International Journal of Plant & Soil Science

Volume 35, Issue 19, Page 1174-1183, 2023; Article no.IJPSS.105651
ISSN: 2320-7035

Calcium Nutrition for Improving the Growth and Yield of Carrot in Acid Soils

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2023/v35i193656

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/105651

Original Research Article

Received: 02/07/2023
Accepted: 26/08/2023
Published: 01/09/2023

ABSTRACT

Aims: To evaluate the effect of various sources, levels and methods of calcium application on the growth, yield and SPAD index of carrots grown on acid soils
Study Design: Factorial randomized block design (FRBD) with three replications.
Place and Duration of Study: A field experiment was conducted in the farmer's field at Takkarbaba Nagar, Ooty from February to June, 2023.
Methodology: A field experiment was conducted with carrot hybrid Zubera using lime at 50% LR and dolomite at 20,40,60 and 80 kg Ca ha^{-1} as basal soil application and foliar spraying of 0.5% calcium EDTA and calcium citrate twice on 30 and 45 DAP in a factorial randomized block design with three replications. The growth parameters such as plant height, petiole length, number of

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leaves per plant, SPAD index and tuber yield were recorded as per standard protocols at different plant growth stages viz., vegetative, tuber development and harvest stages.

Results: A significant linear increase in plant height, petiole length, number of leaves per plant, SPAD index and tuber yield was recorded with the supplementation of calcium at different levels. Higher plant height (26.3 cm, 51.2 cm and 56.1 cm), petiole length (13.8 cm, 23.0 cm and 35.8 cm), number of leaves per plant (7.62, 7.82 and 9.30), SPAD index (22.0, 38.0 and 35.2) and fresh tuber yield (37.2 t ha^{-1}) was registered with NPK+ 80 kg Ca as dolomite along with two sprays of 0.5% Ca EDTA twice which was followed by the same level of calcium as dolomite + foliar spraying of 0.5% calcium citrate twice. The minimum growth and yield response of carrot at all the growth stages was noticed with NPK control.

Conclusion: Application of calcium through soil and foliar spraying showed synergistic influence on the growth and SPAD index of carrot at all stages of growth. Application of NPK+ 80 kg Ca ha^{-1} as dolomite performed better when compared to lime applied at 50% LR. Between Ca EDTA and Ca citrate, the performance of Ca EDTA was better in improving the growth and yield of carrot. It was concluded that the combined application of soil test based NPK+80 kg Ca ha^{-1} as dolomite along with two sprays of 0.5% calcium EDTA on 30 and 45 DAP would be effective in improving the growth, yield and SPAD index of carrot grown on acid lateritic soils.

Keywords: Calcium; foliar spraying; soil application; growth attributes; SPAD; tuber yield; carrot.

1. INTRODUCTION

Calcium is one of the most important elements in soil and is also a very important factor of plant growth and production. It is an integral part of the cell wall where it provides strength and stability by forming intra-molecular linkages between pectin molecules. In the cell membrane, it bridges phosphate and carboxylate groups of phospholipids and, thereby, provides stability to the membrane [1] which results in cell wall rigidity [2],[3] and nitrogen assimilation of plants thus improving the vegetative growth of plants [4]. Calcium plays essential roles in various plant cellular processes, encompassing plant growth and maturation, resilience to environmental challenges [5], [6] hormonal response [7], interaction with pathogenic microorganisms [8], and photosynthesis [9]. It can control the transcription and translation of genes responsible for encoding chloroplast proteins and enzymes engaged in the processes of photosynthesis [10]. It is also involved in signalling on salt perception, gene expression, ion homeostasis and adaptive responses to stress [11]. Deficiency of calcium in plant occurs due to its immobility in soil and plant cells which lead to many physiological disorders like cavity spots, blossom end rot, bitter pit, tip burn and heart rot [12], [13], [14]. It also plays an important role in tuber quality and plant growth of carrot plants.

Root crops are a diverse group of plants cultivated primarily for their edible underground parts, which store essential nutrients and energy. Carrot is a vibrant and adaptable cool-season root crop belonging to the Apiaceae family. It is cultivated throughout the world for its edible roots [15]. Carrots have a broad palatability, and they are consumed in various forms as raw or cooked. It is packed with vitamins, minerals and antioxidants, which helps in improving bone strength, supporting healthy vision, immune function and strengthening the body. In India, carrot is cultivated in an area of about 1,10,220 hectares, with a production of about 1.91 million tonnes. The major producers of carrots in India are Haryana, West Bengal, Punjab, Uttar Pradesh, Madhya Pradesh, Bihar, Tamil Nadu, Karnataka, Assam, and Telangana (First Advance Estimates of 2021-22 of Area and Production of Horticultural Crops).

Plant growth on acidic soils is constrained by many factors like toxicity of aluminium, iron and manganese and also by the reduced availability of many essential plant nutrients. Acid soils in India are mainly distributed in high rainfall areas wherein heavy rainfall leads to leaching of appreciable amounts of exchangeable basic ions like Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} from the surface soil hence the colloidal exchange sites were dominated with H^{+} and Al^{3+} ions [16], [17]. Acid soils can alter soil carbon and nutrient cycling and adversely influence the growth of plant and soil biota, and threaten terrestrial the ecosystem functions [18] These soils lack calcium availability to plants and thereby reduces plant productivity [19]. Liming with calcium and magnesium rich materials is a common soil amelioration practice that promotes the immobilization of toxic heavy metals and alters the transformation and uptake of nutrients by plants, and consequently affecting the productivity of ecosystems [20], [21]. Supplementation of calcium could increase the crop nutrient uptake, growth and yield of carrot grown in acid soils. Therefore, a field study was conducted to study the impact of calcium nutrition on carrots grown on acid soil and to optimize various calcium sources, levels and methods of application for improving the growth and yield.

2. MATERIALS AND METHODS

2.1 Experiment Treatment

A field experiment was structured in a Factorial Randomized Block Design (FRBD) with eighteen treatments each replicated thrice with two calcium sources *viz*. lime at 50% LR and dolomite applied at five different levels (20, 40, 60, 80 kg Ca ha^{-1}) basally along with calcium EDTA and calcium citrate as foliar spray at 0.5% twice on 30 and 45 DAP. The test crop was carrot hybrid Zubera grown in the farmer's field (N 11º18.430, E 076º37.939) at Takkarbaba Nagar, Nilgiris district, Tamil Nadu. Major nutrients like Nitrogen, Phosphorus and Potassium were applied as per recommendation based on Soil Test Crop Response (STCR) for a targeted yield of 35 t ha^{-1}. The seeds were sown and the plants were grown to full maturity. Necessary plant protection measures were carried out as and when needed. The response of carrots for calcium fertilization at vegetative, tuber development and harvest stages were recorded and reported.

2.2 Experimental Soil

The experimental soil was sandy loam textured with slightly acidic pH (6.15) belongs to Ooty soil series. It has medium available nitrogen (337 kg ha^{-1}), high available phosphorus (58 kg ha^{-1}) and potassium (244 kg ha^{-1}) status. The secondary nutrients were medium in availability and the values were 172, 82 and 10.4 mg kg^{-1} for calcium, magnesium and sulphur respectively. All the micronutrients were high in availability with 3.24, 82.0, 27.4 and 4.15 mg kg^{-1} for DTPA zinc, iron, manganese and copper respectively.

2.3 Measurement of Growth Attributes, SPAD Index and Tuber Yield

Growth attributes such as plant height, petiole length and number of leaves per plant was measured at three growth stages viz., vegetative, tuber development and harvest stages. Plant height was measured in five randomly chosen plants as the length of the plant in centimetres from the base of the shoot to the tip of leaves and the average of all readings was recorded and expressed in cm. Petiole length was recorded in selected five plants at all the growth stages using a graduated ruler by measuring the length of petiole of the main compound leaf. The average of all the readings were taken and expressed in cm. The total number of leaves per plant was counted for the selected plants at all the three growth stages of carrots.

The SPAD readings were taken at a wavelength of 940 nm using the chlorophyll meter (SPAD 502, Minolta Camera Co. Ltd., Japan) on uniform leaves from five selected plants in each treatment and the average of readings were taken for each treatment.

For calculating the fresh tuber yield, the harvested tubers were washed, air dried and weighed using a digital weighing balance. The total tuber yield was recorded for each treatment and expressed in t ha^{-1}.

2.4 Statistical Analysis

The data recorded for different parameters were analysed using AGRES software version 7.01 to compare the mean at least significant difference (P = 0.05). The critical difference (CD) was worked out at 5% level of significance wherever the treatment differences were found significant and denoted by a symbol * for 5% and ** for 1% level of significance. NS was used to denote the non-significant comparisons.

3. RESULTS AND DISCUSSION

3.1 Growth Attributes

A positive effect of calcium application on all the growth attributes like plant height, petiole length and number of leaves per plant at all the growth stages of carrot was observed (Tables 1 to 3) which might be due to the role of calcium in improving nitrogen assimilation [4], [13], [22]. There was a linear increase in the growth parameters with an increase in calcium levels. The highest values of plant height (26.3 cm, 51.2 cm and 56.1 cm), petiole length (13.8 cm, 23.0 cm and 35.8 cm) and number of leaves per plant (7.62, 7.82 and 9.30) were observed with the addition of soil test based N, P and K + 80 kg Ca ha^{-1} as dolomite and two sprays of 0.5% calcium EDTA on 30 and 45 DAP. This was followed by the application of same level of calcium along with foliar spraying of 0.5% calcium citrate twice. The lowest values of plant height (13.0 cm, 22.7 cm and 28.2 cm), petiole length (5.24 cm, 9.25 cm and 18.4 cm) and number of leaves per plant (4.39, 4.85 and 6.00) at all the growth stages of the crop was noted with NPK control. Calcium being an important component of cell wall, plays a critical role in cell division and cell elongation [23], therefore, application of calcium at higher rates might have increased the vegetative growth [24]. It also enhances the cell wall formation, cell wall integrity which in turn increases the vegetative growth. Further, foliar spraying of calcium EDTA would have improved the availability of calcium which affect the meristems and results in increased number of stems [25]. Liming also increased the soil pH and created good soil environmental conditions for better plant growth [26]. The better performance of dolomite as compared to the general practice of liming might be due to its ability to supply both calcium and magnesium to the plants besides its higher efficiency.

3.2 SPAD Index

The amount of solar radiation absorbed by a leaf is largely a function of foliar concentrations of photosynthetic pigments. Low concentrations of chlorophyll can therefore directly limit photosynthetic potential and hence primary production [27-29]. Calcium application showed a positive effect on the chlorophyll content of carrot leaves. SPAD index increased linearly during first two plant growth stages and showed a slight decline at harvest stage in all the treatments. Among the basal treatments, calcium applied at 80 kg Ca ha^{-1} as dolomite performed better and followed by lime at 50% LR. The highest SPAD index was recorded by the application of NPK+80 kg Ca ha^{-1} as dolomite with two sprays of 0.5% calcium EDTA on 30 and 45 DAP (22.0, 38.0 and 35.2). The lowest SPAD index of the crop (12.7, 20.3 and 19.1) at all the growth stages was recorded in NPK control (Table 4). This might be due to the role of calcium in enhancing the photosynthetic pigment synthesis and also conquers the degradation of chlorophyll pigment [30], [31]. The increase in chlorophyll index with calcium application might also be due to its role in regulating stomatal movement and reducing the respiration rate besides activating the enzymes NAD kinase which enhances NADP production led to increased photosynthesis [32]. Proper amount of calcium ions may improve the integrity and stability of chloroplast structure, and enhance the activities of Rubisco and PEP carboxylase enzymes, thus improving the carboxylation efficiency of carbon dioxide and the activity of ATPase on the membrane thereby improving the photosynthetic efficiency of plants [33]. Between lime and dolomite, the efficiency was higher with dolomite which might be due to the presence of magnesium, an essential constituent of chlorophyll [28], and activates many enzymes [29], resulting in better photosynthesis and carbohydrate partition in the plant [10].

3.3 Tuber Yield

Application of calcium significantly improved the fresh tuber yield of carrot on acid soil (Fig. 1). The maximum tuber yield (37.2 t ha^{-1}) was obtained with the application of soil test based NPK with 80 kg Ca ha^{-1} as dolomite and foliar spraying of 0.5% Ca EDTA twice on 30 and 45 DAP as compared to NPK control (25.4 t ha^{-1}). This increase in tuber yield was 35.7% over the control which could be due to the effect of calcium in improving the availability of nutrients viz., nitrogen, phosphorus, potassium and boron [34], [35]. Calcium application improve the growth attributes of plants like plant height, petiole length, number of leaves per plant and increased the photosynthetic activity [36] of carrot which would have synergistically influenced the fresh tuber yield (Fig. 2). Lime applied at 50% LR was found to be the second best among the basal treatments after dolomite applied at 80 kg Ca ha^{-1}. Dolomite improved the soil conditions by creating a favorable environment for the overall growth and development of tubers, resulting in more accumulation of photosynthate to the tuber and thus increasing the yield [37]. Application of lime and dolomite would have raised the pH of the soil rendering the availability of many essential nutrients [38].

The relationship between various growth attributes and fresh tuber yield of carrot was computed and furnished in (Fig. 2). It shows that all the growth attributes like plant height (R^2= 0.983), petiole length (R^2= 0.984), number of leaves per plant (R^2= 0.992) and SPAD index (R^2= 0.995) had more than 95% correlation in influencing the fresh tuber yield of the crop.

Table 1. Effect of different sources, levels and methods of Ca application on the plant height of carrot

Treatments (kg ha^{-1})	Plant height (cm)													
	Vegetative stage				Tuber development stage				Harvest stage				
	Soil	Soil + Foliar*		Mean	Soil	Soil + Foliar*		Mean	Soil	Soil + Foliar*		Mean	Grand Mean
		Ca EDTA	Ca citrate			Ca EDTA	Ca citrate			Ca EDTA	Ca citrate		
NPK control	13.0	15.1	14.1	14.1	22.7	25.0	24.1	23.9	28.2	32.4	31.4	30.7	22.9
NPK+50% LR	22.3	24.2	23.1	23.2	42.4	49.4	47.2	46.3	49.9	53.5	51.7	51.7	40.4
NPK+D20	16.7	18.5	17.1	17.4	32.9	36.3	34.5	34.6	38.4	42.7	40.3	40.5	30.8
NPK+D40	19.0	21.5	20.0	20.2	36.4	42.2	38.5	39.0	43.3	47.6	45.9	45.6	34.9
NPK+D60	21.5	23.5	22.3	22.4	41.6	48.9	46.1	45.5	47.5	52.5	51.4	50.5	39.5
NPK+D80	24.0	26.3	25.5	25.3	46.4	51.2	49.5	49.0	51.2	56.1	54.2	53.8	42.7
Mean	19.4	21.5	20.4	20.4	37.1	42.2	40.0	39.7	43.1	47.5	45.8	45.5	35.2
	T	M	TxM		T	M	TxM		T	M	TxM		
SEd	0.46	0.32	0.79		0.78	0.55	1.35		0.79	0.56	1.37		
CD (*P* =0.05)	0.93	0.66	1.62		1.59	1.12	2.75		1.61	1.14	2.79		

**Foliar spraying at 0.5% twice on 30 and 45 DAP   T: Treatments; M: Methods of application*
Levels of Dolomite (D): D20- 20 kg Ca ha^{-1}; D40- 40 kg Ca ha^{-1}; D60- 60 kg Ca ha^{-1}; D80- 80 kg Ca ha^{-1}

Table 2. Effect of different sources, levels and methods of Ca application on the petiole length of carrot

Treatments (kg ha^{-1})	Petiole length (cm)												
	Vegetative stage				Tuber development stage				Harvest stage				
	Soil	Soil + Foliar *		Mean	Soil	Soil + Foliar *		Mean	Soil	Soil + Foliar *		Mean	Grand Mean
		Ca EDTA	Ca citrate			Ca EDTA	Ca citrate			Ca EDTA	Ca citrate		
NPK control	5.24	7.05	5.84	6.04	9.25	13.1	11.2	11.2	18.4	21.6	20.4	20.2	12.5
NPK+50% LR	10.2	12.1	11.5	11.2	17.2	20.9	18.8	19.0	27.7	32.2	30.7	30.2	20.1
NPK+D20	7.26	9.42	8.40	8.36	13.0	16.1	15.1	14.7	20.4	23.7	22.5	22.2	15.1
NPK+D40	8.53	10.7	9.27	9.48	15.4	17.6	16.3	16.4	23.6	26.0	24.7	24.8	16.9
NPK+D60	9.75	11.6	10.5	10.6	16.2	19.9	18.1	18.1	25.4	28.9	27.0	27.1	18.6
NPK+D80	11.0	13.8	12.0	12.3	20.3	23.0	22.5	21.9	30.0	35.8	33.2	33.0	22.4
Mean	8.65	10.8	9.60	9.68	15.2	18.4	17.0	16.9	24.3	28.1	26.4	26.2	17.6
	T	M	TxM		T	M	TxM		T	M	TxM		
SEd	0.41	0.29	0.72		0.34	0.24	0.59		0.52	0.37	0.91		
CD (*P* =0.05)	0.84	0.59	1.46		0.69	0.49	1.20		1.06	0.75	1.84		

**Foliar spraying at 0.5% twice on 30 and 45 DAP   T: Treatments; M: Methods of application*
Levels of Dolomite (D): D20- 20 kg Ca ha^{-1}; D40- 40 kg Ca ha^{-1}; D60- 60 kg Ca ha^{-1}; D80- 80 kg Ca ha^{-1}

Table 3. Effect of different sources, levels and methods of Ca application on the number of leaves per plant of carrot

Treatments (kg ha^{-1})	Number of leaves per plant												
	Vegetative stage				Tuber development stage				Harvest stage				
	Soil	Soil + Foliar*		Mean	Soil	Soil + Foliar*		Mean	Soil	Soil + Foliar*		Mean	Grand Mean
		Ca EDTA	Ca citrate			Ca EDTA	Ca citrate			Ca EDTA	Ca citrate		
NPK control	4.39	5.44	4.97	4.93	4.85	5.79	5.33	5.32	6.00	7.00	6.67	6.56	5.60
NPK+50% LR	6.07	6.89	6.59	6.52	6.42	7.28	6.98	6.89	7.96	9.12	8.89	8.66	7.36
NPK+D20	5.13	6.33	5.90	5.79	5.42	6.63	6.12	6.06	6.67	8.15	7.62	7.48	6.44
NPK+D40	5.45	6.75	6.18	6.13	6.06	7.08	6.67	6.60	7.20	8.44	8.03	7.89	6.87
NPK+D60	5.96	6.74	6.44	6.38	6.30	7.33	6.90	6.84	7.49	8.88	8.26	8.21	7.14
NPK+D80	6.52	7.62	7.17	7.10	6.85	7.82	7.33	7.33	7.92	9.30	8.72	8.65	7.69
Mean	5.59	6.63	6.21	6.14	5.98	6.99	6.56	6.51	7.21	8.48	8.03	7.91	6.85
	T	M	TxM		T	M	TxM		T	M	TxM		
SEd	0.23	0.16	0.40		0.41	0.29	0.71		0.15	0.11	0.26		
CD (*P* =0.05)	0.46	0.33	0.80		0.84	0.59	1.45		0.31	0.22	0.54		

**Foliar spraying at 0.5% twice on 30 and 45 DAP   T: Treatments; M: Methods of application*

Levels of Dolomite (D): D20- 20 kg Ca ha^{-1}; D40- 40 kg Ca ha^{-1}; D60- 60 kg Ca ha^{-1}; D80- 80 kg Ca ha^{-1}

Table 4. Effect of different sources, levels and methods of Ca application on the SPAD index of carrot

Treatments (kg ha^{-1})	SPAD index												
	Vegetative stage				Tuber development stage				Harvest stage				
	Soil	Soil + Foliar*		Mean	Soil	Soil + Foliar*		Mean	Soil	Soil + Foliar*		Mean	Grand Mean
		Ca EDTA	Ca citrate			Ca EDTA	Ca citrate			Ca EDTA	Ca citrate		
NPK control	12.7	14.4	13.5	13.6	20.3	25.5	23.5	23.1	19.1	24.5	22.7	22.1	19.6
NPK+50% LR	16.8	20.1	18.8	18.6	30.7	36.4	34.2	33.7	28.7	34.2	31.2	31.4	27.9
NPK+D20	14.6	16.2	15.6	15.5	26.0	30.6	28.8	28.5	25.0	28.3	27.0	26.8	23.6
NPK+D40	15.0	17.2	16.4	16.2	28.8	33.4	31.8	31.3	26.9	31.4	28.5	29.0	25.5
NPK+D60	16.4	18.6	17.7	17.6	30.9	35.3	33.0	33.1	29.0	32.7	31.4	31.1	27.2
NPK+D80	18.9	22.0	20.2	20.4	32.7	38.0	35.7	35.5	31.5	35.2	33.2	33.3	29.7
Mean	15.8	18.1	17.0	17.0	28.2	33.2	31.2	30.9	26.7	31.1	29.0	28.9	25.6
	T	M	TxM		T	M	TxM		T	M	TxM		
SEd	0.50	0.35	0.87		0.69	0.49	1.20		0.52	0.37	0.90		
CD (*P* =0.05)	1.02	0.72	1.76		1.41	0.99	2.44		1.06	0.75	1.84		

**Foliar spraying at 0.5% twice on 30 and 45 DAP   T: Treatments; M: Methods of application*

Levels of Dolomite (D): D20- 20 kg Ca ha^{-1}; D40- 40 kg Ca ha^{-1}; D60- 60 kg Ca ha^{-1}; D80- 80 kg Ca ha^{-1}

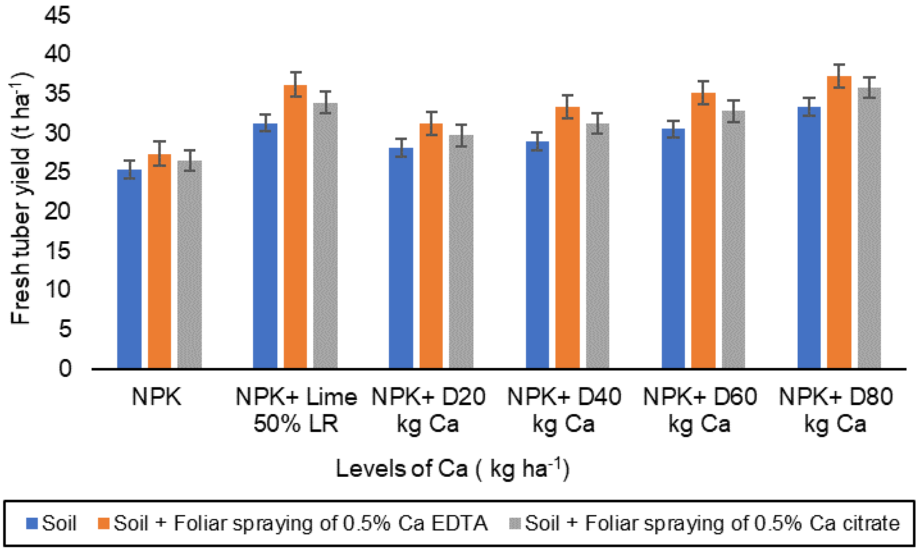

Fig. 1. Effect of different sources, levels and methods of Ca application on the tuber yield of carrot

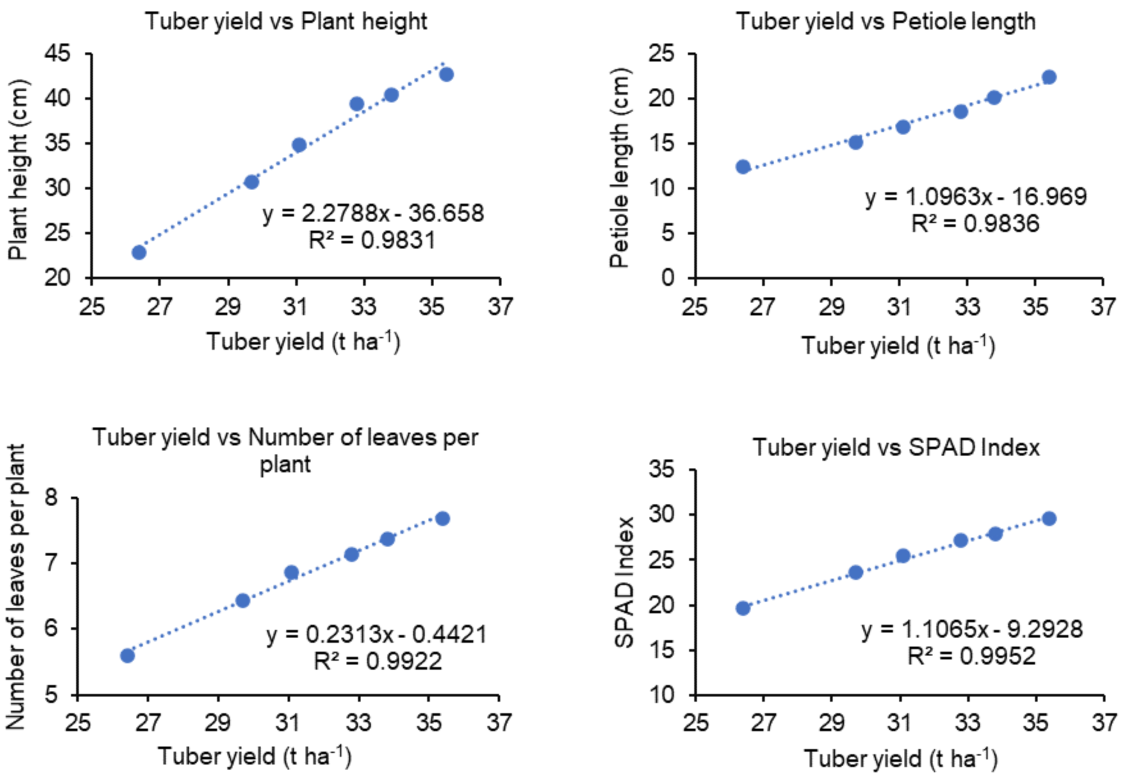

Fig. 2. Relationship between growth attributes and tuber yield of carrot

In the realm of agricultural research, the investigation into calcium nutrition's impact on enhancing carrot growth and yield in acidic soils presents a significant stride toward sustainable crop production. The study examined the pivotal role of calcium in mitigating the adverse effects of soil acidity, a prevalent challenge in numerous agricultural regions. By adopting a comprehensive approach, the researchers meticulously assessed the physiological responses of carrot plants to varying calcium levels in acidic soil conditions. The results unveiled a substantial positive correlation between calcium supplementation and improved growth parameters, including root length, shoot biomass, and overall yield. Notably, the study elucidated the underlying mechanisms by which calcium alleviates aluminum and manganese toxicity, while enhancing nutrient uptake and root development. This research not only underscores the imperative of calcium nutrition in combatting the constraints posed by acidic soils but also underscores its potential to contribute to global food security by maximizing crop productivity under challenging environmental conditions.

4. CONCLUSION

The results indicated that carrot plants responded well to calcium fertilization through different sources, levels and methods of application. Out of the two sources used, dolomite applied at 80 kg Ca ha^{-1} was found to be the best followed by lime at 50% LR. Foliar spraying of 0.5% Calcium EDTA twice performed better than calcium citrate at same level and showed complementary effect. The increased growth attributes like plant height, petiole length and number of leaves per plant of carrot plants and the highest fresh tuber yield was observed with the addition of NPK+80 kg Ca as dolomite+ foliar spraying of 0.5% Ca EDTA twice on 30 and 45 DAP. This was closely followed by the addition of same level of calcium along with two foliar sprays of 0.5% calcium citrate on 30 and 45 DAP. The improved response of carrot to calcium application might be due to the involvement of calcium in cell division, cell wall strengthening, enzyme activation and stress mitigation.

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to the Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore for providing the necessary facilities to carry out the experiment and to the farmer who spared his land for conducting this field experiment.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
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