants of these essential elements that plays an important roles in increasing the quality of tubers and its contents of N, P, K, Ca and Mg. These results may be related to the importance of calcium in plant; Calcium has many roles in plant: participates in metabolic processes of other nutrients uptake; promotes proper plant cell elongation; strengthen cell wall structure. In this respect, many studies showed that increasing tuber calcium content extended tuber storage life, led to plants with reduced disease incidence in the field and more vigorous main stems with less below-ground branching and greater bulb yield (Gunter and Palta, 2001; Hirschi, 2004; Palta, 2010; Hamdi *et al.,* 2015 and Helal and AbdElhady, 2015).

Table 5. influence of foliar calcium and magnesium application and their interactions on N, P, K, Ca and Mg uptake of potato shoots and tubers (kg fed^{-1}) at harvest (averages of the two growing seasons).

Treatments		Shoots-Uptake (kg fed^{-1})					Tubers yield- Uptake (kg fed^{-1})				
		N	P	K	Ca	Mg	N	P	K	Ca	Mg
	Ca_0	12.92	1.407	28.60	15.25	4.83	31.85	6.46	69.07	2.93	1.432
Mg_0	Ca_1	14.20	1.589	31.48	17.71	7.01	35.31	7.45	73.53	3.15	1.862
	Ca_2	16.46	1.720	35.21	20.53	6.77	36.10	7.98	75.40	3.35	1.779
Mean		14.53	1.572	31.76	17.83	6.20	34.42	7.29	72.67	3.14	1.691
	Ca_0	14.24	1.556	32.16	18.93	6.24	36.17	7.83	77.29	3.30	1.905
Mg_1	Ca_1	16.22	1.741	33.85	20.93	7.49	43.09	9.74	91.80	4.22	2.323
	Ca_2	18.03	1.871	34.93	21.48	7.47	44.67	10.33	94.08	4.51	2.554
Mean		16.16	1.723	33.65	20.45	7.07	41.31	9.30	87.72	4.01	2.261
	Ca_0	16.12	1.668	33.58	20.71	6.59	37.09	8.48	78.94	3.61	1.810
Mg_2	Ca_1	16.82	1.664	32.53	19.06	6.63	42.35	9.99	88.87	4.21	3.019
	Ca_2	18.02	1.749	32.40	21.04	6.63	43.73	10.20	92.75	4.42	3.177
Mean		16.99	1.694	32.84	20.27	6.62	41.06	9.56	86.85	4.08	2.669
Means of Ca-levels:											
Ca_0		14.43	1.543	31.45	18.30	5.89	35.04	7.59	75.10	3.28	1.716
Ca_1		15.75	1.665	32.62	19.23	7.04	40.25	9.06	84.73	3.86	2.401
Ca_2		17.50	1.780	34.18	21.02	6.96	41.50	9.50	87.41	4.09	2.503
L.S.D. at 5 % for:											
Mg		0.76	0.100	1.09	1.00	0.36	1.71	0.31	2.12	0.21	0.162
Ca		0.59	0.060	0.93	0.65	0.28	1.04	0.26	2.24	0.19	0.175
Ca*Mg		NS	0.106	1.61	1.13	0.52	1.80	0.45	3.88	0.24	0.261

Data in Table 5 illustrate that foliar application of Mg levels significantly increased shoots and tubers uptake of N, P, K, Ca and Mg; as well as the highest shoots uptake of P (1.723 kg fed^{-1}), K (33.65 kg fed^{-1}), Ca (20.45 kg fed^{-1}) and Mg (7.07 kg fed^{-1}) was obtained at foliar rate of Mg_1 (0.2 % Mg). As for tubers uptake of N, P, K, Ca and Mg differed between the effects of foliar rate of Mg_1 and Mg_2 which were insignificant. The superior treatments for N and K tubers uptake were with foliar spraying Mg_1, so these results demonstrate the importance of foliar application of Mg for improving tubers and yield uptake of nutrients, and in this respect Kene *et al.,* (1990) showed that Mg increase NPK uptake and thereby increase yield and promotes uptake and translocation of phosphorus; also these results agree with those obtained by Orlovius and Mchoul, (2015).

Regarding the effect of interaction on shoots and tubers uptake of nutrients, results in Table 5 show that interactions among Ca and Mg levels had significant effects on the nutrients uptake of shoots and tubers, except shoots uptake of N which was insignificant. N, P, K, Ca and Mg uptake of shoots and tubers were increased with interaction between Ca and Mg. In addition, the highest shoots and tubers uptake of N, P, K and Ca were found at the interaction of $Ca_2 \times Mg_1$. These results are in accordance with the interaction effects on total fresh tubers yield, dry shoots weight and nutrients concentration in leaves and tubers at 90 days.

Generally, it can be concluded that foliar application of Ca and Mg had a positive effect on most parameters of plant growth, tuber yield and its quality and shoots and tubers uptake of N, P, K, Ca and Mg in potato crop grown under clay loam soils. Also, results demonstrate that the superior treatment in tubers yield (as shown in Fig. 1) and its quality as tuber percentages of dry matter, starch and protein and tubers uptake of N, P, K, Ca and Mg was obtained at the interaction of foliar application of Ca at 0.8 % Ca and Mg at 0.2 % Mg ($Ca_2 \times Mg_1$).

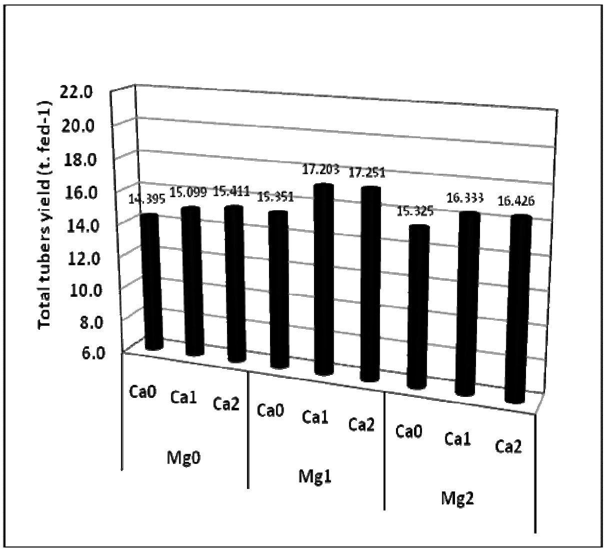

Fig. 1. influence of foliar calcium and magnesium application and their interactions on total tubers yield, t. fed^{-1} (averages of the two growing seasons).

CONCLUSION

From the present study, it can be concluded that foliar application of Ca at 0.8 % as calcium nitrate and foliar application of Mg at 0.2 % as magnesium sulphate twice after emergency and all 10 days (at rate 200 L fed^{-1}) along with addition of the recommended doses of nitrogen, phosphorus and potassium to improve potato growth and achieve the higher tuber yield with the highest quality under the same conditions of Nile Delta region.

REFERENCES

A.O.A.C. (1990). "Official Methods of Analysis of the Association of Official Analytical Chemists". 15th (edition, published by Association of Official Analytical Chemists Arlington, Virginia U.S.A.).

Arvin, M.; A. Habib and J. Donnelly (2005). Effect of calcium concentrations in medium on microtuberization of potato (*Solanum tuberosum* L.). Iranian J. Biotech., 3: 3.

Burton, W.G. (1948). The Potato. Champan and Hall, London, 319 pp.

Gomez, K.A. and A.A. Gomez (1984). Statistical Procedures for Agricultural Research. 2nd Ed., Jhon Wiley and Sons Inc., New York, pp: 95-109.

Guneş, A.; M. Alparslan and A. İnal (2002). Plant nutrition and fertilization. Ankara Univ., Pub. of Agric. Fac., Ankara (in Turkish), II. Print. Publication No. 1526, Textbook: 479.

Gunter, C. C. and J. P. Palta (2008). Exchangeable soil calcium may not reliably predict in-season calcium requirements for enhancing potato tuber calcium concentration. American J. Potato Res., 85: 324-331.

Gunter, C.C. and J.P. Palta (2001). Raising seed tuber calcium may impact its quality and performance. www.hort.wisc.edu/faculty/palta/potato&calcium .htm

Hamdi, W.; L. Helali; R. Beji; K. Zhani; S. Ouertatani and A. Gharbi (2015). Effect of levels calcium nitrate addition on potatoes fertilizer. Int. Res. J. of Eng. and Tech. (IRJET), 2(3): 2006-2013.

Helal, Nesreen A.S. and Slama A. AbdElhady (2015). Calcium and potassium fertilization may enhance potato tuber yield and quality. Middle East J. of Agric. Res., 4(4): 991- 998.

Hesse, P.R. (1971). A Text Book of Soil Chemical Analysis. John Murry Publishers, Ltd, 50 Albemarle Street, London.

Hirschi, K. D. (2004). The calcium conundrum. Both versatile nutrient and specific signal. Plant Physiol., 136: 2438-2442.

Holder, M. (1965). Chlorophylls. In: T. W. Goodwin, Ed., Chemistry and Biochemistry of plant Pigments, Academic Press, New York, pp: 461-488.

Hongwei, T.; D. Chenglin and Z. Liuqiang (2000). Effect of magnesium fertilizer on sustaining upland agricultural development in Guangxi Province. Better Crops International, 14(2): 13-15.

Jackson, M.L. (1967). Soil Chemical Analysis. Printic Hall of India, New Delhi, pp: 144-197.

Kacar, B. (1984).Plant nutrition. Ankara Univ., Pub. of Agric. Fac., Ankara(in Turkish),Textbook,250: 317.

Kacar, B. and A.V. Katkat (2007). Fertilizers and fertilization technique. Nobel Pub. No: 1119, Sci. and Biol. Pub. Series: (in Turkish), 34(2): 560.

Kene, H. K.; S. T. Wankhade and B. N. Sagare (1990). Influenence of nutrient spray on yield and oil content of sunflower. Annals plant physiol. 4(2):249-251.

Kleinhenz, M. D. and J. P. Palta (2002). Root zone calcium modulates the response of potato plants to heat stress. Physiologia Plantarum, 115: 111–118.

Koller, H.R. (1972). Leaf area, Leaf weight relationship in soybean canopy. Crop Sci., 12: 180-183.

Marschner, H. (1995). Mineral nutrition of higher plants. 2nd ed. Academic Press. London.

Mengel, K. and E.A. Kirkby (2001). "Principles of Plant Nutrition", International Potash Institute, Bern, Switzerland.

Modisane, P.C. (2007). Yield and quality of potatoes as affected by calcium nutrition, temperature and humidity. M. Sc. Thesis, in Agron., Fac. of Natural and Agric. Sci., Univ. of Pretoria.

Nookaraju A.; S. K. Pandey; C. P. Upadhyaya; J. J. Heung; H. S. Kim; S. C. Chun; D. H. Kim and S. W. Park (2012). Role of Ca^{2+}-mediated signaling in potato tuberization: An overview. Botanical Studies, 53: 177-189.

Orlovius, K. and J. McHoul (2015). Effect of two magnesium fertilizers on leaf magnesium concentration, yield, and quality of potato and sugar beet. J. of Plant Nutrition, 38(13): 2044-2054.

Ouzounidou, G.M.M and R. Strasser (1977). Sites of action of copper in the photosynthetic apparatus of maize leaves: kinetic analysis of chlorophyll fluorescence oxygen evolution, absorption changes and thermal dissipation as monitored by photoacoustic signals. Australian J. Plant physiol., 24: 81-90.

Ozgen S.; J. P. Palta and M. D. Kleinhenz (2003). Influence of supplemental calcium fertilization on potato tuber size and tuber number. Acta Hort., 619: 329-336.

Ozgen, S.; B. H. Karlsson and J. E. Palta (2006). Response of potatoes (cv russet burbank) to supplemental calcium applications under field conditions: tuber calcium, yield and incidence of internal brown spot. Amer. J. of Potato Res., 83:195-204.

Palta, J. P. (2010). Improving potato tuber quality and production by targeted calcium nutrition: the discovery of tuber roots leading to a new concept in potato nutrition. Potato Res., 53:267–275.

Piper, C.S. (1950). Soil and Plant Analysis. Int. Sci. Publisher Inc., New York.

Ranganna, S. (1977). Manual of Analysis of Fruit and Vegetable Products. Central Food Technological Research Institute Mysore.

Smith, N.R. (1975). Specific Gravity, Potato Processing, The AVI Publishing Comp. Inc., pp: 43-66.

Stark, J.C. and D.T. Westermann (2003). Nutrient management. In Potato Production Systems, eds. J.C. Stark, and S.L. Love, 115–135. Moscow, ID, USA: University of Idaho Agriculture Communications.

Talukder, M. A. H.; M. B. Islam; S. M. A. H. M. Kamal; M. A. Mannaf and M. M. Uddin (2009). Effects of magnesium on the performance of potato in the Tista Meander Floodplain soil. Bangladesh J. Agric. Res., 34(2): 255-261.

تأثير الرش الورقي بالكالسيوم والماغنسيوم علي محصول البطاطس المنزرع بالأراضي الطينية الطميية

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الكالسيوم والماغنسيوم من العناصر الغذائية الثانوية التي يحتاجها النبات لنمو صحي، لذا أجريت تجربتان حقليتان بقرية كفر بساط –مركز طلخا- محافظة الدقهلية - مصر (الواقعة بين خط عرض ٣٠° - ٤٣´ - ٢٢.٠١" وخط طول ٣٠° -١٦´ -٤٤.٥٠") خلال موسمي الزراعة الشتويين ٢٠١٥/٢٠١٤ و ٢٠١٦/٢٠١٥ لتقييم مدي استجابة محصول البطاطس (صنف سيلاني) المنزرع بالأراضي الطينية الطميية للتغذية الورقية بالرش بالكالسيوم والماغنسيوم والتفاعل بينهما علي النمو، تركيز العناصر الغذائية عند عمر ٩٠ يوم والممتص منها عند الحصاد، وكذلك علي المحصول وجودته. صممت التجربة في قطع منشقة في ثلاث مكررات و مثلت معاملات الرش بالماغنسيوم (ثلاث مستويات Mg_0 :كنترول ؛ Mg_1 : ٠.٢ % ماغنسيوم و Mg_2: ٠.٤ % ماغنسيوم كسلفات ماغنسيوم) في القطع الرئيسية و مثلت معاملات الرش بالكالسيوم (ثلاث مستويات Ca_0 :كنترول ؛ Ca_1 : ٠.٦ % كالسيوم و Ca_2: ٠.٨ % كالسيوم كنترات كالسيوم) في القطع الشقية. أوضحت النتائج أهمية إمداد البطاطس المنزرعة بالأراضي الطينية الطميية بالرش الورقي بالكالسيوم والماغنسيوم، فقد أشارت النتائج إلي زيادة معنوية في نمو النبات متمثلا في الوزن الطازج للنبات والمساحة الورقية وتركيز الكلوروفيل (أ ، ب والكلي) وكذلك في محصول الدرنات الكلي (بالطن للفدان) وجودته متمثلة في نسب كل من المادة الجافة، النشا والبروتين بالدرنة و في محتوي الدرنات والعرش من النتروجين والفوسفور والبوتاسيوم والكالسيوم والماغنسيوم. بعد ٩٠ يوم من الزراعة أوضحت النتائج زيادة تركيز كل من النتروجين والكالسيوم والماغنسيوم في الأوراق معنويا مع رش مستويات الكالسيوم والماغنسيوم في حين انخفض تركيز البوتاسيوم. هذا وقد زاد محتوي الدرنات عند الحصاد من النتروجين والفوسفور والبوتاسيوم والكالسيوم والماغنسيوم معنويا مع رش مستويا ت الكالسيوم حتي مستوي ٠.٨ % كالسيوم ومع رش الماغنسيوم حتي مستوي ٠.٢ % ماغنسيوم. كان للتفاعل بين الإضافة الورقية لمستويات الكالسيوم والماغنسيوم تأثير معنوي علي قياسات نمو النبات ومحصول الدرنات الكلي وجودته وعل محتوي العرش والدرنات عند الحصاد من العناصر الغذائية بالكيلوجرام للفدان. سجلت أعلي القيم لمحصول الدرنات الكلي (١٧.٢٥١ طن للفدان) ولنسبة المادة الجافة في الدرنة (٢٤.٧٨ %) والنشا (١٨.٢٤ %) وفي محتوي الدرنات والعرش من النتروجين والفوسفور والبوتاسيوم والكالسيوم عند التفاعل بين رش الكالسيوم عند ٠.٨ % ورش الماغنسيوم عند ٠.٢ %. لذا تؤكد الدراسة علي أهمية الإضافة الورقية للكالسيوم عند تركيز ٠.٨ % والماغنسيوم عند ٠.٢ % لتحسين النمو وزيادة محصول البطاطس وجودته تحت هذه الظروف الحقلية للتربة.