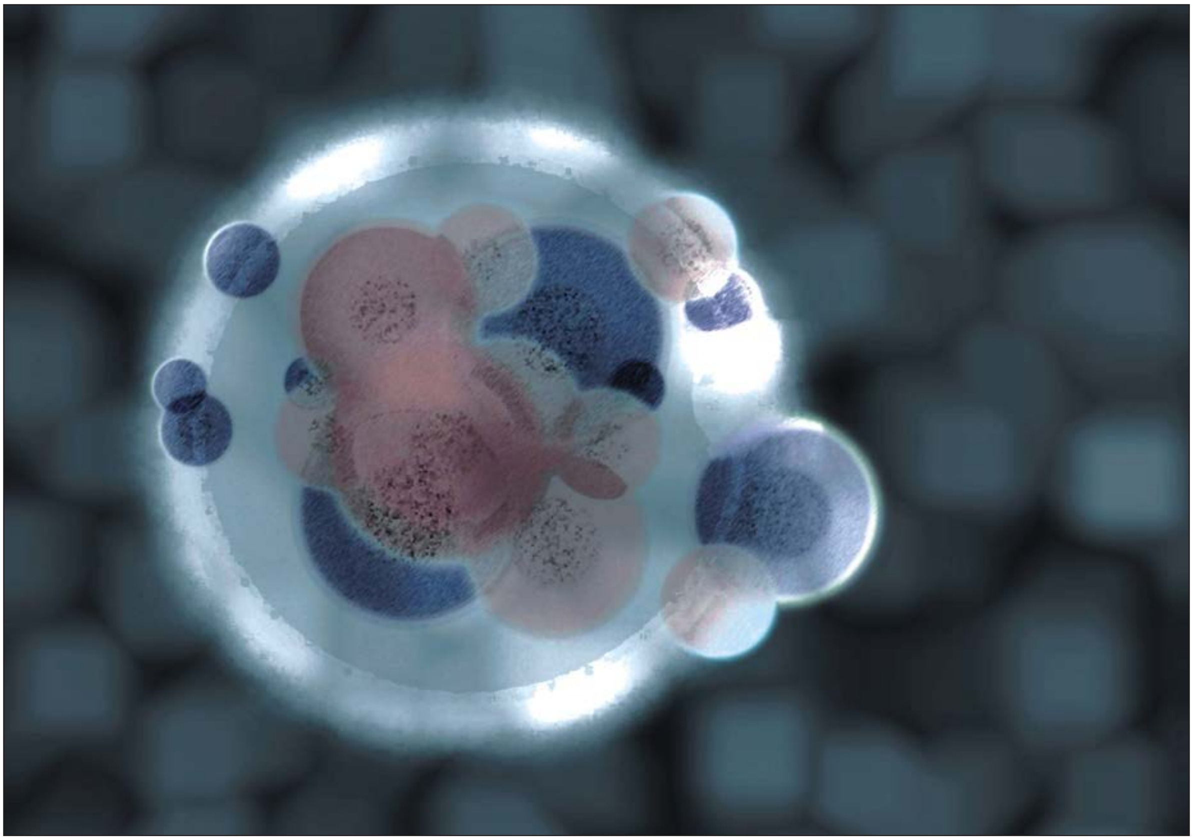

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Effect of Various Mg Concentrations in Nutrient Solution on Growth and Nutrient Uptake Response of Strawberry (*Fragaria*×*Ananassa* Duch.) "Seolhyang" Grown in Soilless Culture

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Abstract: The effect of the variation of Mg concentration (MgC) 0, 0.5, 1, 2, 4 and 6 meq.L^{-1} in the Nutrient Solution (NS) on strawberry (*Fragaria*×*ananassa* Duch.) "Seolhyang" growth was evaluated at 120 days after transplantation of runners. The effect of Mg-deficiency, first seen by the appearance of necrosis in the old leaves. On young leaves a spotted brown or brown area developed on the interveinal area with spotted marginal browning or marginal necrosis. The greatest application of 6 meq.L^{-1} of Mg in NS caused a reduction in pigmentation and suppressed plant growth severely. The MgC 2 meq.L^{-1} resulted in the relatively highest vegetative growth with a favorable Electrical Conductivity (EC) and pH, for a better growth and nutrients uptake. The Dry Weight (DW) and Fresh Weight (FW) were weakly correlated with variation of MgC ($R^2 = 0.024$ and 0.16, respectively). The response to the variation of MgC on the EC and pH were also, weakly correlated ($R^2 = 0.15$ and 0.21, respectively). The MgC 2 meq.L^{-1}compounded initially by 5 K^+, 5 Ca^{2+} 2 Mg^{2+}, 1 Na^+, 10 NO_3^-, 2SO_4^{2-}, 1 $H_2PO_4^-$ with a pH 6.5, EC =2.2 dS m^{-1}, $K^+/(Ca^{2+}+Mg^{2+}) = 0.71$ and Σcations = Σanions (13 meq.L^{-1}) was improved by decreasing a pH, by adding NH_4^+ in NS and by adjusting the ratio cited to around 0.61. Depending of the results of this study, the new solution improved is compounded by 5 Ca^{2+}, 4.5 K^+, 2.3 Mg^{2+}, 2.5 NH_4^+, 5 NO_3^-, 2.3SO_4^{2-} and 1 $H_2PO_4^-$with Σcations = Σcations (14.3 meq.L^{-1}), a pH6 and EC = 2.3 dS m^{-1}.

Key words: Growth characteristics, Mg contents, nutrients uptake, soilless crop, strawberry "seolhyang"

INTRODUCTION

Strawberry (*Fragaria*×*ananassa* Duch.) "Seolhyang" used in this experiment is issued by the crossing of the Akihime (M) and Read Pearl (F) (Kim *et al*., 2004); the cultivation area of this variety has grown rapidly. It reaches more than 60% of the total strawberry cultivation in Korea (Choi *et al*., 2011a). Because, this variety has vigorous growth habits and very high productivity. In the other hand, it has unique nutrient uptake characteristics compared to other varieties. Regarding soil cultivation of this variety in a greenhouse, the pH in the root rhizosphere drops to 4.6, whereas in other varieties it is maintained at around 5.2 (De Kreij *et al*., 1999) to 6 (Choi *et al*., 2011b).

Magnesium is the fourth most abundant element in plants, after N, K and Ca (Epstein and Bloom, 2005). It is an essential nutrient for plant growth as it helps activate more than 300 enzymes and synthesis of organic molecules required by plants for growth (Stys, 1995; Croteau *et al*., 1987; Li *et al*., 2001; Sirijovski *et al*., 2008). Its total levels in plant vary from 0.3 to 1% and therefore, considerable Mg^{2+} uptake occurs(Hammond *et al*., 2003). During chlorophyll synthesis, it is actively inserted into the chlorin ring through a chelatase enzyme action (Ankele *et al*., 2007). In the other hand, the chlorophyll level was found to correlate with Mg and N levels (Hermans *et al*., 2004; Dreyer *et al.,* 1994; Vrataric *et al*., 2006; Parvizi *et al*., 2004; Neves *et al*., 2005; Richardson *et al*., 2002; Scheepers *et al*., 1992; Shaahan *et al*., 1999). It also, plays a major part in the constitution of chlorophyll; base of photosynthesis (Wollman and Diner, 1980; Shaul, 2002; Tomonou and Amao, 2002; Paul and Pellny, 2003; Axelsson *et al*., 2006). Mg is possibly involved in phloem loading because it is an allosteric activator of protein complexes (Cowan, 2002).

In a hydro mineral solution intended for the plants, the concentrations must be adapted to ionic balance (Sonneveld, 2000; Savvas, 2001). Because, most tissue Mg^{2+} resides in the vacuole contributes to turgor generation and charge balancing of anions (Maathuis, 2009). An excess or a deficiency can disturb the uptake of others elements (Mengel and Kirby, 1987; Millero *et al*., 2008) and effects shoot biomass yield, chlorophyll

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content and photosynthesis rat (Ding *et al*., 2008), because the competition between Mg^+, Ca^{2+} and K^{2+}(Appenroth *et al*., 1999; Reimann *et al*., 2002; Appenroth and Gabrys, 2003; San Bautista *et al*., 2009).

The optimal ratio $K^+/(Ca^{2+}+Mg^{2+})$ around 0.67 (Choi and Latigui, 2008), according to the species, contributes, with an adequate pH, in a significant way to the uptake of all other minerals. An excess of K^+ and Ca^{2+} causes Mg deficiency (Mengel and Kirby, 1987; De Kreij *et al*., 1999). Because, Mg^{2+}/Ca^{2+}ratio is a consequence of cation interactions in many plants (Kamel, 2002).

Strawberries have several overlapping stages in a single floral stalk for a periodical distribution of physiological stages (Risser and Navatel, 1997; Choi and Latigui, 2008). This makes the determination of Mg^{2+} concentration according to K^+ and Ca^{2+} to meet all physiological stages difficult. Therefore, to further investigate the importance of nutrient balance on the incidence on growth and nutrient uptake response of 'Seolhyang' strawberry in this experiment, we maintained the levels of Ca^{2+} and K^+ in the NS constant and varied only MgC: 0, 0.5, 1, 4 and 6 $meq.L^{-1}$. It will also, enable us to see the symptoms induced by relatively high concentration 6 $meq.L^{-1}$of Mg and those induced by a total deficiency 0 $meq.L^{-1}$of this cation.

The experiment was carried out during 120 days after planting the runners; period of growth stage prior to flowering in soilless crop system. This duration is sufficient to know the balance of combination: plant/vegetative stage/NS (Choi *et al*., 2011a). For understanding the real effect of uptake and assimilation, plants need to be grown in nutrient solutions (Darnell and Stutte, 2001). Then, according to the results we improve, these solutions for better absorption of all nutrients through the introduction of a new ionic equilibrium value.

MATERIALS AND METHODS

Plant material and growth conditions: This experiment took place in the same culture conditions, with the same procedure and variety than those made by Choi *et al.* (2010) on Nitrogen, by Choi *et al.* (2011a) on ammonium to nitrate ratios and by Choi *et al.* (2013) on Phosphorus. It was carried out in the controlled environment of a glasshouse located in Daejeon (36°20' N, 127°26' E), Korea. The mean day and night temperatures inside the glasshouse were 24 and 15°C, respectively, during the experimental period. The relative humidity was 60-70% and the average photoperiod was 15 h with a photosynthetic photon flux density of 330-370 $\mu mol\ m^{-2}\ S^{-1}$.

Runners 'Seolhyang' strawberry at the three true-leaf stage were planted into plastic pots with a volume of 1600 mL of a 1:1 mixture of coarse and perlite.

The plants were irrigated with distilled water for the first 45 days after planting to decrease the tissue nutrient levels. Older leaves were removed, leaving only 3 newly formed leaves per plant as the baseline measure. This operation avoids any nutrients redistribution issued by catabolism from old leaves to the future younger. The plants were then, fertilized with the different Mg solutions 2 to 3 times per week; depending to physiological stages of plant, luminosity and temperature. During each fertigation, the leaching percentage was controlled at 30 to 40%. This operation allows avoiding salt accumulation in the root media (Munoz *et al*., 2008; Munns, 2002).

The crop growth as influenced by the treatment solutions was checked 120 days after planting by measuring the Number of Leaves (NL), Plant Height (PH), Leaf Length (LL), Leaf Width (LW), Petiole Length (LL), Crown Diameter (CD), Fresh Weight (FW) and Dry Weights (DW). The determination of the crop growth followed the methods described by Choi *et al*. (2000).

Treatments solutions: Six treatment solutions S1, S2, S3, S4, S5 and S6 differentiated by MgCs: 0, 0.5, 1, 2, 4 and 6 $meq.L^{-1}$ respectively were tested in this experiment (Table 1). Hence, these Mg different concentrations gave different $K^{2+}/(Ca^{2+}+Mg^+)$. The composition of other elements was the same for the 6 solutions. It was for macro nutrients ($meq.L^{-1}$) 5 K^+, 5 Ca^{2+}, 10 NO_3^-, $2SO_4^{2-}$, 1 H_2PO_4 and the micronutrients ($mg.L^{-1}$ of solution): 1.81 $MnCl_2{\cdot}4H_2O$, 2.86 H_3BO_3, 0.22 $ZnSO_4{\cdot}7H_2O$, 0.08 $CuSO_4{\cdot}5H_2O$, 0.09 $H_2MoO_4{\cdot}H_2O$ and 0.79 Na_2 FeEDTA. Except Na^+ and Cl^- that was tied with NaH_2PO_4, Na_2SO_4 and $CaCl_2$. It should be noted, that the variation from 0 to 5 and from 1 to 3 $meq.L^{-1}$, respectively for Cl^- and Na^+ in the different NS had no significant effect on growth and development of plants (Keutgen and Keutgen, 2003; Babu *et al*., 2005). Because, these elements and in these concentrations plays a minor role in nutrient plant compared with the other nutrients (Hopkins, 2003; Munns, 2002). In the other hand, Ca^{2+} and K^+ inhibited Na^+ uptake in growth temperature under 32°C (Quintero *et al*., 2008; Rubio *et al*., 2003). While, our experiment was conducted at a temperature between 15 and 24°C. Each treatment was repeated 4 times. The standard stock solution was prepared using $Ca(NO_3)_2$, KNO_3, NaH_2PO_4, $MgSO_4$, $Mg(NO_3)_2$, $NaNO_3$, Na_2SO_4 and $CaCl_2$. They were mixed in separate tanks to prevent salt precipitation.

Nutrients analysis: The differences in plant growth was investigated 120 days after planting by measuring the NL, PH, LL, LW, PL, crown diameter (CD) and fresh weight (FW) and dry weights (DW).

Table 1: Composition of NS used to investigate the effect of MgC

	NH_4^+	K^+	Ca^{2+}	Mg^{2+}	Na^+	NO_3^-	SO_4^{2-}	$H_2PO_4^-$	Cl^-	$K^+/(Ca^{2+}+Mg^{2+})$
NS					(meq.L^{-1})					
S1	0	5	5	0	3	10	2	1	0	1
S2	0	5	5	0.5	2.5	10	2	1	0	0.90
S3	0	5	5	1	2	10	2	1	0	0.83
S4	0	5	5	2	1	10	2	1	0	0.71
S5	0	5	5	4	1	10	2	1	2	0.55
S6	0	5	5	6	3	11	2	1	5	0.45

^{z}Micronutrients (mg L^{-1} solution): $MnCl_2 \cdot 4H_2O$, 1.81; H_3BO_3,2.86; $ZnSO_4 \cdot 7H_2O$, 0.22; $CuSO_4 \cdot 5H_2O$, 0.08; $H_2MoO4 \cdot H_2O$, 0.09 and $Na_2FeEDTA$, 0.79

The tissue of entire above-ground plant parts were harvested for elemental analysis. The collected samples were washed with diluted detergent in distilled water, quickly rinsed in a bath of distilled water and oven dried at 70°C for 48 h. Dried tissue samples were ground, ashed and analysed using the procedure described by Fonteno and Nelson (1990).

Petioles of fully grown young leaves were also collected 120 days after planting and cut into 1 mm long segments for analysis. Samples were put into vial with distilled water (1:10 w/w). Vials were gently shaken for 30 min to allow the electrolytes to leak out from the petiole sections. After filtering with a Whatman No. 2 filter paper, the solutions were used for NO_3^--N analysis following the procedures of Cataldo *et al.* (1975).

The instrument used for nitrogen analysis was Kjeldahl digestion and distillation unit (VELP Scientifica, Model UDK 132). Inductively Coupled Plasma (ICP) Optical Emission Spectrometer (Thermo Elemental Traces can, USA) was used for K, Ca, P, Mg, Fe, Mn, Zn and Cu. The NO_3^- from petiole section was analysed by using spectrophotometer Model CE 5001 (Cecil, England).

Soil solution was also analysed 120 days after planting. It was extracted by the method of Warncke (1986).The pH and EC were measured by a pH meter (Model 900A, Orion) and an EC meter (Model 122, Orion), respectively.

Statistical analysis: Data from the growth measurements, tissue analysis, soil solution pH and EC were subjected to a randomized complete block analysis of variance. The treatment means were separated via LSD test. Data were also subjected to a polynomial regression analysis using the CoStat program (CoHort Software version 6.3, Monterey, CA).

RESULTS

Effect on growth characteristics: The number of leaves (Table 2) is not affected by the variation of MgC. The same results were found by Vrataric *et al.* (2006) and Kristek *et al.* (2000) on soybean and sugar beets. By cons, Rao and Rajput (2011) on oregano (Origanum vulgare ssp. hirtum) and Cakmak *et al.* (1994) on bean plant found that MgC variation has an effect on number leaves. It decreases when deficiency was induced.

The higher PH was obtained by S3 and S4 (Table 2). (Pritts, 1998; Marschner, 1995; Mengel and Kirkby, 2001) showed that the variation of MgC had a significant effect on PH and chlorophyll. However, the CD was not affected by the Mg variation. Because, according to (Tabatabaei *et al.*, 2008; Maroto *et al.*, 1996), it is affected only by plant densities.

The DW of the whole above ground plant tissue was weakly correlated (Fig. 3) and not influenced (Table 2) by the variation of MgCs in NS. The FW is also not influenced (Table 2) and weakly correlated with the variation of MgC (Fig. 4). These correlations concerned specially the concentrations 0.5, 1, 2 and 4 meq.L^{-1}. (Azuma *et al.*, 2010; Keutgen and Pawelzik, 2008; Suarez, 2011) showed that the decrease in LW is concomitant with the reduced photosynthesis caused by an inappropriate MgC (Ding *et al.*, 2008). In the same condition, Choi and Latigui (2008) found that the high quantity of chlorophyll in "seolhang" is obtained by an MgC varying between 1.4 and 2.8 meq.L^{-1}. While, in sugar beet (Hermans *et al.*, 2006) and in broad beans (Hariadi and Shabala, 2004; Chou *et al.*, 2011), the studies demonstrated that plant biomass is not effective for diagnosis of Mg deficiency in this vegetative stage. Furthermore, no difference was observed by the variation of Mg in DM. Because, according to Tei *et al.* (2002) is not affected by the irrigation practices.

The S3 and S4 gave the higher area of leaf (Table 2) represented by LL and WL in this experiment. However, the deficiency of Mg in S1 and S2 reduced leaf. This is due, according to Assuero *et al.* (2004) to the reduction in the meristematic zone where the rate of cell production became lower. The important elevation of Mg in S6 gave lower leaf area. Azuma *et al.* (2010), Kchaou *et al.* (2010), Perez-Tornero *et al.* (2009), Suarez (2011) and Razavi *et al.* (2008) showed that high Salinity generally inhibits the development of leaf area and decreases the leaf fresh weight and chlorophyll content.

The visible effects of MgC variations: The effect of Mg-deficiency in S1, after 120 days of the treatment, first seen by the appearance of necrosis in the old leaves (Fig. 1).

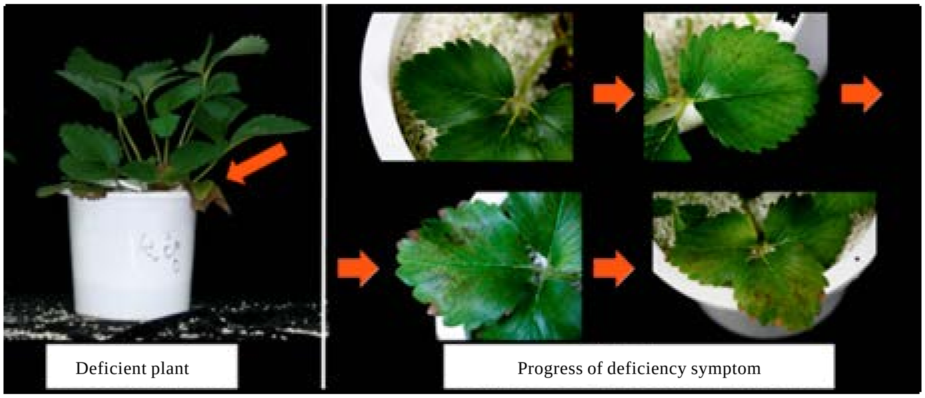

Fig. 1: Induced magnesium deficiency symptoms in ‘Seolhyang’ strawberry

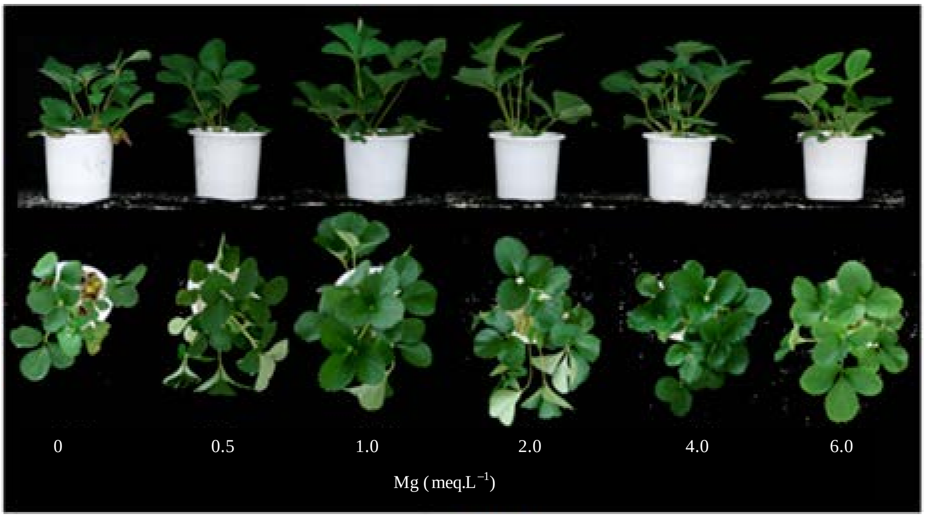

Fig. 2: Differences in crop growth of ‘Seolhyang’ strawberry at 120 days after transplanting as influenced by elevated MgC in NS

Table 2: Influence of elevated MgC in NS on growth characteristics of ‘Seolhyang’ strawberry at 120 days after transplanting

	NL	PH	LL	LW cm	PL	CD	FW g P^{-1}	DW
NS	(cm)						g P^{-1}	
S1	6.29^{az}	30.6^{c}	8.0^{c}	8.0^{c}	11.8^{d}	1.01^{a}	27.8^{ab}	7.25^{a}
S2	7.00^{a}	29.3^{c}	10.6^{b}	8.0^{c}	17.1^{c}	9.40^{a}	25.3^{b}	6.82^{a}
S3	7.71^{a}	35.2^{a}	12.3^{a}	9.4^{a}	20.7^{ab}	1.12^{a}	35.7^{a}	8.93^{a}
S4	7.57^{a}	36.3^{a}	11.7^{ab}	9.3^{a}	22.6^{a}	1.05^{a}	37.6^{a}	7.82^{a}
S5	7.29^{a}	34.4^{ab}	11.4^{ab}	9.2^{a}	20.6^{ab}	1.01^{a}	33.6^{ab}	7.88^{a}
S6	7.29^{a}	31.8^{bc}	10.8^{b}	8.3^{b}	18.5^{bc}	1.05^{a}	32.4^{ab}	7.33^{a}
Linear	NS	NS	NS	**	*	NS	NS	NS
Quadratic	NS	***	***	***	***	NS	*	NS

[z]Mean separation by Duncan’s multiple range test at $p \leq 0.05$. Values followed by the same letter within columns are not significantly different NS: *,**,***Non significant or significant at $p \leq 0.05$, 0.01 and 0.001, respectively

Because, this deficiency decreased chlorophyll concentrations, photosynthetic activity and soluble protein (Cakmak *et al*., 1994; Ericsson and Kahr, 1995; Hermans *et al*., 2004; Cakmak and Kirkby, 2008; Ding *et al*., 2008; Marschner, 1995; Mengel and Kirkby, 2001; Paul and Pellny, 2003; Pritts, 1998) by the phenomenon of photosynthates redistribution to phloem-fed tissues (Hermans *et al.*, 2005) and to young immature leaves (Hermans *et al.*, 2006; White and Broadley, 2009) which are the sink (Bonnemain, 1964) in this case. In the other hand, Mg^{2+} is mobile in plants and can be transported to developing organs meristems, buds and flowers (Shaul, 2002).

The Fig. 1 shows, also on young leaves a spotted brown or brown area developed on the interveinal area with spotted marginal browning or marginal necrosis. By cons, in other varieties, the characteristic symptom of Mg deficiency is only, interveinal chlorosis (Bennett, 1997). These leaves eventually dried and withered.

The application of 6 meq L^{-1} of Mg in NS (Fig. 2) caused a reduction in pigmentation. (Cambrolle *et al.*, 2011; Chakraborty *et al.*, 2012), on Arabidosis, explained that this depigmentation is caused by a reduction of K^+, Ca^{2+} and Mg^{2+}. However, S3 and S4 induced a relatively optimal growth.

Effect on tissue nutrient contents

Macronutrients: An optimal Mg content on shoots, where Mg^{2+} is usually measured (Mengel and Kirby, 1987) is between 0.30-0.50% in many varieties (Marschner, 1995) and 0.04% on vantana strawberry (Palencia *et al.*, 2010) depending of culture condition. In our experiment (Table 3), excepted for S6 where the content is relatively high, all solutions gave the acceptable rate. While Chou *et al.* (2011) found, in rice that Mg deficiency resulted in a decrease in MgC in shoot and roots. Because, according to (Perez-Tornero *et al.*, 2009; Razavi *et al.*, 2008), the Mg analysis remains the most accurate tool to diagnose Mg deficiency. The elevated MgC in NS and magnesium concentrations content of the whole above ground plant tissue (Fig. 3) and in petiole sap (Fig. 4) are highly correlated. However, those on changes in dry weight and magnesium content of the whole above ground plant tissue (Fig. 3) is leakely correlated. In the other hand, the response of MgC in fresh weight (Fig. 4) of the whole above ground plant tissue was also leakely correlated.

The concentration of P (Table 3) obtained by S4 and S5 is near to the optimum 0.32 % noted by Palencia *et al.* (2010). The high content is obtained by S6. By cons, in olive tree the levels of K^+ and Mg^2+ in leaf and fruit remained relatively constant with respect to the different salinity treatments (Vigo *et al.*, 2005).

Potassium is the nutrient absorbed at the highest rates followed by Ca and N. It is absorbed at similar rates than Mg and P (Tagliavini *et al.*, 2005). The increases of K^+ (Table 2) in all treatments were proportional to increasing to those of Mg^{2+} in input solutions. This explains the synergisms P/K, P/Mg and P/N (Leikam *et al.*, 1983; Falade, 2006; Watanabe *et al.*, 2007). The lowest percentage of major elements studied was recorded by the treatment S1. In other hand, the Concentration of Na^+ was found for all treatments under the toxic level 0.2% (Bernstein, 1975).

Micronutrients: Excepted for the T-N, P, Fe and Cu (Table 3), the analysis of variance showed highly significant effects of different treatments MgC on the NS based on the DW of the above-ground tissue.

The results showed that for Mn, Zn and Cu no significant differences were recorded for all treatments.

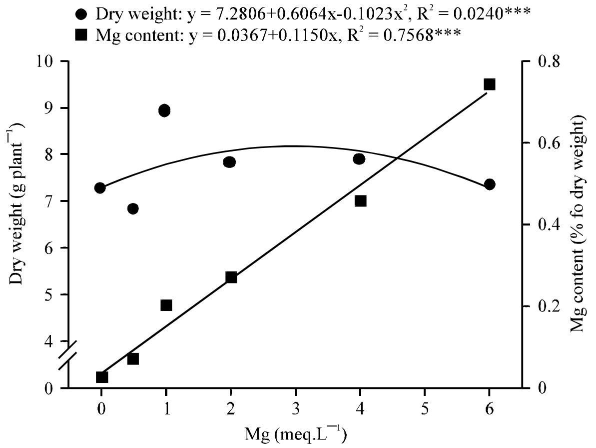

Fig. 3: Effect of elevated MgC in the NS on changes in dry weight and magnesium content of the whole above ground plant tissue of 'Seolhyang'

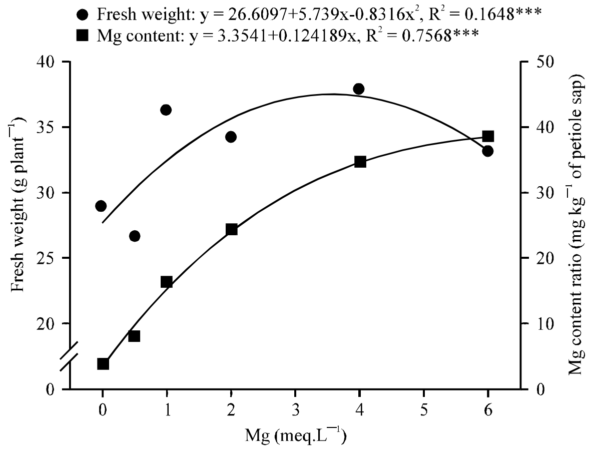

Fig. 4: Effect of elevated MgC in the NS on changes in fresh weight of above ground plant tissue and MgC in petiole sap of 'Seolhyang' strawberry at 120 days after transplanting

Table 3: Influence of elevated MgC in NS on tissue nutrient contents of 'Seolhyang' strawberry based on whole above ground plant tissue

	T-N	P	K	Ca	Mg	Na	Fe	Mn	Zn	Cu
Treatments	(%)							(mg kg^{-1})		
S1	1.41^{az}	0.297^{ab}	1.57^{b}	0.85^{b}	0.27^{c}	0.011^{c}	193.5^{a}	440.3^{a}	44.5^{a}	12.3^{a}
S2	1.32^{a}	0.242^{b}	2.05^{ab}	0.39^{c}	0.03^{e}	0.004^{c}	129.2^{b}	267.4^{b}	34.2^{b}	9.5^{a}
S3	1.39^{a}	0.381^{a}	2.07^{ab}	0.58^{c}	0.07^{de}	0.005^{c}	193.4^{b}	415.9^{a}	44.5^{a}	11.7^{a}
S4	1.52^{a}	0.267^{b}	2.33^{a}	0.45^{c}	0.20^{cd}	0.004^{c}	153.6^{b}	140.0^{bc}	27.6^{b}	11.4^{a}
S5	1.46^{a}	0.357^{a}	2.36^{a}	1.06^{b}	0.46^{b}	0.054^{b}	671.3^{b}	164.8^{bc}	35.8^{b}	12.0^{a}
S6	1.31^{a}	0.364^{a}	2.40^{a}	1.31^{a}	0.74^{a}	0.090^{a}	82.9^{b}	61.0^{c}	29.3^{b}	9.0^{a}
Linear	NS	NS	**	***	***	***	NS	***	*	NS
Quadratic	NS	NS	**	***	***	***	NS	***	NS	NS

^{z}Mean separation by Duncan's multiple range test at $p \le 0.05$. Values followed by the same letter within columns are not significantly different. NS,*, **, ***Non significant or significant at $p \le 0.05$, 0.01 and 0.001, respectively

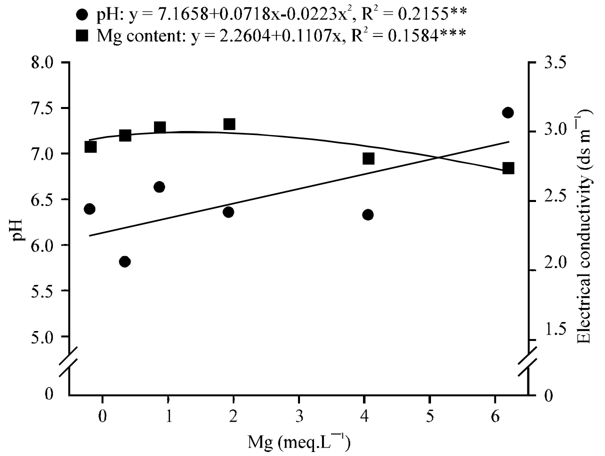

Fig. 5: Effect of elevated MgC in the NS on changes in pH and EC in soil solution of root media at 120 days after transplanting of 'Seolhyang' strawberry

However, the S2 gave the greatest and optimal weight of Fe found by Palencia *et al.* (2010). The values of Zn and Cu found in plants of S1 and S2 are similar to those found by the same authors whom are 40 and 39 mg kg^{-1}, respectively. By cons, the value of Mn is much higher than that found by the same authors. So, the concentrations of this element used in NS must be decrease (Table 1) to the ideal 0.64 mg L^{-1} (Blanc, 1987). Because according to Palencia *et al.* (2010), the values of Zn and Cu had to be 40 and 39 mg kg^{-1}, respectively.

Effect on EC and pH: The standard parameter for EC of strawberry crop is between 1.5 to 2.5 dS.m^{-1} (Saied *et al.*, 2005; D'Anna *et al.*, 2003; Carusoa *et al.*, 2011) which is in accordance with the results obtained in S1, S2, S3and S4 (Fig. 5). While in S6, it is so higher. EC superior to 2.2 mS cm^{-1} results in the reduction of plant biomass and leaf area (Klamkowski and Treder, 2008). In other hand and in our experiment, the response to the variation of Mg on the EC (Fig. 5) was leakely correlated.

Excepted in S4 and S6, the pH was superior to 7 (Fig. 5). This elevated pH is caused by the absence of NH_4^+ (Mengel and Kirkby, 2001) in all NS. An alkaline pH in NS does not allow the uptake of micronutrients. By cons, slight acidity, fewer than 6.5 is beneficial to absorption of all trace micronutrients (Babiker *et al.*, 2004; De Paz and Ramos, 2004; Albregts and Howard, 1980). In our experiment, the response to the variation of Mg on the pH was weakly correlated.

DISCUSSION

This study aims to determine the optimal concentration of Mg to de Strawberry (*Fragaria*×*ananassa* Duch.) "Seolhyang" growing in soilless culture. In the same growing conditions and with the same variety, previous works has been done by Choi *et al.* (2010) on N, by Choi *et al.* (2011a) on NH4^{+} to NO_3^- ratios and by Choi *et al.* (2013) on P. The mg uptake is depending to the optimal concentration of K^+ and Ca^{2+} in NS. Because, when Ca2+, Mg^{2+} and K^+ concentrations are in the adequate range, they have a significant impact on yield, even without vegetative signs of deficiency (Brennan *et al.*, 2007; Paranjpe *et al.*, 2008; Murillo-Amador *et al.*, 2006).

The all results on growth characteristic, on tissue nutrient contents had shown that the solution S4 would allow the relatively best uptake of nutrients and a normal growth of plants. However, its ratio $K^+/(Ca^{2+}+Mg^+) = 0.71$ can create a nutritional imbalance during the evolution of strawberry physiological stages. This ratio must be according to Latigui (1992) and Choi *et al.* (2013) around 0.61. The relatively best pH, less than 7 allowing the best uptake of micronutrients is obtained, also by S4. The high pH for all solution is due to the absence of NH_4^+ in NS. Because, According to (Britto and Kronzuker, 2002; Kotsiras *et al.*, 2002; Klamkowski and Treder, 2007), the use of the two forms NO_3^- and NH_4^+ is necessary for a normal growth. In this fact, It must be introduced the NH_4^+ in NS (Choi *et al.*, 2010; Choi *et al.*, 2011a).

The S4 compounded initially by 5 K^+, 5 Ca^{2+} 2 Mg^{2+}, 1 Na^+, 10 NO_3^-, 2 SO_4^{2-}, 1 H_2PO_4 with a pH 6.5, EC = 2.2, $K^+/(Ca^{2+}+Mg^{2+}) = 0.71$ and Σcations = Σcanions

(13 meq.L^{-1}) must be improved by decreasing a pH and adjusting this ratio to around 0.61. In this fact, it is necessary to introduce in NS 2.5 meq.L^{-1} of NH_4^+ in place to Na. Mengel and Kirkby (2001) showed that 20% NH_4^+ in total N ensures in most cases, the best possible balance.

Other changes in the levels of K^+, $Ca^{2+}$and Mg allowed K+/(Ca^{2+}+Mg^{2+}) to be equal to 0.61 which is ideal as regards the ionic balance at this stage of development. Depending of results of this study, the new solution improved would be compounded by 5Ca^{2+}, 4.5 K^+, 2.3 Mg^{2+}, 2.5 NH_4^+, 5 NO_3^-, 2.3SO_4 and 1 $H_2PO_4^-$with Σcations = Σanions (14.3 meq.L^{-1}). Because, the main tool to balance the total cation-to-anion uptake ratio appearing to be beneficial to the plant (Sonneveld, 2002; Klamkowski and Treder, 2007).

CONCLUSION

This experiment complements the works already done on Nitrogen, ammonium and Phosphorus. It was conducted by the same authors in the same conditions on the same variety Strawberry (*Fragaria×ananassa* Duch.) "Seolhyang" growing in soilless culture. It showed that, the MgC $_2$ meq.L^{-1} in the NS resulted in the relatively highest vegetative growth with a favorable EC and pH for a better growth and nutrients uptake. This solution compounded initially by 5 K^+, 5 Ca^{2+} 2 Mg^{2+}, 1 Na^+, 10 NO_3^-, 2 SO_4^{2-}, 1 $H_2PO_4^-$with a pH6.5, EC = 2.2, K^+/(Ca^{2+}+Mg^{2+}) = 0.71 and Σcations = Σanions (13 meq.L^{-1}) has been improved by decreasing a pH and adjusting the ratio cited to around 0.61. Depending of the results of this study, the new solution improved is compounded by 5 Ca^{2+}, 4.5 K^+, 2.3 Mg^{2+}, 2.5 NH_4^+, 5 NO_3^-; 2.3 SO_4^{2-} and 1 $H_2PO_4^-$ with Σcations = Σanions (14.3 meq.L^{-1}), a pH6 and EC = 2.3 dS.m^{-1}.

This new configuration would allow, according to several authors, a relatively best nutrients uptake allowing thus, a best growth and higher fruits yield.

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REFERENCES

Albregts, E.E. and C.M. Howard, 1980. Accumulation of nutrients by strawberry plants and fruit grown in annual hill culture. J. Am. Soc. Hortic. Sci., 105: 386-388.

Ankele, E., P. Kindgren, E. Pesquet and A. Strand, 2007. *In vivo* visualization of Mg-protoporphyrin IX, a coordinator of photosynthetic gene expression in the nucleus and the chloroplast. Plant Cell, 19: 1964-1979.

Appenroth, K.J., H. Gabrys and R.W. Scheuerlein, 1999. Ion antagonism in phytochrome-mediated calcium-dependent germination of turions of *Spirodela polyrhiza* (L.). Schleiden Planta, 208: 583-587.

Appenroth, K.J. and H. Gabrys, 2003. Ion antagonism between calcium and magnesium in phytochrome-mediated degradation of storage starch in *Spirodela polyrhiza*. Plant Sci., 165: 1261-1265.

Assuero, S.G., A. Mollier and S. Pellerin, 2004. The decrease in growth of phosphorus-deficient maize leaves is related to a lower cell production. Plant Cell Environ., 27: 887-895.

Axelsson, E., J. Lundqvist, A. Sawicki, S. Nilsson and I. Schroder *et al*., 2006. Recessiveness and dominance in barley mutants deficient in Mg-chelatase subunit D, an AAA protein involved in chlorophyll biosynthesis. Plant Cell, 18: 3606-3616.

Azuma, R., N. Ito, N. Nakayama, R. Suwa and N.T. Nguyen *et al*., 2010. Fruits are more sensitive to salinity than leaves and stems in pepper plants (*Capsicum annuum* L.). Scientia Horticulturae, 125: 171-178.

Babiker, I.S., M.A.A. Mohamed, H. Terao, K. Kato and K. Ohta, 2004. Assessment of groundwater contamination by nitrate leaching from intensive vegetable cultivation using geographical information system. Environ. Int., 29: 1009-1017.

Babu, C.R., C. Vijayalakshmi and S. Mohandass, 2005. Evaluation of rice (*Oryza sativa* L.) genotypes for salt tolerance. J. Food Agric. Environ., 3: 190-194.

Bennett, W.F., 1997. Nutrients Deficiencies and Toxicities in Crop Plants. The American Phytopathological Society Press, St Paul, MN., USA.

Bernstein, L., 1975. Effects of salinity and sodicity on plant growth. Ann. Rev. Phytopathol., 13: 295-312.

Blanc, D., 1987. Les Cultures Hors Sol. Ouvrage Collectif INRA, Paris, Pages: 409.

Bonnemain, J.L., 1964. Transport du ^{14}C assimile chez les Solanacees. Rev. Gen. Bot., 75: 579-610.

Brennan, R.F., M.D.A. Bolland and G.H. Walton, 2007. Comparing the calcium requirements of wheat and canola. J. Plant Nutr., 30: 1167-1184.

Britto, D.T. and H.J. Kronzucker, 2002. NH_4^+ toxicity in higher plants: A crutial review. J. Plant Physiol., 159: 567-584.

Cakmak, I., C. Hengeler and H. Marschner, 1994. Changes in phloem export of sucrose in leaves in response to phosphorus, potassium and magnesium deficiency in bean plants. J. Exp. Bot., 45: 1251-1257.

Cakmak, I. and E.A. Kirkby, 2008. Role of magnesium in carbon partitioning and alleviating photooxidative damage. Physiol. Plant., 133: 692-704.

Cambrolle, J., S. Redondo-Gomez, E. Mateos-Naranjo, T. Luque and M.E. Figueroa, 2011. Physiological responses to salinity in the yellow-horned poppy *Glaucium flavum*. Plant Physiol. Biochem., 49: 186-194.

Carusoa, G., G. Villarib, G. Melchionnac and S. Conti, 2011. Effects of cultural cycles and nutrient solutions on plant growth, yield and fruit quality of alpine strawberry (*Fragaria vesca* L.) grown in hydroponics. Scientia Horticulturae, 129: 479-485.

Cataldo, D.A., M. Haroon, L.E. Schrader and V.L. Youngs, 1975. Rapid colorimetric determination of nitrate in plant tissue by nitration of salicylic acid. Soil Sci. Plant Anal., 6: 71-80.

Chakraborty, K., R.K. Sairam and R.C. Bhattacharya, 2012. Differential expression of salt overly sensitive pathway genes determines salinity stress tolerance in *Brassica* genotypes. Plant Physiol. Biochem., 51: 90-101.

Choi, J.M., S.K. Jeong, K.H. Cha, H.J. Chung and K.S. Seo, 2000. Deficiency symptom, growth characteristics and nutrient uptake of Nyoho strawberry as affected by controlled nitrogen concentration in fertilizer solution. J. Korean. Soc. Hortic. Sci., 41: 339-344.

Choi, J.M. and A. Latigui, 2008. Effect of various magnesium concentrations on the quantity of chlorophyll of 4 varieties of strawberry plants (*Fragaria ananassas* D.) cultivated in inert media. J. Agron., 7: 244-250.

Choi, J.M., A. Latigui and Y.M. Kyung, 2010. Growth and nutrient uptake of seolhyang strawberry (Fragaria x ananassa Duch) responded to elevated nitrogen concentrations in nutrient solution. Korean J. Hort. Sci. Technol., 285: 777-782.

Choi, J.M., A. Latigui and C.W. Lee, 2011a. Growth and nutrient uptake responses of Seolhyang strawberry to various ratios of ammonium to nitrate nitrogen in nutrient solution culture using inert media. Afr. J. Biotechnol., 10: 12567-12574.

Choi, J.M., J.Y. Park and A. Latigui, 2011b. Impact of physicochemical properties of root substrates on growth of mother plants and occurence of daughter plants in seolhyang strawberry propagation through bag culture. Kor. J. Hort. Sci. Technol., 29: 95-101.

Chou, T.S., Y.Y. Chao, W.D. Huang, C.Y. Hong and C.H. Kao, 2011. Effect of magnesium deficiency on antioxidant status and cadmium toxicity in rice seedlings. J. Plant Physiol., 168: 1021-1030.

Choi, J.M., A. Latigui and C.W. Lee, 2013. Visual symptom and tissue nutrient contents in dry matter and petiole sap for diagnostic criteria of phosphorus nutrition for 'Seolhyang' strawberry cultivation. Environ. Biotechnol., 54: 52-57.

Cowan, J.A., 2002. Structural and catalytic chemistry of magnesium-dependent enzymes. Biometals, 15: 225-235.

Croteau, R., H. El-Bialy and S.S. Dehal, 1987. Metabolism of monoterpenes: Metabolic fate of (+) camphor in sage (*Salvia officinalis*). Plant Physiol., 84: 643-658.

D'Anna, F., G. Incalcaterra, A. Moncada and A. Miceli, 2003. Effects of different electrical conductivity levels on strawberry grown in soilless culture. Acta Hort., 609: 355-360.

Darnell, R.L. and G.W. Stutte, 2001. Nitrate concentration effects on NO_3-N uptake and reduction, growth and fruit yield in strawberry. J. Am. Soc. Hort. Sci., 125: 560-563.

De Kreij, C., W. Voogt and R. Baas, 1999. Nutrient Solutions and Water Quality For Soilless Cultures. Research Station for Floriculture and Glasshouse Vegetables (PBG) Brochure, The Netherlands, Pages: 32.

De Paz, J.M. and C. Ramos, 2004. Simulation of nitrate leaching for different nitrogen fertilization raters in a region of Valencia (Spain) using a GIS-GLEAMS system. Agric. Ecosyst. Environ., 103: 59-73.

Ding, Y.C., C.R. Chang, W. Luo, Y.S. Wu, X.L. Ren, P. Wang and G.H. Xu, 2008. High potassium aggravates the oxidative stress inducedy by magnesium deflciency in rice leaves. Pedosphere, 18: 316-327.

Dreyer, E., J. Fitchter and M. Bonneau, 1994. Nutrient content and photosynthesis of young yellowing Norway spruce trees (*Picea abies* L. Karst.) following calcium and magnesium fertilisation. Plant Soil, 160: 67-78.

Epstein, E. and A.J. Bloom, 2005. Mineral Nutrition of Plants: Principles and Perspectives. 2nd Edn., Sinauer Associates, Sunderland, MA, USA., ISBN:13-9780878931729, Pages: 400.

Ericsson, T. and M. Kahr, 1995. Growth and nutrition of birch seedlings at varied relative addition rates of magnesium. Tree Physiol., 15: 85-93.

Falade, A.J., 2006. Effects of macronutrients on mineral distribution in cashew (*Anacardium occidentale* L.). J. Sci. Food Agric., 29: 81-86.

Fonteno, W.C. and P.V. Nelson, 1990. Physical properties of and plant response to rock-wool amended media. J. Am. Soc. Hort. Sci., 115: 375-381.

Hammond, J.P., M.J. Bennett, H.C. Bowen, M.R. Broadley and D.C. Eastwood *et al*., 2003. Changes in gene expression in arabidopsis shoots during phosphate starvation and the potential for developing smart plants. Plant Physiol., 132: 578-596.

Hariadi, Y. and S. Shabala, 2004. Screening broad beans (*Vicia faba*) for magnesium deficiency. I. Growth characteristics, visual deficiency symptoms and plant nutritional status. Functional Plant Biol., 31: 529-537.

Hermans, C., G.N. Johnson, R.J. Sstsrasser and N. Verbruggen, 2004. Physiological characterisation of magnesium deficiency in sugar beet: Acclimation to low magnesium differentially affects photosystems I and II. Planta, 220: 344-355.

Hermans, C., F. Bourgis, M. Faucher, R.J. Strasser, S. Delrot and N. Verbruggen, 2005. Magnesium deficiency in sugar beets alters sugar partitioning and phloem loading in young mature leaves. Planta, 220: 541-549.

Hermans, C., J.P. Hammond, P.J. White and N. Verbruggen, 2006. How do plants respond to nutrient shortage by biomass allocation? Trends Plant Sci., 11: 610-617.

Hopkins, W.G., 2003. Introduction to Plant Physiology. Wiley, New York, Pages: 66.

Kamel, M., 2002. The effect of sudden sodium chloride stress on the ion composition and the mechanism of osmotic adjustment in *Vicia faba*. Pak. J. Biol. Sci., 5: 885-890.

Kchaou, H., A. Larbi, K. Gargouri, M. Chaieb, F. Morales and M. Msallem, 2010. Assessment of tolerance to NaCl salinity of five olive cultivars, based on growth characteristics and Na^+ and Cl^- exclusion mechanisms. Sci. Hort., 124: 306-315.

Keutgen, A.J. and E. Pawelzik, 2008. Quality and nutritional value of strawberry fruit under long term salt stress. Food Chem., 107: 1413-1420.

Keutgen, A.J. and N. Keutgen, 2003. Influence of NaCl salinity stress on fruit quality in strawberry. Acta Hort., 609: 155-157.

Kim, T.I., W.S. Jang, J.H. Choi, M.H. Nam, W.S. Kim and S.S. Lee, 2004. Breeding of Maehang strawberry for culture. Korean J. Hortic. Sci. Technol., 22: 434-437.

Klamkowski, K. and W. Treder, 2007. Morphological and physiological responses of strawberry plants to water stress. Agric. Conspectus Sci., 71: 159-165.

Klamkowski, K. and W. Treder, 2008. Response to drought stress of three strawberry cultivars grown under greenhouse conditions. J. Fruit Ornamental Plant Res., 16: 179-188.

Kotsiras, A., C.M. Olympios, J. Drosopoulos and H.C. Passam, 2002. Effects of nitrogen form and concentration on the distribution of ions within cucumber fruits. Sci. Hort., 95: 175-183.

Kristek, A., V. Kovacevic and M. Antunovic, 2000. Response of sugar beet to foliar magnesium fertilization with Epsom salts. Rostlinna Vyroba, 46: 147-152.

Latigui, A., 1992. Effect of different fertilizations of the eggplant and tomatoes grown in inert media on the biotic potential of *Macrosiphum euphorbiae*. PhD Thesis, University Aix Marseille III, France.

Leikam, D.F., L.S. Murphy, D.E. Kissel, D.A. Whitney and H.C. Mserh, 1983. Effect of nitrogen and phosphorus application and nitrogen source in winter wheat grand yield and leaf tissue phosphorus. Soil. Sci. Soc. Am. J., 47: 530-535.

Li, L., A.F. Tutone, R.S. Drummond, R.C. Gardner and S. Luan, 2001. A novel family of magnesium transport genes in Arabidopsis. Plant Cell, 13: 2761-2775.

Maathuis, F.J.M., 2009. Physiological functions of mineral macronutrients. Curr. Opin. Plant Biol., 12: 250-258.

Maroto, J.V., S. Lopez-Galarza, A. San Bautista and B. Pascual, 1996. Cold stored and fresh multicrown strawberry plants for autumn-winter production in eastern Spain. Acta Hort., 439: 545-548.

Marschner, H., 1995. The Mineral Nutrition of Higher Plants. 2nd Edn., Academic Press, London, UK.

Mengel, K. and E.A. Kirby, 1987. Principle of Plant Nutrition. International Potash Institute, Bern, Switzerland.

Mengel, K. and E.A. Kirkby, 2001. Principles of Plant Nutrition. Springer, London, UK., ISBN-13: 9781402000089, Pages: 849.

Millero, F.J., R. Feistel, D.G. Wright and T.J. McDougall, 2008. The composition of standard seawater and the definition of the reference-composition salinity scale. Deep Sea Res. I: Oceanogr. Res. Pap., 55: 50-72.

Munns, R., 2002. Comparative physiology of salt and water stress. Plant Cell Environ., 25: 239-250.

Munoz, P., A. Anton, A. Paranjpe, J. Arino and J.I. Montero, 2008. High decrease in nitrate leaching by lower N input without reducing greenhouse tomato yield. Aron. Sustainb. Dev., 28: 489-495.

Murillo-Amador, B., H.G. Jones, C. Kaya, R.L. Aguilar and J.L. Garcia-Hernandez *et al*., 2006. Effects of foliar application of calcium nitrate on growth and physiological attributes of cowpea (*Vigna unguiculata* L. Walp) grown under salt stress. Environ. Exp. Bot., 58: 188-196.

Neves, O.S.C., J.G. de Carvalho, F.A.D. Martins, T.R.P. de Padua and P.J. de Pinho, 2005. Use of SPAD-502 in the evaluation of chlorophyll contents and nutritional status of herbaceous cotton to nitrogen, sulphur, iron and manganese. Pesquisa Agropecuaria Brasileira, 40: 517-521.

Palencia, P., F. Martinez, E. Ribeiro, M. Pestana and F. Gama *et al*., 2010. Relationship between tipburn and leaf mineral composition in strawberry. Sci. Hortic., 126: 242-246.

Paranjpe, A.V., D.J. Cantliffe, P.J. Stoffella, E.M. Lamb and C.A. Powell, 2008. Relationship of plant density to fruit yield of Sweet Charlie strawberry grown in a pine bark soilless medium in a high-roof passively ventilated greenhouse. Scientia Horticulturae, 115: 117-123.

Parvizi, Y., A. Ronaghi, M. Maftoun and N.A. Karimian, 2004. Growth, nutrient status and chlorophyll meter readings in wheat as affected by nitrogen and manganese. Commun. Soil Sci. Plant Anal., 35: 1387-1399.

Paul, M.J. and T.K. Pellny, 2003. Carbon metabolite feedback regulation of leaf photosynthesis and development. J. Exp. Bot., 54: 539-547.

Perez-Tornero, O., C.I. Tallon, I. Porras and J.M. Navarro, 2009. Physiological and growth changes in micropropagated *Citrus macrophylla* explants due to salinity. J. Plant Physiol., 166: 1923-1933.

Pritts, M., 1998. Soil and Nutrient Management. In: Strawberry Production Guide, Pritts, M. and D. Handley (Eds.). NRAES Publications, New York, USA.

Quintero, J.M., J.M. Fournier and M. Benlloch, 2008. Na^+ accumulation in shoot is related to water transport in K^+-starved sunflower plants but not in plants with a normal K^+ status. J. Plant Physiol., 16: 1248-1254.

Rao, B.R.R. and D.K. Rajput, 2011. Response of palmarosa {*Cymbopogon martini* (Roxb.) Wats. var. *Motia* Burk.} to foliar application of magnesium and micronutrients. Ind. Crops Prod., 33: 277-281.

Razavi, F., B. Pollet, K. Steppe and M.C. van Labeke, 2008. Chlorophyll fluorescence as a tool for evaluation of drought stress in strawberry. Photosynthetica, 46: 631-633.

Reimann, R., G. Ritte, M. Steup and K.J. Appenroth, 2002. Association of α-amylase and the R1 protein with starch granules precedes the initiation of net starch degradation in turions of *Spirodela polyrhiza*. Physiol. Plant., 114: 2-12.

Richardson, A.D., S.P. Duigan and G.P. Berlyn, 2002. An evaluation of noninvasive methods to estimate foliar chlorophyll content. New Phytologist, 153: 185-194.

Risser, G. and J.C. Navatel, 1997. Monographie: La Fraise Plants et Varietes. CTIFL, France, Pages: 103.

Rubio, F., P. Flores, J.M. Navarro and V. Martinez, 2003. Effects of Ca^{2+}, K^+ and cGMP on Na^+ uptake in pepper plants. Plant Sci., 165: 1043-1049.

Saied, A.S., A.J. Keutgen and G. Noga, 2005. The influence of NaCl salinity on growth, yield and fruit quality of strawberry cvs. Sci. Hortic., 103: 289-303.

San Bautista, A., S. Lopez-Galarza, A. Martinez, B. Pascual and J.V. Maroto, 2009. Influence of cation proportions of the nutrient solution on tipburn incidence in strawberry plants. J. Plant Nutr., 32: 1527-1539.

Savvas, D., 2001. Nutritional Management of Vegetables and Ornamental Plants in Hydroponics. In: Crop Management and Postharvest Handling of Horticultural Product, Dris, R., R. Niskanen and S.M. Jain (Eds.). Vol. 1, Science Publishers, Enfield, NH., pp: 37-87.

Scheepers, J.S., D.D. Francis, M. Vigil and F.M. Below, 1992. Comparison of corn leaf-nitrogen concentration and chlorophyll meter readings. Commun. Soil Sci. Plant Anal., 23: 2173-2187.

Shaahan, M.M., A.A. El-Sayed and E.A.A. Abou El-Nour, 1999. Predicting nitrogen, magnesium and iron nutritional status in some perennial crops using a portable chlorophyll meter. Scientia Horticult., 82: 339-348.

Shaul, O., 2002. Magnesium transport and function in plants: The tip of the iceberg. Biometals, 15: 307-321.

Sirijovski, N., J. Lundqvist, M. Rosenback, H. Elmlund, S. Al-Karadaghi, R.D. Willows and M. Hansson, 2008. Substrate-binding model of the chlorophyll biosynthetic magnesium chelatase BchH subunit. J. Biol. Chem., 283: 11652-11660.

Sonneveld, C., 2000. Effects of salinity on substrate grown vegetables and ornamentals in greenhouse horticulture. Ph.D. Thesis, Wageningen University, The Netherlands.

Sonneveld, C., 2002. Composition of Nutrient Solutions. In: Hydroponic Production of Vegetables and Ornamentals, Savvas, D. and H.C. Passam (Eds.). Embryo Publications, Athens, Greece, pp: 179-210.

Stys, D., 1995. Stacking and separation of photosystem I and photosystem II in plant thylakoid membranes: A physico-chemical view. Physiol. Plantarum, 95: 651-657.

Suarez, N., 2011. Effects of short- and long-term salinity on leaf water relations, gas exchange and growth in *Ipomoea pes-caprae*. Flora-Morphol. Distribut. Funct. Ecol. Plants, 206: 267-275.

Tabatabaei, S.J., M. Yusefi and J. Hajiloo, 2008. Effects of shading and NO_3: NH_4 ratio on the yield, quality and N metabolism in strawberry. Scientia Horticult., 116: 264-272.

Tagliavini, M., E. Baldi, P. Lucchi, M. Antonelli, G. Sorrenti, G. Baruzzi and W. Faedi, 2005. Dynamics of nutrients uptake by strawberry plants (*Fragaria*? *Ananassa* Dutch.) grown in soil and soilless culture. Eur. J. Agron., 23: 15-25.

Tei, F., P. Benincasa and M. Guiducci, 2002. Critical nitrogen concentration in processing tomato. Eur. J. Agron., 18: 45-55.

Tomonou, Y. and Y. Amao, 2002. Visible light induced hydrogen production with Mg chlorophyll-a from *spirulina* and colloidal platinum. Biometals, 15: 391-395.

Vigo, C., I.N. Therios and A.M. Bosabalidis, 2005. Plant growth, nutrient concentration and leaf anatomy of olive plants irrigated with diluted seawater. J. Plant Nutr., 28: 1001-1021.

Vrataric, M., A. Sudaric, V. Kovacevic, T. Duvnjak, M. Krizmanic and A. Mijic, 2006. Response of soybean to foliar fertilization with magnesium sulfate (Epsom salt). Cereal Res. Commun., 34: 709-712.

Warncke, D.D., 1986. Analyzing greenhouse growth media by the saturation extraction method. HortScience, 21: 223-225.

Watanabe, T., M.R. Broadley, S. Jansen, P.J. White and J. Takada *et al*., 2007. Evolutionary control of leaf element composition in plants. New Phytol., 174: 516-523.

White, P.J. and M.R. Broadley, 2009. Biofortification of crops with seven mineral elements often lacking in human diets-iron, zinc, copper, calcium, magnesium, selenium and iodine. New Phytologist, 182: 49-84.

Wollman, F. and B.A. Diner, 1980. Cation control of emission, light scatter and membrane stacking in pigment mutants of *Chlamydomona sreinhardi*. Arch. Biochem. Biophys., 201: 646-659.