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Effects of NPK Deficiencies on Root Architecture and Growth of Cucumber

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ABSTRACT

A hydroponic culture was carried out to study the effects of N, P, K deficiencies on root traits of cucumber, including root length, root surface area, projected area, average root diameter and biomass. The results showed that compared with control, N and K deficiencies reduced cucumber shoot weight by 17.39 g/plant and 7.31 g/plant, root mass by 5.68 and 7.05 g/plant correspondingly, and decreased all values of root traits. P deficiency lessened 9.72 g/plant shoot weight but increased 0.45 g/plant root weight by raised 71.1% root volume, 31.4% total root length, 44.3% surface area, 48.7% projected area and 8.8% average diameter. The ratio of root/shoot was enhanced by 101.8% in N deficiency and 74.1% in P deficiency, but reduced by 33.3% in K treatment. It reveals a potential of shaping root system by deficient nutrient application. © 2012 Friends Science Publishers

Key Words: Root; Cucumber; NPK Deficiency; Root/shoot ratio

INTRODUCTION

Roots are important organs (Mitsuhiro *et al*., 2011). A strong root system can be helpful in the biological control of plant diseases, and improvement of root system promotes active acquisition of water and nutrients for the production of high yields (de Dorlodot *et al*., 2007) and better quality of seedlings. Plug transplants, featuring with intact root system (Bish *et al*., 2001; Poling & Maas, 2000) is widely used in vegetable production (George *et al*., 2006). This technique has several distinct advantages (Poling & Parker, 1990), including the minimal root damage during transplanting which provides rapid root establishment, and plant survival that is greater thus giving a more uniform stand and potentially greater yields (Eric & Daniel, 1996). A better root system is unsurprisingly becoming a greatest objective in vegetable plug transplant seedling industry, in which NAA, GA and other phytohormone are currently broadly employed, because of their functions in promoting lateral root initiation, regulating the emergence of lateral root (Casimiro, 2001; Fu & Harberd, 2003; Dill *et al*., 2004) and so on. However, as we all known, it is risky to use phytohormone commonly in vegetable production, because it only works well when being carefully used, if not, the quality and safety of vegetable product would be disturbed (Wang, 2009).

As a matter of fact, root architecture traits such as length, weight, number, thickness, and density of primary, lateral, and adventitious roots are highly influenced by many environmental factors includes nutrients (Zheng *et al*., 2003; Lafitte *et al*., 2004). N, P and K require the greatest agricultural investment with regard to fertilizer inputs worldwide (Kochian, 2000), they are essential for cucumber growth (Hawkin *et al*., 2008), but to some extent, deficiency can stimulate root growth.

Recently, much attention has been attracted to the regulation mechanism of nutrients on plant root growth and corresponding nutrient efficient breeding practice (Angela, 2011; Obara *et al*., 2011; Rajeev *et al.*, 2011), but few attempt has been made by using above knowledge to control seedling growth in intensive vegetable transplant industry. In this study, hydroponic cultured cucumber, one of the most popular vegetables in plug transplant industry, was used to test whether and how these macro nutrients insufficient situations positively affect its roots in seedling stage. We explore and report the effects of three most necessary nutrient elements on cucumber root growth with final aim in developing a nutrient management strategy for efficient and environmental friendly vegetable transplant cultivation.

MATERIALS AND METHODS

Plant growth conditions: Seeds were soaked for 24 h in water, surface sterilized for 5 min in 10% (v/v) H_2O_2 before germination and germinated in dark on germination papers soaked with 0.5 mm $CaSO_4$ in darkness at 30°C. All experiments were arranged in a randomized complete block

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design with three replications. Seven days after germination, uniform seedlings were transplanted into nutrient solution with indicated treatments.

Four treatments: control, low nitrogen (LN), low phosphorus (LP) and low potassium (LK) were designed. The control, full strength modified nutrient solution, was composed of (in g/L): KNO_3, 0.607; NH_4NO_3, 0.053; Ca $(NO_3)_2$, 0.826; $MgSO_4$, 0.370; K_2SO_4, 0.087; KH_2PO_4, 0.181; Na_2Fe-EDTA, 20; $MnSO_4.H_2O$, 1.54; $ZnSO_4.7H_2O$, 4.5; $CuSO_4 \cdot 5H_2O$, 0.08; H_3BO_3, 2.86 and $(NH_4)_6Mo_7O_{24} \cdot 4H_2O$, 0.02. There was no nitrogen in LN, no phosphorous in LP and no potassium in LK treatments; the others were same as control. K_2SO_4, $CaCl_2$ and NH_4NO_3 were used to complement K, Ca in N deficient treatment, K in P treatment and N in K treatment. Solutions were well aerated and pH was daily maintained between 5.8 and 6.5. Plants were grown in greenhouse. All experiments had three replicates.

Determination of fresh weight and root morphological characteristics and data analysis: Plants were harvested at 20th day after transplantation. Plants were washed with tap water, rinsed in distilled water, and divided into roots and shoots. The fresh weight (FW) was measured soon after harvest. Root length, average diameter (AD), projected area (PA) and surface area (SA) of roots were quantified with computer image analysis with the DT_scan program (Delta_T Devices Ltd., England) and the WinRhizo program (Regent Instruments Inc. Canada). Single factor or two factors ANOVA were analyzed by Excel 5.0 (Microsoft Excel 5.0, 1995, Microsoft Corporation).

RESULTS

Shoot and root biomass: Nutrient deficiency decreased cucumber biomass to different extents. Loss of N, P and K reduced cucumber shoot biomass from 23.87 g/plant of the control to 6.48 in LN treatment, 14.15 in LP treatment, and 16.56 g/plant in LK treatment (Fig. 1). Root biomass were also declined by 5.68 and 7.05 g/plant, respectively because of N and K shortage, but slightly increased with P deficiency. Results indicate that among three tested nutrients, P limitation, in some way, stimulated cucumber root growth.

Root/shoot ratio of cucumber was profoundly enhanced with absence of N and P, by 101.8% and 74.1%, respectively as Fig. 2 showed, but difference between above two treatments was not significant. Without K supply, however, resulted in a 33.3% reduction for root/shoot ratio.

Effect of NPK deficiencies on root traits: The effects of NPK deficiencies on root growth can be seen from Table I. Compared with completely nutrient condition, total root length, surface area (SA), projected area (PA) and volume (V), average diameter (AD) of cucumber per plant were all affected by NPK deficiencies. The highest increase, 71.1%, was observed in root volume, then 31.4% in total root length, 44.3% in SA, 48.7% in PA and 8.8% in AD when zero P was supplied. On the contrary, the other two nutrient deficiencies reduced all root traits of cucumber from highest 45% in root volume under K deprivation to lowest 5.9% in total root length in N shortage (Table I). Fig. 3 showed a systemic image of difference of roots under deficiencies.

Table I: Root traits under NPK deficiency stresses

Treatment	Total root length (cm)	Root surface area (cm^2)	Projected area (cm^2)	Volume (cm^3)	Average diameter (mm)
CK	1551.1a	239.05b	76.1b	2.6b	0.446a
LP	2282.7a	355.05a	113.05a	4.45a	0.493a
LK	1483.0a	158.33b	51.37b	1.433b	0.352b
LN	1598.2a	182.4b	58.04b	1.65b	0.351b

Different letters indicate significant differences within each vertical column (Duncan's test, $P \leq 0.05$)

DISCUSSION

Root plays important roles in plant growth and development cycle (Liao, 1995) and its development is remarkably sensitive to variations in the supply of inorganic nutrients in the soil (Brain & Helena, 2001). Based on the results, N deficiency resulted in a marked decrease in shoot, while K shortage resulted in a significantly decrease of root weight. Interestingly, differing from other two treatments, P deficiency promoted root growth. Since a large root system is more advantageous to the plant than a small one for efficiently acquiring water and fertilizer (Kramer, 1969; Gedroc *et al.*, 1996), impact of P limitation on root architecture was therefore particularly concerned.

Only a balanced growth is good for plant's nutrient status (Chapin, 1980; Agren & Ingestad, 1987). Root/shoot ratio, therefore as the combined influence on shoot and root, was evaluated. Consistent with Ericsson (1995), the results showed that absences of N, P resulted in a shift in weight allocation in favour of root growth, but supposedly by different reasons. Fig. 1 and Fig. 2 were taken together, we assume that greater restriction in shoot than root was account for the increase of root/shoot ratio under N treatment, but the increase of root/shoot ratio in P treatment was more like the consequence of promoted root system. Of the nutrients tested, only K failed to elicit an increase response in root/shoot ratio.

Measurement of the relative biomass of shoot and root may still fail to reveal the subtleties of the root responses to changes in nutrient supply (Brian, 2001). Detailed root characteristics under treatments were then analyzed to further support our hypothesis (Table I). The figures revealed that comparing with control; PA, V, and finally roots weight of cucumber were in a decrease in, LN treatment. While according to Wang *et al.* (2004), N could promote maize root growth. This discrepancy can be explained in following three ways. Firstly, we didn't apply any nitrogen to cucumber seedlings at all, but Wang *et al.* (2004) treated their maize root with highest concentration of the nitrogen for 4 mM, then reduced N dose gradually.

Fig. 1: Shoot and root biomass under NPK deficiency

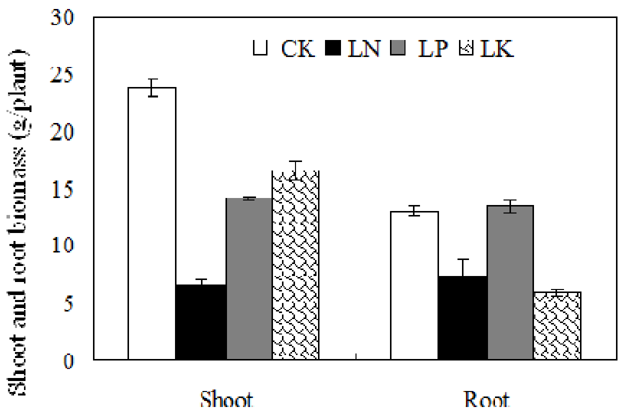


Fig. 2: Root/shoot ratio under NPK deficiency

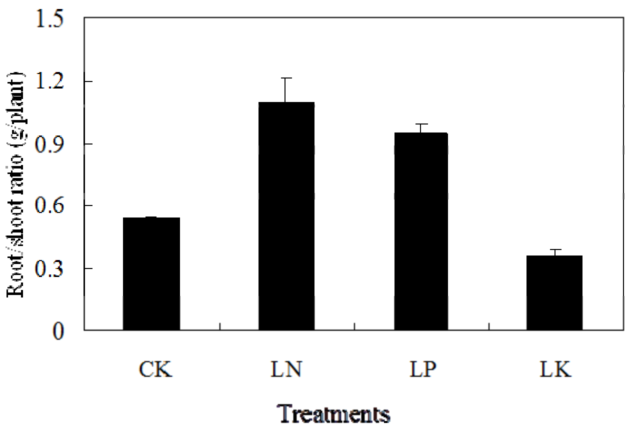
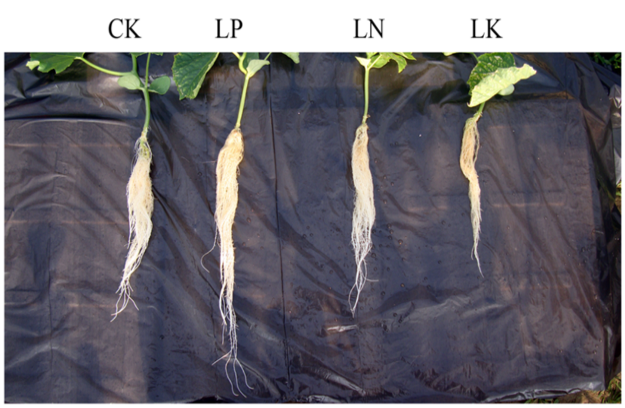


Fig.3: Root system of cucumber in CK and PNK deficiency

CK: control; LP: low phosphorous treatment; LN: low nitrogen treatment; LK: low potassium treatment



Secondly, contrasting effects on lateral root and primary root were observed in their research, but no lateral or primary roots were distinguished in our experiment, so it can't tell, which parts of root restriction resulted in smaller AD and PA, or contributed to slightly improved SA in N deficiency. Thirdly, N-NO_3 and N-NH_4 make different effects on root development, we didn't analysis their individually either. Root architectural responded to P availability have been observed in lupins, Arabidopsis and may be ubiquitous in the plant kingdom (Jose *et al.*, 2003). Accordance with former reports, LP stimulates root hair growth (Bates & Lynch, 1996), alters lateral root development in Arabidopsis thaliana (Claudia *et al.*, 2008), we present preliminary evidence that LP also favored root growth by increased SA, PA, V and AD in cucumber.

In crus, among tested nutrients, N, K deficiency showed few positively regulation symptom in root architecture, but P deficiency might be positive for a vigorous cucumber seedling with strong root and well-balanced root/shoot ratio and maybe either applicable to other vegetables. But, further study about details on critical P amount and how long it should be last is still needed.

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