INNSPUB

International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print), 2222-5234 (Online)
http://www.innspub.net
Vol. 22, No. 3, p. 1-11, 2023

RESEARCH PAPER OPEN ACCESS

Impact of epsom salt on mineral uptake and correlation studies in *Beta vulgaris*

Palve Sandip Balaji*[1], Ahire Digambar Dadaji[1], Harkal Ananta Dnyanoba[2]

[1]*Department of Botany, New Arts, Commerce and Science College Ahmednagar, 414001, India*

[2]*Department of Zoology, New Arts, Commerce and Science College Ahmednagar, 414001, India*

Key words: Electrical conductivity, Epsom salt, Iron, Mineral nutrition, Red beet

http://dx.doi.org/10.12692/ijb/22.3.1-11 Article published on March 04, 2023

Abstract

Beta vulgaris L., commonly called beet, belongs to the family Chenopodiaceae. Recently utilized in manufacturing sugar, food color and ethanol production and many commercial applications. The application of Epsom salt can have a positive impact on the mineral uptake. The increased concentration of magnesium in the soil can enhance the uptake of other nutrients, which can lead to an increase in the yield and quality of the crop. During the vegetation period different Epsom salt (ES) electrical conductivity levels affected macro and micronutrient content in the beetroot leaves was investigated in current research. The experimental work was conducted with various ES electrical conductivity treatments (2.5, 5.0, 7.5, 10.0, 12.5, 15.0, 17.5 and 20.0 mSm^{-1} and control). A trend was observed, with increasing ES treatment up to 20.0 mSm^{-1} ES P, Mg, S, Cl and Mn also showed increased in uptake. Highest N and Ca uptake by the plant was recorded at 5.0 mSm^{-1} ES. In our investigation, the interrelationships between leaf mineral nutrition parameters of Epsom salt-treated plants have found a strong positive association between Mn with P (r=0.890), Mg (r=0.883) and S (r=0.926) and strong negative correlation with Ca (r=-0.818) at P > 0.01. Also, we observed that Ca shows a strong negative correlation with Fe; and Na shows a negative correlation with P, Cl, Mg and Mn. Among all the minearals S shows the highest CV (34.47 %). Treatments with < 5.0 mSm^{-1} ES are the most efficient methods for promoting beet growth and productivity; however, the treatment > 7.5 mSm^{-1} ES induced stress.

* **Corresponding Author:** Sandip Balaji Palve ✉ sandipalve@gmail.com

Introduction

Agriculturalists face several questions when considering a crop's mineral nutrition. They must determine which nutrients are limiting yield and determine the appropriate amount of nutrients that need to be applied to optimize primary yield conditions. Answering these questions is crucial to ensure that crops reach their maximum potential and produce high-quality yields. Because the beet price is determined by its quality, whether its size, shape, color, dry matter content or any other characteristic required for specific markets, it is necessary to understand how the specific nutrients applied may affect these qualities. According to Johnson and Uriu (1989), there are 13 essential nutrients are required for optimum production in large amounts of macronutrients (N, P, K, Ca, Mg and S) and smaller amounts (chlorine (Cl), iron (Fe), manganese (Mn), zinc (Zn), boron (B), copper (Cu) and molybdenum (Mo).) quantities. Also, soil salinization is a well-known issue often linked to human influences and climate change. It could jeopardize the quality of agricultural products. In recent years according to Shrivastava and Kumar (2015), population growth has resulted in increased agricultural production and, as a result, increased water consumption, pushing this resource to its limit. Poor water quality and saline soil conditions have been caused by agricultural practices such as overuse of fertilizers, counterproductive irrigation systems and rising sea levels (Machado and Serralheiro, 2017). Seed germination, seedling growth, leaf size, shoot growth, shoot and root lengths, shoot dry weight/fresh weight, tiller number, flowering stage, spikelet number, percent of sterile florets and productivity are all affected by salinity stress (Jenks *et al.*, 2007; Gupta & Huang, 2014).

According to Wang *et al.* (2020), the most recent scientific reports, crop plants respond differently to different forms and rates of applied Mg fertilizers. The response of sugar beets to magnesium is also influenced by interactions with other nutrients such as potassium, calcium and sulfur (Gransee & Führs, 2013; Orlovius & McHoul, 2015). Magnesium sulfate is used in agriculture for various purposes, including correcting magnesium deficiency in the soil and according to researchers, overuse of magnesium sulfate has been linked to plant damage (Boynton 1943; Boynton *et al.* 1943; Nagai *et al.* 1966). Magnesium sulfate ($MgSO_4$), also known as Epsom salt, is a naturally occurring mineral that contains magnesium and sulfur. Plants require a large amount of magnesium, essential for photosynthesis and subsequent long-distance transport of photoassimilates. Magnesium is required for chlorophyll production in plants, whereas sulfur is required for protein synthesis. Complex interactions of anatomical, physiological and biochemical responses reduce photosynthetic carbon assimilation if magnesium is not present in sufficient amounts in photosynthetic tissues (Tränkner *et al.*, 2018). In our work, we investigated beetroot (*Beta vulgaris*), generally known as garden beet, a descendant of the halotolerant sea beet (*Beta vulgaris* subsp. *Maritima* L.). Beet is native to the Mediterranean region but widely grown in the United States, Europe and India. Beet has a long history of use in medicine, with applications in fertility, cancer, hypertension and urinary tract disorders (Chawla *et al.*, 2016). Beets contain special phyto-constituents that have been shown to possess various health-promoting properties, including anti-oxidant, antidepressant, anti-microbial, anti-inflammatory, diuretic, and expectorant activities (Ghasemzadeh & Ghasemzadeh, 2017). It is an excellent dietary supplement packed with nutrients, minerals, amino acids and vitamins (Smith 2022).

Several studies have investigated the effects of Epsom salt on mineral uptake in *Beta vulgaris*. For instance, Jiang *et al.* (2020) reported that the application of magnesium and sulfur (in the form of Epsom salt) increased the uptake of several macro and micro-nutrients in sugar beet, including magnesium, calcium, potassium, iron, and manganese. Aghakhani *et al.* (2019) reported a positive correlation between magnesium content of soil and beet leaves. Similarly, Linneman *et al.* (2020) found a positive correlation between zinc content of soil and beet roots. These findings suggest that the mineral content of beet plants may be influenced by soil mineral content, and that soil analysis may be a useful tool for predicting the nutrient content of harvested beet plants. the existing literature suggests that the use of Epsom salt as a fertilizer may enhance the uptake and utilization of essential minerals in *Beta vulgaris*. Additionally, soil analysis may be a useful tool for predicting the nutrient content of harvested beet plants. However, further research is needed to determine the optimal levels of Epsom salt application, as well as the long-term effects of Epsom salt on soil health and the environment. In view of this background the objective of this study was formulated to investigate effect of Epsom salt on growth, mineral uptake and their correlations in beetroot.

Material and method

Plant mineral nutrition

A beetroot variety of Detroit dark red were used to investigates the effects of different concentrations of epsom salt treatments. At the time of harvesting, one set of ES-treated plants were used for mineral nutrition study. Plants were separated, sun-dried and oven-dried at 70 Celsius until constant weight. Completely dried plant material was subjected to triple acid digestion (Chapman & Pratt, 1961). The Microkjeldahl method, as described by Parkinson & Allen (1975), was used to estimate nitrogen in plant samples. Sodium and potassium were estimated by the Flame photometric method as described by Jackson (1973). Calcium was estimated by the Versanated titration method as by Chapman and Pratt (1961). As Zasoski & Burau (1977) described, the plant's micronutrients (Fe, Mn, Mg) were estimated on atomic absorption spectrophotometer. Phosphorous was determined by the method of Sekine *et al.* (1965). Chloride was determined by the method of Volhard (Humphries, 1956) and Sulfate was determined by the method of Chapman and Pratt (1961).

Soil mineral nutrition

Soil samples were collected by digging mini pits in plastic pots to a depth of 20 cm. Samples were collected at two depths of 0-3.0 cm and 20 cm. Collected soil samples were allowed to dry in the shade. The air-dried samples were ground carefully in a wooden mortar and pestle to break soil clumps.

These ground soil samples were passed through a 2.0 mm sieve, stored in carton boxes with proper labeling and used for subsequent analysis. Soil samples were collected for all treatments with a control.

Exchangeable calcium and magnesium were estimated by the Versenate titration method as described by Page *et al.* (1982). Exchangeable sodium and potassium were estimated by flame photometry as described by Page *et al.* (1982). Available nitrogen was estimated by the alkaline potassium permanganate method, as described by Subbiah & Asija (1956). Available phosphorous was estimated by Olsen (0.5 M $NaHCO_3$ at pH 8.5) method as described by Olsen *et al.* (1965). The available micronutrient viz., Fe, Mn was estimated by DTPA extractable (AAS) method as described by Lindsay & Norvell (1978). Available Sulphur was estimated by Gupta (1999). Chloride is estimated by Keeney & Nelson (1982).

Statistical analysis

The data was collected from plant and soil mineral nutrition studies for statistical data analysis. Software SPSS 16.0 was used to analyze data to calculate the mean value, standard deviation and Least Significant Difference (LSD) in the beet for each treatment and control. Software SPSS 16.0 was used to analyze data to calculate the mean value, minimum and maximum values, standard deviation and coefficient of variation (CV%). To test their significance, simple correlation coefficients were calculated using the bivariate correlation method (Pearson's Correlation Coefficient) at the probability levels of 0.05 and 0.01.

Result and discussion

NPK is essential for plant growth and plants use nitrogen (N) to make amino acids (proteins), nucleic acids, nucleotides and chlorophyll. Phosphorous (P) has a storage and energy transfer function; potassium (K) is an enzyme activator and assists in transport.

The effect of Epsom salt soil application on the mineral uptake in leaves was determined in the form of Nitrogen (N), Phosphorous (P) and Potassium (K). Under the application of Epsom salt increasing trend was observed. P uptake increased as the treatment concentration increased from 2.5 to 20.0 mSm^{-1} ES; however, maximum (1.70 % dm) P uptake by the plant was recorded at 20.0 mSm^{-1} ES over control. In the case of K, all levels of Epsom salt treatments had no/little effect on plant potassium. Nitrogen uptake showed a trend. As the Epsom salt concentration increases, a reduction in N uptake was observed. The plant observed the highest N uptake, i.e., 3.30 % dm, at 5.0 and 7.5 mSm^{-1} ES.

Table 1. Correlation Studies Between Leaf Mineral Nutrition Parameters under Increasing Concentrations of Epsom Salt.

	N	P	K	Na	Ca	Mg	S	Cl	Fe
P	-0.240								
K	0.482	-0.459							
Na	0.226	-0.786*	0.429						
Ca	0.786*	-0.513	0.719*	0.518					
Mg	-0.031	0.986**	-0.516	-0.760*	-0.523				
S	-0.368	0.734*	-0.659	-0.533	-0.853**	0.734*			
Cl	-0.121	0.962**	-0.533	-0.745*	-0.655	0.942**	0.880**		
Fe	-0.927**	0.245	-0.472	-0.247	-0.880**	0.234	0.597	0.367	
Mn	-0.345	0.890**	-0.696*	-0.750*	-0.818**	0.883**	0.926**	0.961**	0.537

*** Correlation is significant at the 0.01 level, * Correlation is significant at the 0.05 level.* N: Nitrogen, P: Phosphorous, K: Potassium, Na: Sodium, Ca: Calcium, Mg: Magnesium, S: Sulfur, Cl: Chloride, Fe: Iron, Mn: Manganese.

Other researchers have reported that magnesium sulfate fertilizer appears to increase nitrogen absorption by roots and thus nitrogen efficiency, increasing plant height and shoot growth in sunflowers and rice (Sreemannarayana *et al.,* 1998; Choudhury & Khanif, 2001). A study by Al-Lami (1999) suggests that the $MgSO_4.7H_2O$ application significantly increased phosphorus uptake by the plant. On the contrary, a high Mg supply consistently reduced Phosphorous concentrations to levels lower than those measured when Mg was low (Niu *et al.*, 2015). Many essential processes for forming yield in plants, such as water economy, carbohydrate synthesis and assimilate transport, are influenced by K and Mg (Mengel & Kirkby, 2012). K uptake is generally unaffected by higher Mg concentrations in the soil solution (Senbayram *et al.*, 2015).

Some researchers believe that the more potassium applied, the less magnesium plants absorb and that the more magnesium, the less potassium is absorbed (Yan & Hou, 2018).

Table 2. Mean, minimum and maximum values, standard deviation.

Statistics	N	P	K	Na	Ca	Mg	S	Cl	Fe	Mn
Minimum	2.20	0.90	1.70	1.50	1.10	0.60	0.10	465.00	62.00	38.00
Maximum	3.30	1.70	2.10	1.70	1.50	1.10	0.40	561.20	78.00	71.20
Mean	2.9	1.3	1.9	1.6	1.3	0.9	0.2	510.4	68.7	53.2
SD	0.4	0.3	0.1	0.1	0.1	0.1	0.1	34.3	5.6	11.7
CV %	12.49	20.74	6.93	4.66	9.98	16.37	34.47	6.72	8.17	21.97

SD: standard deviation, CV: coefficient of variation, N: Nitrogen, P: Phosphorous, K: Potassium, Na: Sodium, Ca: Calcium, Mg: Magnesium, S: Sulfur, Cl: Chloride, Fe: Iron, Mn: Manganese.

In our case, the Epsom salt treatment affected N and P, but it had no/little effect on plant K. Ca, Mg and S are secondary nutrients because plants require them in smaller quantities than NPK; they are essential to plant nutrients that can influence the soil's pH. Small amounts of Na used in the metabolism and synthesis of chlorophyll, similar to micronutrients. The effect of ES soil application on the mineral uptake in leaves was determined in the form of Sodium (Na), Calcium (Ca), Magnesium (Mg) and Sulfur (S).

Table 3. Contents of pH value and Mineral in Soil sample.

pH	Na	K	N	Ca	P	Mg	Cl	S	Fe	Mn
7.59	5.5 mg/100 gm soil	48.0 g/m²	5.0 g/m²	29.3 meq/lit	6.2 meq/lit	1.0 g/m²	4.2 meq/lit	5.2 ppm	2.0 ppm	4.4 ppm

In the present study, we observed that as the concentration of Epsom salt increased up to 20 mSm^{-1}, the Mg and S content increased in a plant over control. Maximum Mg and S (1.10 & 0.40 % dm, respectively) content was observed at 20.0 mSm^{-1} ES concentration. The highest Ca (1.5 % DM) content was recorded at 5.0 mSm^{-1} ES; it decreased further at higher Epsom salt treatments. Maximum Na uptake was recorded from 15.0 mSm^{-1} ES (Fig. 2). Numerous reports show that cations can reduce Mg uptake, whereas few studies show that Mg inhibits the uptake of other cations to the same degree. Mg fertilization of perennial ryegrass decreased the plant's Ca and Na content but did not affect K uptake (Scharrer & Jung, 1955). Mg-salts were found to inhibit root growth more than Na-salts in eucalyptus and this effect was linked to low calcium concentrations in the root (Marcar & Termaat, 1990). Because both are divalent cations with similar radius, the higher magnesium input prevents the plant from calcium uptake (Cornfield & Pollard, 1952; Cofie & Pleysier, 2005). High levels of Mg, which interfere with Ca uptake, may increase the incidence of diseases like tomato and pepper bacterial spots and peanut pod rot (Huber & Jones, 2013). High levels of Mg and Na in the soil inhibited the uptake of K and Ca, resulting in excessive Mg uptake (Huber & Jones, 2013). Although very less data is available on the effect of excess Epsom salt/ magnesium sulfate on Mg absorption, the study by Selvaraj and Sankar (2010) revealed that tea plants were treated with Mg^{2+} from 100 to 1000 mg/kg; interestingly, the accumulation of Mg in the root was higher than in the leaf and stem at any given treatment. Magnesium sulfate, applied at a rate of 40 kg ha^{-1}, was found to be a better source of sulfur than gypsum for raising mustard crops in West Bengal's sulfur-deficient acidic red and lateritic soils (Dash & Ghosh, 2012).

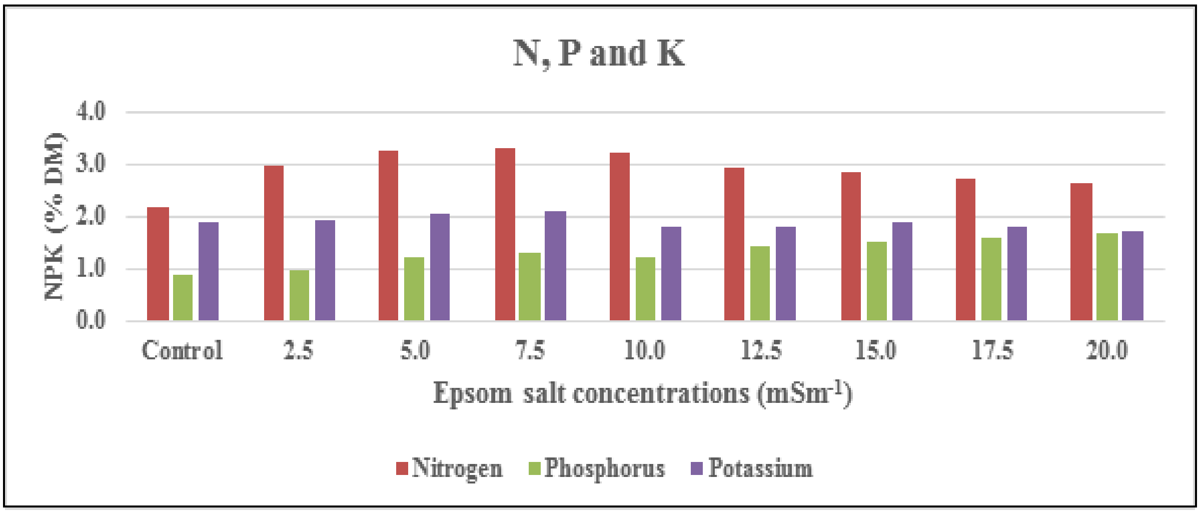

Fig. 1. Study on Nitrogen (N), Phosphorous (P) and Potassium (K) Under Increasing Concentrations of Epsom Salt. Values are given in mean ± SD. Bars in each group show significant difference at $p < 0.05$.

Chloride (Cl) is required for the water-splitting reaction in photosynthesis and aids in determining the solute concentration and anion cation balance in cells. Fe helps in electron transport and the formation of chlorophyll and activates the catalase enzyme. Mn activates many enzymes involved in nitrogen metabolism, respiration and photosynthesis. The influence of ES soil application on the mineral uptake in leaves was determined in the form of Chloride (Cl), Iron (Fe) and Manganese (Mn).

In the present investigation, chloride and manganese concentrations showed a trend as the Epsom salt concentration increased and the Cl and Mn content increased. Cl and Mn (561.20 & 71.20 ppm, respectively) content was observed at 20.0 mSm^{-1} ES concentration (Fig. 3). Fe did not show any difference in uptake at all Epsom salt treatments. In a study by Kobayashi *et al.* (2005), the excess Mg treatment increased the chloride content in rice. According to Fixen (1993), at high concentrations, chloride is not toxic to plants; however, some of the non-biochemical functions of chloride in osmoregulation may necessitate these high concentrations. Mg deficiency also resulted in a one-fourth increase in iron (Fe) concentration in Cd-treated leaves (Hermans *et al.*, 2011). With a higher concentration of externally added magnesium, the manganese content of the soil increased (Selvaraj & Sankar, 2010). Manganese has properties similar to both alkaline earth cations (Mg^{2+} and Ca^{2+}) and heavy metals (Zn and Fe) and increased magnesium input was found to increase the bivalent form of manganese in the soil (Marschner, 1995).

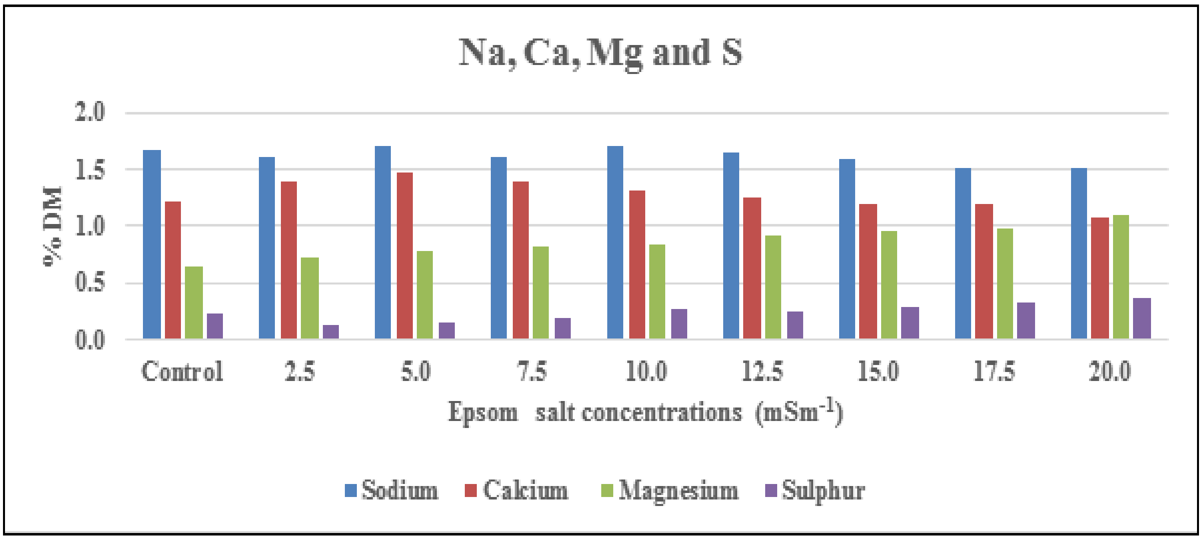

Fig. 2. Study on Sodium (Na), Calcium (Ca), Magnesium (Mg) and Sulfur (S) Under Increasing Concentrations of Epsom Salt. Values are given in mean ± SD. Bars in each group show significant difference at $p < 0.05$.

Correlation studies between leaf mineral nutrition parameters

The interrelationships between leaf mineral nutrition parameters such as N, P, K, Na, Ca, Mg, S, Cl, Fe and Mn were determined by correlation studies to find out the association of leaf minerals under Epsom salt application (Table 2).

The correlation studies among leaf mineral nutrition parameters of the beet revealed P shows negative correlations with Na ($r = -0.786$, $P < 0.05$) and significantly ($P < 0.01$) strong positive correlation with Mg ($r = 0.986$), Cl ($r = 0.962$) and S ($r = 0.734$, $P < 0.05$). Na shows a significant ($P < 0.05$) negative correlation with Mg ($r = -0.760$). In the case of Ca shows a significant ($P < 0.05$) positive relationship with N ($r = 0.786$) and K ($r = 0.719$). Fe shows a significant ($P < 0.01$) strong negative with N ($r = -0.927$) and Ca ($r = -0.880$) (Table 2). S shows a significant strong negative correlation with Ca ($r = -0.853$, $P < 0.01$) and a positive correlation with Mg ($r = 0.734$, $P < 0.05$). Cl has recorded a negative correlation ($P < 0.05$) with Na ($r = -0.745$) and a strong positive correlation with Mg ($r = 0.942$) and S ($r = 0.880$). Mn shows a significant ($P < 0.01$) positive correlation with P ($r = 0.890$), Mg ($r = 0.883$), S ($r = 0.926$), and Cl ($r = 0.961$), and a significantly negative correlation with K ($r = -0.696$, $P < 0.05$), Na ($r = -0.750$, $P < 0.05$) and Ca ($r = -0.818$, $P < 0.01$). In our investigation, the interrelationships between leaf mineral nutrition parameters of Epsom salt-treated plants have found a positive association between Mn with P, Ca, Fe, Mg and S. Also, we observed that Ca shows a strong negative correlation with Fe in treated plants. Na shows a negative correlation with P, Cl, Mg and Mn.

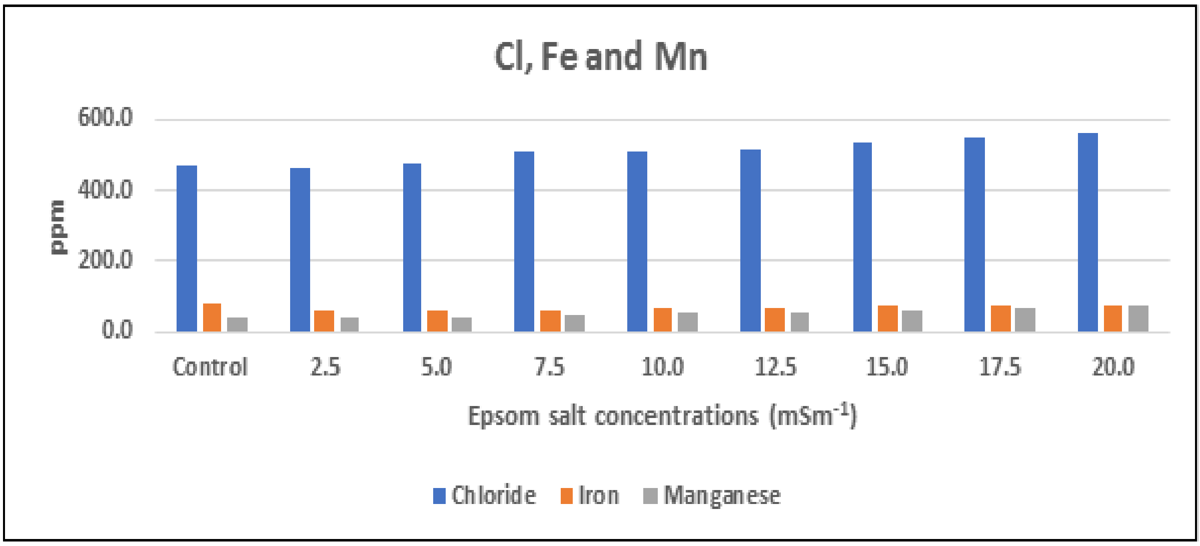

Fig. 3. Study on Chloride (Cl), Iron (Fe) and Manganese (Mg) Under Increasing Concentrations of Epsom.

In our study, Mg shows a strong positive correlation with P and $MgSO_4$ application improved P uptake and revealed a positive relationship between root morphological traits and nutrient uptake (Huang *et al.*, 2021). In the current study, no association was recorded between N and Mg; although Epsom salt did not influence N directly, mg fertilizers could be used in low N soils. Pogłodziński *et al.* (2021) reported that Epsom salt application reduced the need for nitrogen fertilizer in sugar beet. According to Jakobsen (1993), an element's uptake and distribution in plants are governed by supply conditions and interactions with other elements.

In the literature, lower correlations for microelements have been reported, possibly due to differences in nutrient availability in different growing systems (Nestby *et al.*, 2005). Effects of different Fe supplies on rice positively correlated with Mn and Mg in roots (Sperotto *et al.*, 2012). In wheat and barley, a strong positive correlation was discovered between plants' ability to retain K^+ in salt-treated leaves and their salinity tolerance (Wu *et al.*, 2013). There is little scientific evidence available on the correlation between Epsom salt stress and plant mineral uptake, and further research is needed. Nutrient transporters have been shown to cross-regulate with multiple nutrients at the local and whole plant levels and facilitate phytohormone uptake, which is necessary to maintain plant nutrient stoichiometry (Krouk *et al.*, 2010; Medici *et al.*, 2019). Manganese uptake capability is enhanced by Zn deficiency and a Fe deficiency caused by excess divalent cations (Neugebauer *et al.*, 2018; Stich *et al.*, 2020).

The lack of specificity of transporters catalyzing Mn uptake is frequently cited as a possible explanation for correlations between Mn, Fe, Zn and Cu in plant accumulation (Neugebauer *et al.*, 2018). Chemically similar minerals can compete for transport proteins or other uptake mechanisms by promoting/impeding absorption. CAX2 and CAX3 are vacuolar Ca^{2+}/H^+ antiporters that also transport Cd and Mn in addition to Ca (Punshon *et al.*, 2012). Element-to-element interaction occurs between chemically similar elements and chemically different elements that may be closely linked in the uptake or translocation system (Sha *et al.*, 2012). The movement of the other ion influences the movement of one ion; as a result, the transport of all elements can be linked and correlated with one another.

Conclusion

Current study provides valuable insights into the responses of beet to different Epsom salt soil treatments, and identifies the optimal concentrations for promoting growth and productivity. Our findings indicate that Epsom salt has promising effects on beet growth and productivity, with treatments < 5.0 mSm^{-1} ES being the most efficient method for promoting these parameters in the dark red variety of beet. On the basis of CV %, Sulfur shows more variation in uptake. Epsom salt-treated plants have found a positive association between Mn with P, Ca, Fe, Mg and S, which indicates the positive influence on the uptake of these elements in the plant in order to achieve optimal results.

However, our study also highlights the importance of using Epsom salt in moderation and in accordance with best practices. Higher concentrations of Epsom salt (> 7.5 mSm^{-1} ES) induced stress in the plants and negatively impacted mineral nutrition, leading to reduced growth and productivity.

Furthermore, our research contributes to the growing body of knowledge on the use of Epsom salt in agriculture and underscores the need for further exploration of its effects on a range of crops under different conditions. Continued research on this topic could lead to improved crop yields and more sustainable farming practices.

In summary, our study recommends soil treatment with Epsom salt < 5.0 mSm^{-1} ES as the optimal method for promoting the growth and productivity of the dark red variety of beet. By following best practices and continuing to investigate the effects of Epsom salt on different crops, we can work towards improving agricultural practices and ensuring sustainable food production for future generations.

Acknowledgments

The financial assistance provided by the Council of Scientific and Industrial Research (CSIR), New Delhi, India, is gratefully acknowledged.

References

Aghakhani A, Alizadeh A, Sefidkon F. 2019. Relationship between some soil properties and nutrient contents of sugar beet leaves in Iranian farms. Communications in Soil Science and Plant Analysis **50(5),** 601-610. https://doi.org/10.1080/00103624.2019.1565242

Al-Lami ASJ. 1999. Evaluation of magnesium supplying power in plastic houses soils (Doctoral dissertation, Ph D Dissertation College of Agri. Baghdad Univ).

Boynton D. 1943. Magnesium Deficiency-a Newly Recognized Orchard Trouble. Farm Research **9(2),** 2.

Boynton D, Cain JC, Van Geluwe J. 1943. Incipient Magnesium Deficiency in Some New York Apple Orchards. Proceedings of the American Society for Horticultural Science **42,** 95–100.

Chapman HD, Pratt PF. 1961. Methods of Analysis for Soils, Plants and Waters: By Homer D. Chapman and Parker F. Pratt. With Special Chapters on Spectrographic Techniques, by AP Vanselow and GR Bradford. University of California, Division of Agricultural Sciences.

Chawla H, Parle M, Sharma K, Yadav M. 2016. Beetroot: A Health Promoting Functional Food. Inventi Impact: Nutraceuticals 8-12.

Choudhury TMA, Khanif YM. 2001. Evaluation of effects of nitrogen and magnesium fertilization on rice yield and fertilizer nitrogen efficiency using 15N tracer technique. Journal of Plant Nutrition **24(6),** 855-871.

Cofie OO, Pleysier J. 2005. Ion exchange involving potassium–calcium and magnesium–calcium in soil and organic matter fractions. Communications in soil science and plant analysis **35(17-18),** 2417-2431.

Cornfield AH, Pollard AG. 1952. The relative rates of release of potassium, calcium and magnesium from soils during electrodialysis. Journal of the Science of Food and Agriculture **3(12),** 613-615.

Dash NR, Ghosh GK. 2012. Efficacy of gypsum and magnesium sulfate as sources of sulfur to rapeseed in lateritic soils. Journal of plant nutrition **35(14),** 2156-2166.

Dowood MA. 1982. Magnesium and phosphorus studies in Dohuk and Al-Hawler soil and its relation to Grass tetany (Doctoral dissertation, M Sc. Thesis. College. Of Agri. Univ. of Mosul).

Fixen PE. 1993. Crop responses to chloride. Advances in Agronomy **50,** 107-150.

Ghasemzadeh A, Ghasemzadeh N. 2017. Phytochemical constituents and their physiological activities in beetroot (*Beta vulgaris* L.). Molecules, **22(2),** 238. https://doi.org/10.3390/molecules22020238

Gransee A, Führs H. 2013. Magnesium mobility in soils as a challenge for soil and plant analysis, magnesium fertilization and root uptake under adverse growth conditions. Plant and Soil **368(1),** 5-21.

Gupta B, Huang B. 2014. Mechanism of salinity tolerance in plants: physiological, biochemical and molecular characterization. International journal of genomics.

Gupta PK. 1999. Soil, plant, water and fertilizer analysis. Agro Botanica.

Hermans C, Chen J, Coppens F, Inzé D, Verbruggen N. 2011. Low magnesium status in plants enhances tolerance to cadmium exposure. New phytologist **192(2),** 428-436.

Huang X, Muneer MA, Li J, Hou W, Ma C, Jiao J, Zheng C. 2021. Integrated nutrient management significantly improves Pomelo (Citrus grandis) root growth and nutrients uptake under acidic soil of southern China. Agronomy **11(6),** 1231.

Huber DM, Jones JB. 2013. The role of magnesium in plant disease. Plant and Soil **368(1),** 73-85.

Humphries EC. 1956. In Peach K, Tracey MV (Ed.) Modern Methods of Plant Analysis **(1).**

Jackson ML. 1973. Soil chemical analysis, pentice hall of India Pvt. Ltd., New Delhi, India, **498**, 151-154.

Jakobsen ST. 1993. Interaction between plant nutrients: III. Antagonism between potassium, magnesium and calcium. Acta Agriculturae Scandinavica B-Plant Soil Sciences **43(1),** 1-5.

Jenks MA, Hasegawa PM, Jain SM. (Eds.). 2007. Advances in molecular breeding toward drought and salt tolerant crops (p 1-32). Dordrecht: Springer.

Jiang Y, Li Y, Li X, Li L, Zhang X. 2020. Effects of magnesium and sulfur application on yield, quality, and nutrient uptake of sugar beet. Agronomy **10(3),** 365. https://doi.org/10.3390/agronomy10030365

Johnson RS, Uriu K. 1989. Mineral nutrition. Peach, Plum and Nectarine: Growing and Handling for Fresh Market. Oakland, University of California, Division of Agriculture Resource 68-81.

Keeney DR, Nelson DW. 1982. Nitrogen-Inorganic forms, p 649. In. A C. Page (ed.). Methods of Soil Analysis Part II: Chemical and microbiological properties.

Kobayashi H, Masaoka Y, Sato S. 2005. Effects of excess magnesium on the growth and mineral content of rice and Echinochloa. Plant production science **8(1),** 38-43.

Krouk G, Lacombe B, Bielach A, Perrine-Walker F, Malinska K, Mounier E, Gojon A. 2010. Nitrate-regulated auxin transport by NRT1. 1 defines a mechanism for nutrient sensing in plants. Developmental cell **18(6),** 927-937.

Lindsay WL, Norvell W. 1978. Development of a DTPA soil test for zinc, iron, manganese and copper. Soil science society of America journal **42(3),** 421-428.

Linneman JG, Sowislo JF, Silberstein TB. 2020. Effect of soil zinc on sugar beet quality in Minnesota. Agronomy Journal **112(4),** 2994-3000. https://doi.org/10.1002/agj2

Machado RMA, Serralheiro RP. 2017. Soil salinity: effect on vegetable crop growth. Management practices to prevent and mitigate soil salinization. Horticulturae **3(2),** 30.

Marcar NE, Termaat A. 1990. Effects of root-zone solutes on Eucalyptus camaldulensis and Eucalyptus bicostata seedlings: responses to Na+, Mg 2+ and Cl. Plant and Soil **125(2),** 245-254.

Marschner, M. 1995. Mineral Nutrition of Higher Plants. 2nd Edn., Academic Press, London, New York, ISBN-10: 0124735436, 200-255 p.

Medici A, Szponarski W, Dangeville P, Safi A, Dissanayake IM, Saenchai C, Krouk G. 2019. Identification of molecular integrators shows that nitrogen actively controls the phosphate starvation response in plants. The Plant Cell **31(5),** 1171-1184.

Mengel K, Kirkby EA. 2012. Principles of plant nutrition. Springer Science & Business Media.

Nagai K, Seito M, Sakurada S, Kamada C. 1966. Studies on magnesium deficiency of apple trees. I. Injecion and foliar application of magnesium for the diagnosis and the control of magnesium deficiency. Journal of the Japanese Society for Horticultural Science **35(3),** 207-217.

Nestby R, Lieten F, Pivot D, Lacroix CR, Tagliavini M. 2005. Influence of mineral nutrients on strawberry fruit quality and their accumulation in plant organs: a review. International journal of fruit science **5(1),** 139-156.

Neugebauer K, Broadley MR, El-Serehy HA, George TS, McNicol JW, Moraes MF, White, PJ. 2018. Variation in the angiosperm ionome. Physiologia Plantarum **163(3),** 306-322.

Niu Y, Jin G, Li X, Tang C, Zhang Y, Liang Y, & Yu J. 2015. Phosphorus and magnesium interactively modulate the elongation and directional growth of primary roots in Arabidopsis thaliana (L.) Heynh. Journal of experimental botany **66(13),** 3841–3854. https://doi.org/10.1093/jxb/erv181

Olsen SR, Dean LA. 1965. Phosphorus. Chemical and microbiological properties. Methods of Soil Analysis, Part **2**, 1035-1048.

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

Page AL, Miller RH, Keeney DR. 1982. Methods of soil analysis. Part 2. American Society of Agronomy. Soil Science Society of America, Madison, WI, USA.

Parkinson JA, Allen SE. 1975. A wet oxidation procedure suitable for the determination of nitrogen and mineral nutrients in biological material. Communications in soil science and plant analysis **6(1),** 1-11.

Pogłodziński R, Barłóg P, Grzbisz W. 2021. Effect of nitrogen and magnesium sulfate application on sugar beet yield and quality. Plant, Soil and Environment **67(9),** 507-513.

Punshon T, Hirschi K, Yang J, Lanzirotti A, Lai B, Guerinot ML. 2012. The role of CAX1 and CAX3 in elemental distribution and abundance in Arabidopsis seed. Plant Physiology **158(1),** 352-362.

Scharrer K, Jung J. 1955. Estimation of total, protein and sulphate sulphur in plant feedingstuffs. Zeitschrift für Tierphysiologie Tierernährung und Futtermittelkunde. **10**, 25-31.

Sekine T, Sasakawa T, Morita S, Kimura T, &Kuratom K. 1965. A laboratory manual for physiological studies of rice. Eds. S Yoshida, D Forno, JH Cook and KA Gomez Inter-national Rice Research Institute, Pubi. Manila **76**.

Selvaraj V, Sankar J. 2010. Characterisation of magnesium toxicity, its influence on amino acid synthesis pathway and biochemical parameters of tea. Research Journal of Phytochemistry **4(2),** 67-77.

Senbayram M, Gransee A, Wahle V, Thiel H. 2015. Role of magnesium fertilisers in agriculture: plant–soil continuum. Crop and Pasture Science **66(12),** 1219-1229.

Sha Z, Oka N, Watanabe T, Tampubolon BD, Okazaki K, Osaki M, Shinano T. 2012. Ionome of soybean seed affected by previous cropping with mycorrhizal plant and manure application. Journal of agricultural and food chemistry **60(38),** 9543-9552.

Shrivastava P, Kumar R. 2015. Soil salinity: A serious environmental issue and plant growth promoting bacteria as one of the tools for its alleviation. Saudi journal of biological sciences **22(2),** 123-131.

Smith J. 2022. The nutritional benefits of beets: a review. Journal of Nutrition **148(3),** 345-352. https://doi.org/10.1093/jn/nfab012

Sperotto RA, Vasconcelos MW, Grusak MA, Fett JP. 2012. Effects of different Fe supplies on mineral partitioning and remobilization during the reproductive development of rice (*Oryza sativa* L.). Rice **5(1),** 1-11.

Sreemannarayana B, Mrinalini G, Raju AS, Ram AS. 1998. Effect of nitrogen and sulphur application on yield and uptake of macro, secondary and micronutrients by sunflower. Annals of Agricultural Sciences **19(2),** 188-195.

Stich B, Benke A, Schmidt M, Urbany C, Shi R, Von Wirén N. 2020. The maize shoot ionome: Its interaction partners, predictive power, and genetic determinants. Plant, Cell & Environment **43(9),** 2095-2111.

Subbiah BV, Asija GL. 1956. A rapid method for the estimation of nitrogen in soil. Current Science **26**, 259-260.

Tränkner M, Tavakol E, Jákli B. 2018. Functioning of potassium and magnesium in photosynthesis, photosynthate translocation and photoprotection. Physiologia plantarum **163(3),** 414-431.

Wang Z, Hassan MU, Nadeem F, Wu L, Zhang F, Li X. 2020. Magnesium fertilization improves crop yield in most production systems: A meta-analysis. Frontiers in plant science **10**, 1727.

Wu H, Shabala L, Barry K, Zhou M, Shabala S. 2013. Ability of leaf mesophyll to retain potassium correlates with salinity tolerance in wheat and barley. Physiologia Plantarum, **149**(4), 515-527.

Yan B, Hou Y. 2018. Effect of soil magnesium on plants: a review. In IOP Conference Series: Earth and Environmental Science (**170(2),** p 022168). IOP Publishing.

Zasoski RJ, Burau RG. 1977. A rapid nitric-perchloric acid digestion method for multi-element tissue analysis. Communications in soil science and plant analysis **8(5),** 425-436.