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Effect of potassium application on celery growth and cation uptake under different calcium and magnesium levels in substrate culture

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ABSTRACT

The effect of potassium (K) on celery (*Apium graveolens* L.) growth and cation uptake was studied under different calcium (Ca) and magnesium (Mg) levels in substrate culture in the greenhouse. Shoot and root fresh and dry weight and leaf area increased with increasing K application up to 8 mmol l^{-1}. High level of Ca and Mg (16 mmol l^{-1}) significantly inhibited celery growth compared to lower levels (4 and 8 mmol l^{-1}). In this study, K concentration in celery increased with increasing K application up to 8 mmol l^{-1}, but did not change significantly with further increases in K application. In contrast to K, the opposite trends were found for Na, Ca and Mg concentrations in celery. The order of K concentration in celery root, stalk and leaf was: stalk > root > leaf and for Ca was: leaf > stalk > root. Mg concentration in celery root and leaf was high when compared with stalk. In addition, 8 and 16 mmol l^{-1} of Ca and Mg levels increased celery cation uptake as compared with 4 mmol l^{-1} of Ca and Mg level. This study suggested that 4–8 mmol l^{-1} K applications under the condition of 8 mmol l^{-1} of Ca and Mg level were appropriate for the improvement of celery growth and nutrient uptake

1. Introduction

Celery (*Apium graveolens* L.) is a popular leafy vegetable that is cultivated widely under greenhouse conditions, especially in China, due to its short crop cycle and potential to fetch premium prices at market. However, celery is very sensitive to nutritional disorders and growers frequently experience a variety of quality problems that can often be traced to nutrient deficiencies, excesses or imbalances (Tremblay et al., 1993; Pardossi et al., 1999; Madrid et al., 2008).

At present, excessive fertilizer applications are used to ensure plant growth and yield (Owen et al., 2008). However, this can cause salinization of growing media, ultimately resulting in inhibition of plant growth. Therefore, nutrient salt leaching using good quality water must be conducted periodically (Xu et al., 1995), which can result in the fertilizer waste and the risk of water pollution. Studies show that the dominant cations in the substrate are Ca and Mg salts, but not Na in intensive horticultural production, which could result in K imbalance for plant uptake given that K, Ca and Mg are essential elements of plant which are all required in large quantities (Grattan and Grieve, 1999; Savvas and Gizas, 2002; Lv and Si, 2004). Therefore, the optimization of their doses is helpful for to maintain low cost and high productivity of substrate-grown celery.

The aims of this experiment are to study the growth and cation uptake of celery in soilless substrate culture under different K, Ca and Mg levels and determine optimum application rates to improve celery growth and nutrient uptake.

2. Materials and methods

2.1. Substrate and nutrient solution

The substrate used in this experiment was a mixture of sand and peat moss (95:5, w/w) prepared as described in our previous manuscript (Li et al., 2010). The prescriptions of nutrient solution were achieved utilizing Yamazaki nutrient formulation with modification based on our previous studies (Sun et al., 2004; Ao et al., 2008). K was applied as K_2SO_4 at concentrations of 0, 2, 4, 8, 16 and 32 mmol l^{-1}, and Ca and Mg were applied as $CaCl_2$, $Ca(H_2PO_4)_2{\cdot}H_2O$, $Mg(NO_3)_2{\cdot}6H_2O$ and $MgSO_4{\cdot}7H_2O$, respectively, at concentrations of 4 mmol l^{-1} Ca and 4 mmol l^{-1} Mg (low level), 8 mmol l^{-1} Ca and 8 mmol l^{-1} Mg (medium level), and 16 mmol l^{-1} Ca and 16 mmol l^{-1} Mg (high level), resulting in 18 nutrient solution treatments. Meanwhile, the concentrations of P and N were 4 mmol l^{-1} and 8 mmol l^{-1}, respectively. The concentrations of micronutrients were NaFeEDTA 0.1 mmol l^{-1}, H_3BO_3

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4×10^{-2} mmol l^{-1}, $MnSO_4 \cdot 4H_2O$ 1×10^{-2} mmol l^{-1}, $ZnSO_4 \cdot 7H_2O$ 1×10^{-3} mmol l^{-1}, $CuSO_4 \cdot 5H_2O$ 3×10^{-4} mmol l^{-1}, and $(NH_4)_6 Mo_7O_{24} \cdot 4H_2O$ 1×10^{-5} mmol l^{-1}. The pH of all nutrient solutions was adjusted to 6.0 with dilute NaOH. All nutrient solutions were prepared with de-ionized water. All of the above nutrient salts were of analytical-reagent grade (Sinopharm Chemical Reagent Shanghai Co., Ltd., China)

2.2. Plant material and experimental design

Celery variety "Shanghai Huangxin Qin" was used as plant material. The pot experiment was performed in an unheated solar greenhouse in Chongming Modern Agricultural Zone, Shanghai, China (31°35′N, 121°47′E). In this region, celery is usually planted in the fall and winter seasons. On 29 October 2008, 25 d old uniform celery seedlings were transplanted into the plastic pots. Three seedlings were grown in each plastic pot. For each of the 18 treatments, there were three replicates where the experimental unit was one pot with three seedlings. Treatments were distributed using the randomized complete block design. Plants were irrigated using 100 ml of their corresponding nutrient solution treatments every 2 d from 2 November to 20 December. Additional irrigation water (de-ionized water) was applied as needed using a weighing method every week to maintain container moisture capacity. During this experiment period, mean air temperature was of 13.7 °C (with an oscillation between 8 and 18 °C), while the cumulated value of global radiation inside the greenhouse was 316 MJ m^{-2}.

2.3. Sample collection and measurement

Substrate electrical conductivity (EC) was measured weekly from the onset of treatments by using *in situ* "direct stick" EC meter (model 2265FS, Aozuo Ecology Instrumentation Ltd., Beijing, China) (Scoggins and van Iersel, 2006). Each measurement was performed 1 h after irrigation of nutrient solution. The measurement point was 8 cm below substrate surface. On 21 December 2008, one plant per pot was randomly selected and harvested. The plants were washed with tap water, rinsed in distilled water, and divided into roots, stalks and leaves. The above-ground fresh weight and leaf area per plant were investigated. Dry weights of the plant organs were measured after drying at 60 °C for one week. Dry plant materials were ground to pass through a 917 μm mesh screen, and then analyzed using ICP-AES (Iris Advangtage 1000, Thermo Electron, USA) for Ca, Mg, K, and Na following digestion in a nitric-perchloric acid mixture (Bao, 2005). In addition, according to the methodology for soil measurement of Bao (2005), (0)–15 cm depth substrate cores were collected and analyzed for K, Na, Ca and Mg under natural moisture conditions. Available K, Na, Ca and Mg in substrate were extracted using 1 mol l^{-1} acetic ammonium. Na and K were measured using the atomic emission spectrometry, and Ca and Mg using atomic absorption spectrometry (AA6800; Shimadzu Corp., Kyoto, Japan). The elemental concentrations in the substrate (c) were calculated using the following equation:

$$c = \frac{c_m}{1 - p}$$

where c_m and p represented substrate elemental concentrations measured under natural moisture condition and the moisture content in substrate, respectively.

2.4. Statistical analysis

Analysis of variance of the data was performed using the SAS 6.12 software (SAS Institute, Cary, NC, USA). Regression analysis was carried out to identify relationships between possible parameters using the SigmaPlot 9.0 software.

3. Results

3.1. Substrate EC

EC values reflect changes in substrate salinity. The measurements of *in situ* EC every week indicated that EC values did not change significantly over time (Fig. 1). EC values were significantly affected by Ca and Mg level and K application. In general, EC value significantly increased with increasing Ca and Mg level, which could be partly attributed to increased Cl and SO_4 concentrations (Li et al., 2010). According to Fig. 1, K application increased substrate EC. Especially under the low level of Ca and Mg, K application significantly ($P < 0.01$) increased substrate EC compared to 0 mmol l^{-1} K treatment. In addition, the changes of substrate EC values were 0.22–0.37 mS cm^{-1} and 0.29–0.51 mS cm^{-1} under medium and high levels of Ca and Mg, respectively.

3.2. Change of cation concentrations in substrate

According to Fig. 2, available K concentrations in the substrate were significantly affected ($P < 0.001$) by K application, but not by Ca and Mg level or their interaction. Relationship between available K concentration in the substrate and K application could be fit using a power function ($y = 42.7 + 39.7x^{0.55}$, $R^2 = 0.92$, $P < 0.001$, $n = 18$), indicating that available K in the substrate increased more rapidly per unit of applied K than it did at the higher levels of K application. Similarly, available Na concentrations in the substrate were significantly affected by K application ($P < 0.001$), but not by Ca and Mg level or their interaction. Substrate Na concentrations significantly increased with increasing K application up to 8 mmol l^{-1}, but did not change significantly with further increases in K application. Substrate Ca concentrations were significantly affected by Ca and Mg level and K application ($P < 0.001$), but not by their interaction. In general, available Ca concentrations in substrate decreased with increasing K application. In each K treatment, substrate Ca concentrations increased with increasing Ca and Mg level. Similarly, increased Ca and Mg level significantly increased substrate Mg concentrations ($P < 0.001$). However, substrate Mg concentration did not change significantly with increase in K application or the interaction of K application × Ca and Mg level.

3.3. Effects of K, Ca and Mg application on celery growth

The effects of K applications on celery growth under different Ca and Mg levels are shown in Fig. 3. K, Ca and Mg levels significantly affected celery shoot dry weight, root dry weight, shoot fresh weight and leaf area ($P < 0.001$). For celery fresh weight and leaf area there was a significant interaction of K application × Ca and Mg level ($P < 0.01$). Celery shoot dry weight, root dry weight, shoot fresh weight and leaf area increased with increasing K application up to 8 mmol l^{-1}, but did not change significantly with further increases in K application. High application levels of Ca and Mg significantly reduced celery shoot and root dry weights compared with low and medium levels of Ca and Mg ($P < 0.001$), irrespective of K application. However, under 0 mmol l^{-1} K application, medium and high levels of Ca and Mg significantly decreased celery shoot fresh weight and leaf area compared with low level of Ca and Mg. K application significantly alleviated the stress of medium Ca and Mg level on celery shoot fresh weight and leaf area.

3.4. Effects of K, Ca and Mg application on uptake of Ca, Mg, K and Na

In general, the order of K concentrations in celery root, stalk and leaf was: stalk > root > leaf. The K concentrations of celery roots, stalks and leaves increased with increasing K application from 0 to