Europ.J.Hort.Sci., **79** (5). S. 278–282, 2014, ISSN 1611-4426. © Verlag Eugen Ulmer KG, Stuttgart

Effect of Calcium Amendment on the Calcium Content and Storage Quality of Carrot (*Daucus carota* L.)

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Summary

Calcium (Ca) is an essential plant nutrient affecting the cell wall structure and many cell functions. Our earlier study carried out on carrot farms indicated a positive association between high Ca content in soil and good storage quality of carrots. Based on these preliminary results, the present study was conducted with the aim to improve the Ca status of carrot plants and strengthen the storage quality of carrot roots. Ca was added to soil by applying gypsum that contained calcium sulphate ($CaSO_4 \cdot 2H_2O$). Field experiments were performed on four separate farms located in southwestern Finland in 2009 and 2010. Three Ca dosages were compared: 0, 575 and 1150 kg of Ca ha^{-1}. Soil and carrots were analyzed for their Ca contents, and the storability of carrots was measured in storage experiments at 0.5 °C. Soil amendment with gypsum had minor effects on the soil Ca content, but it did not increase the Ca content of the carrot roots. The soil sulphur (S) content increased considerably, but the higher S supply in soil did not enhance the S uptake of the plant. The Ca fertilization did not improve the storage quality of carrots. However, the Ca content of carrots showed great variation between different fields. Further research is needed to investigate the significance of the nutrient status in terms of the storage quality of carrot.

Key words. fertilization – gypsum – nutrients – postharvest diseases – sulphur – vegetables

Introduction

Carrot (*Daucus carota* L.) is the most important field vegetable in Finland. To provide fresh carrots to consumers all year round, most of the yield harvested in September–October is stored in cold stores at 0–1 °C until the next growing season. During storage, carrots are susceptible to spoilage microbes, which cause significant economic losses to producers. The most important storage diseases in northern Europe are caused by the soil-borne fungi, e.g. *Mycocentrospora acerina* and *Sclerotinia sclerotiorum*, and the common *Botrytis cinerea* (Suojala 1999; Hermansen et al. 2012**).** Usual losses due to diseases are within the range of 20–50 % of the carrot yield in storage (Hermansen and Amundsen 1995).

The magnitude of storage losses is determined by the resistance of carrot, the occurrence of pathogens and the environmental conditions. In our earlier study, we assessed the effects of variety, soil type, crop rotation, use of fungicides and the amounts of different nutrients on the storage quality of carrot (Vanhala 2008). The study covered two growing seasons, and for each season, carrot samples and cultivation data from 24–26 fields were analyzed using linear mixed models. In 2005, high Ca content in soil was associated with good storage quality. High soil manganese content and spraying with fungicide had a positive influence on the storage quality. In 2006, however, fewer significant effects were found. Kastelein et al. (2007) also reported that a high Ca content of roots was associated with a low incidence of *Rhexocercosporidium carotae*, a major storage pathogen. On the basis of these findings, we were interested in exploring the possibilities to improve the Ca status of the plant and thereby to strengthen the storage quality of carrot roots. So far, there are few published results on the effect of Ca fertilization on the quality of carrot roots.

Calcium (Ca) is an essential plant nutrient with many functions within plant tissues. It is an important component of the plant cell wall; it binds together the strands of pectin and helps to maintain tissue firmness. It is also involved in maintaining the membrane integrity and serves as a major regulatory ion in horticultural crops. At cellular level, Ca is a potential regulator of postharvest physiology (Aghdam et al. 2012).

There are different alternatives for adding Ca to plants. Preharvest Ca spraying is used to improve the postharvest quality of apple (Ortiz et al. 2011; Holb et al. 2012) or broccoli microgreens (Kou et al. 2014). Liming is the common way of adding large amounts of Ca to soil, but it cannot be used in all fields due to the rising pH. Gypsum, a

by-product formed in industrial processes, is a good source of Ca that does not affect soil pH. It is found to be effective in reducing phosphorus losses from field cultivation (Ekholm et al. 2012). Gypsum is also recommended to be used when growing peanuts for seeds (Tillman et al. 2010).

The aim of this study was to investigate if it is possible to improve the Ca content of carrot roots and thereby to enhance the storage quality of carrot by applying gypsum to soil.

Materials and Methods

Experimental set-up

Field experiments were performed on farms located in southwestern Finland in 2009 and 2010. In both years, four fields (one field per farm) were used as experimental sites. In 2009, soil type was organic in three fields and sandy clay in one field (Table 1). In 2010, three fields had mineral soil (loam or sandy clay) and one field had organic soil. The organic soils were tentatively classified as histic gleysol according to the FAO/UNESCO soil map system. The mineral soils had high organic matter content (3–12 %). The initial Ca and S status of the experimental fields is shown in Table 1.

To add Ca to soil, gypsum containing Ca sulphate ($CaSO_4 \bullet 2H_2O$), with 23 % of Ca and 18 % of sulphur (S), manufactured by Yara Suomi Ltd, Finland, was spread on the field. Three gypsum dosages were compared: 0, 2500 and 5000 kg ha^{-1} (including 0, 575 and 1150 kg of Ca ha^{-1}, respectively). Treatments were replicated in three blocks within each field. The size of the plot was 5 × 10 m. Gypsum was applied to the plots manually in late April–early May and incorporated into the soil by the normal spring tillage before sowing carrot. Carrot cultivars suitable for storage were grown in the fields according to each farm's normal practice, including standard fertilization programs.

Sampling and analyses

Soil samples (depth 0–25 cm) were taken from each block in April before amending the soil with gypsum and from each plot at the time of harvest. Samples were analyzed for mineral nutrients (e.g. exchangeable Ca) according to a normal soil analysis procedure (Vuorinen and Mäkitie 1955), in which dry soil is extracted with a solution of 0.5 M ammonium acetate and 0.5 M acetic acid at pH 4.65.

Carrots were harvested manually from the experimental plots in late September or early October before the mechanical harvest of the whole field. The total root yield per area was measured. Two samples (8 kg each) per plot were taken for the storage experiment performed at MTT Piikkiö. Carrots were stored in woven polypropylene bags (75 g m^{-2}). The temperature during storage was 0.5 ± 0.5 °C and relative humidity 90–100 %.

In addition, 20 carrot storage roots per plot were collected for mineral nutrient analyses of the roots. The roots were washed, grated and dried at 60 °C to determine the dry matter content. The mineral nutrient concentrations were analyzed at MTT Chemistry Laboratory, using the accredited ICP-OES (Inductively Coupled Plasma-Optical Emission Spectrometry) method. Samples were digested in concentrated nitric acid (10 ml) and evaporated to approx. 1–2 ml. The sample was transferred into 50 ml volumetric flask, diluted with MILLI-Q purified water and filtered before the ICP-OES measurement.

In January, the first half of the storage experiment was analyzed to determine the proportions of healthy roots and carrots spoilt by storage diseases (*M. acerina* and other storage pathogens). The pathogens were identified by visual symptoms. The determination of the species was confirmed by growing pathogen samples on potato dextrose agar (PDA). Carrots with even minimal, incipient symptoms were regarded as diseased. The other half of samples was analyzed for storage results in March.

Statistical analysis

The Ca and S concentrations in carrot storage root, Ca and S in soil at harvest, and the proportions of healthy and diseased carrots after storage were statistically analyzed by means of a mixed model with field and Ca treatment as fixed factors and block (nested in field) as a random factor. The SAS Mixed procedure (Littell et al. 2006) was applied to fit the model, using the restricted maximum likelihood (REML) estimation method.

Results

The exchangeable Ca content in soil varied between different fields (Table 1). Soil amendment with gypsum had minor effects on the soil Ca content at harvest: on average, Ca content in soil was 270 mg l^{-1} higher in the high Ca (1150 kg ha^{-1}) treatment than in the 0 Ca treatment in 2009 (Table 1). In 2010, the difference between the high Ca and 0 Ca treatments was only 108 mg l^{-1}.

Ca fertilization did not affect the total yield or the dry matter content of the roots (data not shown). Neither did the treatments affect the Ca concentration of the roots (Table 1). However, the average Ca content of the roots varied a lot between the fields.

Because of high S content in gypsum, the treatments increased the S content of soil significantly. However, the higher S supply did not affect the root S concentrations (Table 1).

The storage quality of carrots showed great variation between the fields (Fig. 1). The major pathogen affecting the stored carrots was *M. acerina*. The mean proportion of diseased carrots after storage varied between 45 and 87 % in the yields of 2009, the year with poor storability.

Table 1. Soil Ca and S contents before fertilization in spring and at harvest and effects of gypsum amendment on the Ca and S concentrations of the carrot roots in different fields (denoted by alphabets) for the years 2009 and 2010. Probability values (p) are given for the effects of field, treatment and their interaction.

Field	Soil type	Ca treatment	Ca in soil (mg l^{-1})		Ca in carrot root	S in soil (mg l^{-1})		S in carrot root
		(kg ha^{-1})	Spring	Harvest	(g kg^{-1} dw)	Spring	Harvest	(g kg^{-1} dw)
2009								
B	Organic	0	2033	2067	1.52	23	144	1.49
		575		2300	1.58		415	1.43
		1150		2333	1.60		430	1.45
P	Organic	0	1113	937	2.00	27	102	0.94
		575		1097	2.01		202	0.98
		1150		1087	1.99		151	1.11
L	Organic	0	1733	1900	1.87	28	100	1.14
		575		1933	1.99		157	1.17
		1150		2067	1.90		323	1.13
D	Clay	0	2300	2667	2.08	74	158	1.09
		575		2767	2.06		341	1.20
		1150		3467	2.14		475	1.12
P (field)				< 0.001	< 0.001		0.050	< 0.001
P (treatment)				< 0.001	0.483		< 0.001	0.244
P (f × t)				0.005	0.722		0.110	0.038
2010								
P	Organic	0	2433	2700	1.87	37	136	1.26
		575		2833	1.81		273	1.25
		1150		2833	1.75		511	1.28
H	Sandy loam	0	913	1267	2.24	22	90	1.31
		575		1267	2.13		191	1.27
		1150		1367	2.24		242	1.51
N	Clay	0	1633	1767	1.98	29	143	1.00
		575		1667	1.91		152	0.97
		1150		1767	2.03		188	1.00
U	Clay	0	2200	1767	2.17	22	51	1.03
		575		1900	2.49		90	1.17
		1150		1967	2.33		135	1.16
p (field)				0.009	0.013		< 0.001	0.065
p (treatment)				0.070	0.807		< 0.001	0.112
p (f × t)				0.478	0.010		< 0.001	0.280

dw: dry weight

In 2010, the mean proportion of diseased carrots was lower, varying between 9 and 41 % in different fields. Ca treatments had no statistically significant effect on the proportion of saleable carrots.

Discussion

Soil amendment with gypsum slightly increased the Ca content of soil, but the observed changes were small. In

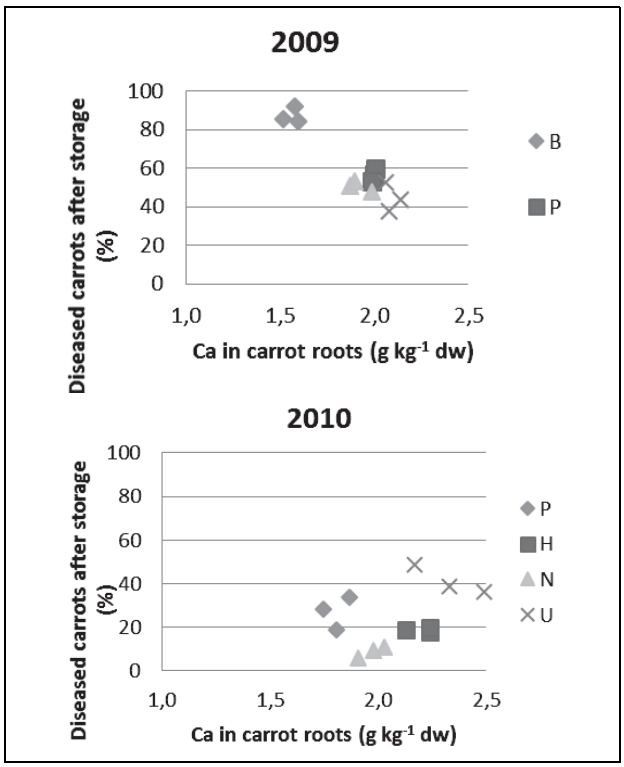


Fig. 1. Proportion (%) of diseased carrots after storage (the mean of two storage times) in relation to the Ca content in roots in 2009 and 2010. Points marked with the same symbol represent the results obtained from the three different Ca treatments on each field (denoted by alphabets).

contrast, soil S content was increased. This is in accordance with the study by Ekholm et al. (2012) in which gypsum (4100 kg ha^{-1}) was added to soil in autumn. They found no effect on soil Ca content the following year, but soil S content was increased. Uusitalo et al. (2012) measured the leaching of nutrients in soils amended with 3000 or 6000 kg ha^{-1} gypsum and observed increased Ca and S concentrations and electrical conductivity in the percolation water. In our experiment, part of the added Ca may have leached to lower soil layers, thus explaining the reason for small changes in soil Ca status in the 0–25 cm layer.

To avoid the accumulation of large amounts of S in soil, the application rates of gypsum cannot be much higher than the rates used in our experiments. Furthermore, increasing the Ca supply in soil may potentially lead to changes in the uptake of other nutrients. Uusitalo et al. (2012) found an increase in leaching of K and Mg as a consequence of adding gypsum to soil, which is due to the competition for cation exchange sites.

Applying gypsum to the soil did not increase the Ca concentrations of carrot storage roots. The Ca concentrations of carrots varied a lot between the individual fields, but they were not clearly related to the Ca content in soil. Relatively high Ca concentrations were measured even in those roots that were grown on fields with a low Ca content (field P in 2009, field H in 2010). The overall Ca concentrations in carrot storage roots per 100 g fresh weight were 17.9–28.1 mg in 2009 and 18.5–24.4 mg in 2010. These values are lower than those reported in other studies (Masamba and Nguyen 2008; Singh et al. 2010) or available in databases (29 mg 100 g^{-1} fw, National Institute For Health And Welfare 2013; 33 mg 100 g^{-1} fw,). This may be explained by the generally low Ca supply in Finnish soils.

In practice, it is difficult to increase the Ca content of carrot by adding Ca to soil. This was also reported by El-Tarabily et al. (1997), who examined the use of lime and gypsum to control *Pythium* infestation. Within the plant, Ca transportation is driven by transpiration stream (White and Broadley 2003). Therefore, in addition to the adequate Ca supply in soil, maintaining good water status is among the important factors affecting plant Ca uptake. In our experiment, the Ca concentrations of the carrot leaves were not analyzed, and thus we cannot give an estimate of the total Ca uptake.

Based on the mineral analyses of carrot storage roots, Ca amendment did not affect the availability of other nutrients to carrot (data not shown). Despite the high supply of S in soil, plants apparently did not increase their S uptake, as the S concentrations of the carrots were not affected.

The expected positive effects of increased Ca supply on the storage quality were not established. When looking at the storage results and carrot Ca status, a trend was observed in the 2009 yield that the carrots from the field with the lowest Ca content had the poorest storage performance (Fig. 1). This was not the case in the data from 2010. Due to the small number of experimental fields, we cannot claim that Ca is the main factor explaining the large variation in storage results; for example, crop rotation affects the occurrence of soil-borne pathogens. Our findings, however, emphasize the need to further examine the influence of different nutrients, especially Ca, on the storage quality of carrot so as to seek good fertilization strategies to ensure high quality.

Conclusions

Amending soil with gypsum at the rates of 2500 or 5000 kg ha^{-1} (including 575 and 1150 kg of Ca ha^{-1}, respectively) was not effective in improving the Ca content in carrot roots or enhancing carrot storability. The treatment did not, however, increase the carrot S content either. Further research is needed to investigate the significance of the plant nutrient status in terms of the storage quality of carrot.

Acknowledgments

This project was financially supported by the European Agricultural Fund for Rural Development, and Maiju and Yrjö Rikala's Horticultural Foundation, which is grate-

fully acknowledged. The authors wish to thank the carrot growers who offered their fields for use in the experiments, and Yara Suomi for their co-operation.

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Received 01/20/2014 / Accepted 06/02/2014

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