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Hydroponic cultivation of carrots using modified rockwool blocks

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Abstract

Three varieties of carrot (*Daucus carota* L.), 'Tokinashigosun', 'Hitokuchi' and 'Kurodagosun' were cultured hydroponically with rockwool blocks (56×8×30 cm high) in a greenhouse for 90 days. Two types of rockwool block, with holes and without holes were used in the study. Rockwool blocks with holes had seven rooting holes (10 cm in depth and 2.5 cm in diameter) 8 cm apart, which were filled with vermiculite for promoting root development. Rockwool blocks without holes were used as the control for comparison. Two rockwool blocks were placed side by side in a plastic box (58×18×18 cm high) and 14 plants were grown in each plastic box. The rockwool blocks were automatically sub-irrigated with a nutrient solution containing 35 ppm total N, 14 ppm P, 59 ppm K, 23 ppm Ca, 10 ppm Mg, 0.62 ppm Fe, 0.12 ppm Mn, 0.06 ppb B, 0.02 ppm Cu, 0.04 ppm Zn and 0.01 ppm Mo. The solution was added to the plastic boxes twice a day to keep the depth of the solution at 15 cm. The fresh and dry weights of the storage roots were 2 to 3 times greater in the rockwool blocks with holes than those without holes in each variety. The storage roots produced in the rockwool blocks with holes were 2 times longer than without holes in all the varieties. The diameter of storage roots was also greater in rockwool blocks with holes than without holes. Greater weights of the whole-plant and percent harvest index were obtained in the rockwool blocks with holes than in the without holes in all the varieties. Carbon dioxide concentration inside the rockwool blocks at a depth of 8 cm from the top surface and 1 cm beside the storage roots were lower in the rockwool blocks with holes (0.08%) than in the without holes (0.11%). Carbon dioxide gas diffusion coefficient in the rockwool media was greater in the rockwool blocks with holes than in the without holes. The hardness of the growing media was lower in the rockwool blocks with holes containing vermiculite than in the without holes. Therefore, better aerating conditions inside the rockwool blocks with holes containing vermiculite and lower hardness of the media would partly account for the better growth of storage roots in the rockwool blocks with holes than in the without holes in all the tested varieties.

Key words: CO_2 concentration, CO_2 gas diffusion coefficient, *Daucus carota,* growth, harvest index, storage roots, yield

Introduction

The part of the Asia extending from the west coast of India to Japan covers about 15% of the world land surfaces, but contains more than 50% of the world's population (Herald *et al.,* 1993). The population density is roughly six times that of the rest of the world. Furthermore, most of the increase in the world's population in the next decades is expected to be in this region (Herald *et al.,* 1993). Recently, shortages of food and energy have become serious problems in these countries due to the rapid increase of the population and subsequent decrease in arable lands. The challenge facing global agriculture is to more than double food production. Recently, consumption of vegetables has been increasing in the developing countries of the world due to the rapidly growing population. Now it is necessary to develop some suitable methods and techniques for increasing vegetable production in limited space with increasing cropping intensity to meet an acute shortage of vegetable crops for the hungry millions to solve severe malnutrition problem of the densely populated countries of the world.

Carrot is an important vegetable crop especially in tropical and subtropical areas. It is rich in carotene, a precursor of vitamin A, and contains appreciable quantities of thiamine and riboflavin. Deficiency of vitamin A is the cause of xerophthalmia, which can cause blindness in children, and was formerly common in India, Africa and Southeast Asia (Phillip and Rix, 1993). Therefore, the extension of carrot cultivation can be achieved with diverse growing methods under different environmental conditions increasing the cropping intensity, yield and production in a limited space.

Carrot yields and root length are strongly influenced by the water table and the water content of the growing media during the vegetative period (Henkel, 1970; Millette, 1983; White, 1992 and Islam *et al.*, 1998). The storage roots of carrots generally show poor growth under water-saturated conditions due to inadequate air permeability of the rooting medium, resulting in short and forked storage roots (White and Strandberg, 1979). So far the authors knowledge, there are no reports available on the successful cultivation of carrots using hydroponic or soil-less method of cultivation.

The goal of the present study was to develop a method to produce carrots following a simple method of hydroponics. Two types of rockwool blocks were examined in the study to provide the aerial spaces in the storage roots growing zone in order to obtain better growth and development of storage roots of carrots in hydroponics. In the present study, the growth characteristics and yield of three carrot varieties were investigated to examine the possibility of producing carrots using suitable method of use of rockwool blocks in the hydroponic cultivation.

Materials and methods

Cultural conditions and treatments: The experiment was conducted in a greenhouse of Osaka Prefecture University (34°33′ north latitude and 135°31′ east longitude with 30 m elevation on the sea level), Japan during the period from mid May to mid August. The average temperature during the growing period inside the greenhouse was maintained at 27±4°C. Two types of rockwool block, with holes and without holes were used in the study. Rockwool blocks with holes had seven rooting holes (10 cm in depth and 2.5 cm in diameter) 8 cm apart, which were filled with vermiculite for promoting root development (Fig. 1). Rockwool blocks without holes were used as the control for comparison. Two rockwool blocks (56×8×30 cm high) were placed side by side in a plastic box (58×18×18 cm high) and 14 plants were grown in each plastic box. The rockwool blocks were sub-irrigated with a nutrient solution containing 35 ppm total N, 14 ppm P and 59 ppm K, 23 ppm Ca, 10 ppm Mg, 0.62 ppm Fe, 0.12 ppm Mn, 0.06 ppb B, 0.02 ppm Cu, 0.04 ppm Zn and 0.01 ppm Mo. The solution was automatically added to the plastic boxes twice a day to keep the depth of the solution at 15 cm.

Three cultivars of carrot, 'Tokinashigosun', 'Hitokuchi' and 'Kurodagosun' were cultured hydroponically. Seeds were placed on seven points 8 cm apart on each rockwool block either having holes or without holes. The seeds were germinated one week later. Insecticides were sprayed three times to control the infestations of insects during the growing period.

Harvesting and data recording: Twenty plants from four boxes in the rockwool blocks with holes containing vermiculite and rockwool blocks without holes in each variety excluding the border plants were randomly sampled and harvested after 90 days of seed sowing for data recording. Fresh weight of above-ground parts and the storage roots were determined just after harvesting. Their dry weights were determined after drying for 72 hours at 80°C in an oven. The number of leaves, the lengths of the laminas and petioles, and the mean lengths and diameters of the storage roots were also recorded just after harvesting. The percentage of the storage roots that were split or forked was recorded according to the presence of radial longitudinal cracking and branching, respectively. A SPAD-502 (Minolta Co., Ltd. Japan) chlorophyll meter was used for measuring the chlorophyll content.

Shoot-root ratio (S/R) was calculated as S/R = (above-ground dry weight / storage root dry weight). Percent harvest index (HI) was calculated as HI = (storage root dry weight / whole-plant dry weight) ×100. Carbon dioxide concentration was determined by using a gas chromatograph (Model 633, Hitachi Co. Ltd., Japan). Carbon dioxide and oxygen gas samples were collected inside the rockwool blocks at a depth of 8 cm from the top surface and 1 cm beside the storage roots using a syringe and needle. Carbon dioxide gas diffusion coefficient was estimated based on the water content inside the materials following the relationships between water content and gas diffusion coefficient for rockwool and vermiculite (Yabuki and Kitaya, 1984; Kitaya, 1995). The hardness of the rockwool media was determined using a cone penetrometer (Rheo meter, Fudoh Co. Ltd., Tokyo, Japan).

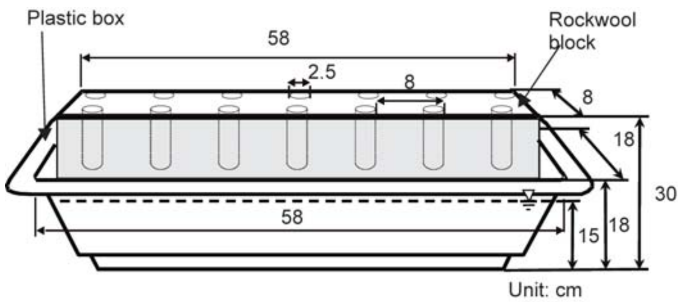

Fig.1. Schematic diagram of the culture box with rockwool blocks in hydroponic cultivation.

Experimental design and data analysis: The experiment was laid out in a randomized block design with four replications. Fisher's Least Significance Difference (LSD) method was used for comparing the growth characteristics and yield of three varieties of carrots and two types of rockwool after an ANOVA test. Mean differences of the parameters in the treatments were compared using Fisher's LSD Test at 5% level of significance.

Results

The differences in growth and morphological characteristics of storage roots and above-ground parts between the rockwool blocks with holes and the rockwool blocks without holes had almost the similar trend in all the varieties. Storage roots of carrots showed better growth in the rockwool blocks with holes than in the without holes in all the varieties (Fig. 2). The fresh and dry weights of storage roots were 2 to 3 times greater in the rockwool blocks with holes than in the without holes in all the varieties (Fig. 3). In the rockwool blocks with holes, the storage roots of the varieties Tokinashigosun and Kurodagosun had higher fresh and dry weights than the variety Hitokuchi.

Storage roots had greater length and diameter in the rockwool blocks with holes than in without holes in all the varieties (Table 1). The length of the storage roots of each variety in the rockwool blocks with holes were almost double of those in the without holes. Cracking of the storage roots was observed only in the variety Tokinashigosun. In this variety, the percent of cracking was higher in the rockwool blocks without holes than in the with holes. The percent of storage roots that were forked was higher in the rockwool blocks without holes than in the with holes in all the varieties.

The growth of the above-ground plant parts was also greater in the rockwool blocks with holes than in the rockwool blocks without holes in each variety. The varieties Kuradagosun and Tokinashigosun showed 2.2 and 1.7 times greater fresh and dry weights of above-ground parts, respectively in the rockwool blocks with holes than without holes. The fresh and dry weights of the total phytomass per plant were 1.7 to 2.4 times greater in the rockwool blocks with holes than in the rockwool blocks without holes (Table 2).

Number of leaves per plant was greater in the rockwool blocks with holes than in the rockwool blocks without holes in the varieties, Tokinashigosun and Kurodagosun. The length of laminas of the Kurodagosun was higher in the rockwool blocks with holes than in the rockwool blocks without holes. Petiole lengths in the rockwool blocks with holes and rockwool blocks without holes were not significantly different in any of the varieties. Significantly greater chlorophyll content was recorded in the rockwool blocks with holes than without holes only in the variety, Tokinashigosun (Table 3).

In each variety, the shoot-root ratio was significantly (1.6 to 2.9 times) greater in the rockwool blocks without holes than with holes (Table 4). Percent harvest index was significantly (1.1 to 1.7 times) greater in the rockwool blocks with holes than without holes in the varieties, Toknashigosun and Hitokuchi (Table 4).

Carbon dioxide concentrations inside the rockwool blocks were lower in the rockwool blocks with holes than without holes (Fig. 4). Carbon dioxide gas diffusion coefficient was greater in the rockwool blocks with holes than in the rockwool blocks without

Fig. 2. Photograph of carrots grown on rockwool blocks with holes (right) and without holes (left) at harvest.

Table 1. Morphological characteristics of storage roots of carrots grown on rockwool blocks with rooting holes containing vermiculite or without rooting holes

Varieties	Rockwool block	Length (cm)	Diameter (cm)	Cracking (%)	Forking (%)
Tokinashigosun	With holes	12.1a	2.7a	10	0
	Without holes	6.1bc	2.0b	20	50
Hitokuchi	With holes	12.4a	2.2a	0	10
	Without holes	7.6b	1.6b	0	60
Kurodagosun	With holes	11.0a	2.7a	0	0
	Without holes	5.3c	2.2a	0	20
Varieties (V)		**	**	-	-
Rockwool types (R)		**	*	-	-
V×R		**	*	-	-

Figures with same letter in a same column do not differ significantly at 5% level by Fisher's LSD test.
Analysis of variance was applied for 6 treatments; 3 varieties and 2 rockwool types.
* and ** indicate significant differences at the P=0.05 and P=0.01, respectively.

Table 2 Weight of total phytomass and above-ground parts of carrots grown on rockwool blocks with rooting holes containing vermiculite or without rooting holes

Varieties holes	Rockwool block	Whole-plant weight ($g\ plant^{-1}$)		Above-ground parts weight ($g\ plant^{-1}$)	
		Fresh	Dry	Fresh	Dry
Tokinashigosun	With holes	79.0b	11.5b	36.7b	6.1b
	Without holes	35.4d	5.5d	20.5d	3.5c
Hitokuchi	With holes	54.9c	7.8c	25.6c	4.1c
	Without holes	32.4d	5.3d	21.8d	3.8c
Kurodagosun	With holes	118.3a	18.9a	79.5a	13.6a
	Without holes	48.6c	7.4c	35.6b	5.7b
Varieties (V)		**	**	**	**
Rockwool types (R)		**	**	**	**
V×R		**	**	**	**

Figures with a same letter in each column do not differ significantly at 5% level by Fisher's LSD test.
Analysis of variance was applied for 6 treatments; 3 varieties and 2 rockwool types.
** indicates significant differences at P=0.01

Table 3. Characteristics of leaves of carrots grown on rockwool blocks with rooting holes containing vermiculite or without rooting holes.

Varieties	Rockwool block	Number of leaves plant	Lamina length (cm)	Petiole length (cm)	Chlorophyll content
Tokinashigosun	With holes	12.8a	20.8c	26.3a	52.7a
	Without holes	9.5b	19.6c	27.0a	46.2c
Hitokuchi	With holes	9.2b	21.0c	23.9b	50.1ab
	Without holes	9.4b	21.3c	24.5b	48.2bc
Kurodagosun	With holes	13.9a	32.1a	27.1a	54.2a
	Without holes	10.1b	26.0b	26.5a	50.1ab
Varieties (V)		**	*	NS	NS
Rockwool types (R)		**	*	NS	*
V×R		**	*	NS	NS

Figures with same letter in a same column do not differ significantly at 5% level by Fisher's LSD test.
Analysis of variance was applied for 6 treatments; 3 varieties and 2 rockwool types.
* and ** indicate significant differences at the P=0.05 and P=0.01, respectively. NS indicates non significant.

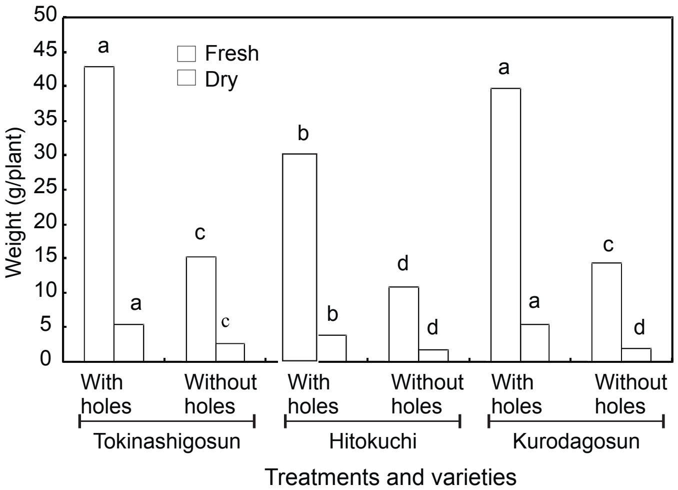

Fig. 3. Weight of storage roots of carrots grown in hydroponic method using rockwool blocks.

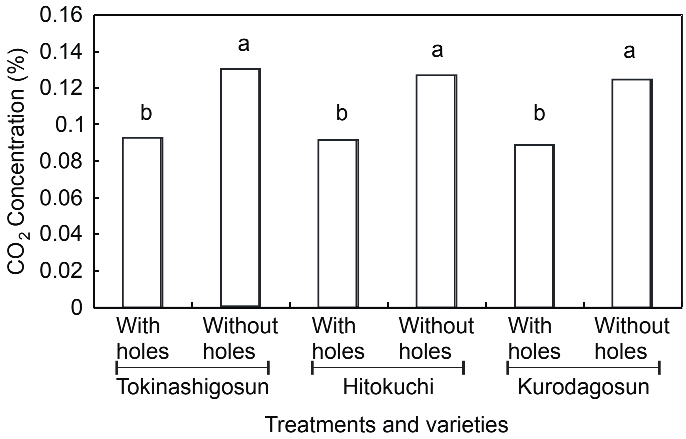

Fig. 4. CO_2 concentration inside the rockwool blocks with holes and without holes at a depth of 8 cm from the top surface and 1 cm beside the storage roots of carrots.

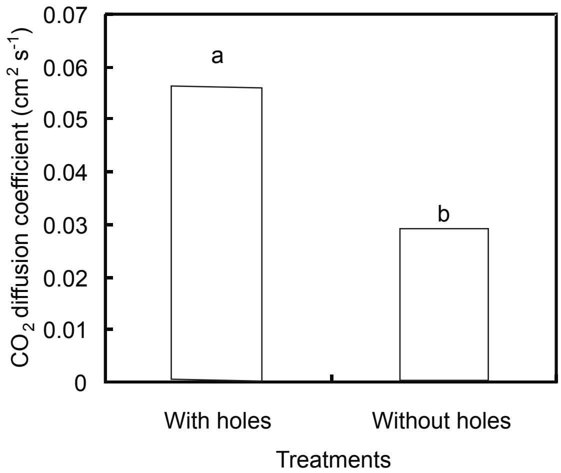

Fig. 5. CO_2 gas diffusion coefficients of vermiculite in the holes of rockwool blocks and rockwool blocks without holes.

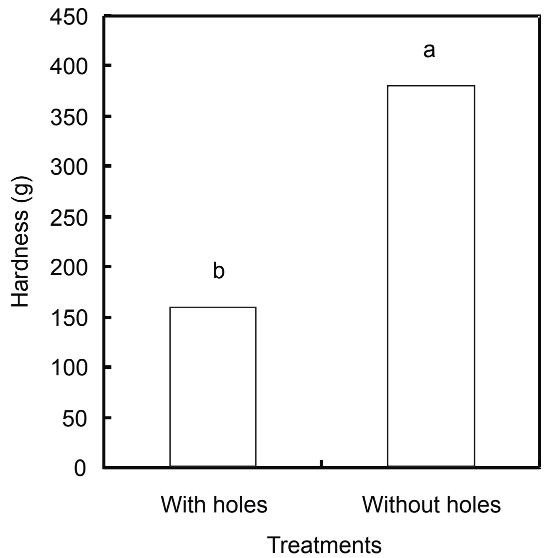

Fig. 6. Hardness of the rockwool media used as with holes and without holes.

holes (Fig. 5). The hardness of vermiculite in the rockwool blocks with holes was lower than in the rockwool blocks without holes (Fig. 6).

Discussion

The whole-plant, above-ground parts and storage roots showed better growth and development in the rockwool blocks with holes than without holes regardless of the variety. The fresh and dry weights, and length and diameter of storage roots showed greater growth and development in the rockwool blocks with holes containing vermiculite than in the rockwool blocks without holes. The short and forked storage roots of carrots were also observed by White and Strandberg (1979) when grown at water-saturated conditions due to inadequate air-permeability of the rooting medium. In a previous study, Islam *et al.* (1998) found that the length of storage roots of carrots was shorter when grown

Table 4. Shoot-root ratio and harvest index of carrots grown on rockwool blocks with rooting holes containing vermiculite or without rooting holes

Varieties	Rockwool block	Shoot-root (S/R) ratio	Harvest index (%)
Tokinashigosun	With holes	1.2c	46.5a
	Without holes	2.2b	33.6b
Hitokuchi	With holes	1.3c	47.2a
	Without holes	3.8a	28.3bc
Kurodagosun	With holes	2.7b	28.8bc
	Without holes	4.3a	25.6c
Varieties (V)	**	**	
Rockwool types (R)	**	**	
V×R	**	**	

Figures with same letter in a same column, do not differ significantly at 5% level by Fisher's LSD test.
†Analysis of variance was applied for 6 treatments; 3 varieties and 2 rockwool types.
** Significant differences at P=0.01

with higher water table levels. The forking of the storage roots was prominent in the rockwool blocks without holes regardless of the varieties. The better aeration and less hardness of the vermiculite would partly account for the better growth of carrot in the rockwool blocks with holes containing vermiculite.

Insufficient aeration in the root zone is a great problem for plant growth and thus has received a great deal of attention by the researchers. Poor aeration inhibits water and nutrient absorption of plants and thus inhibits growth (Lowton, 1945; Russell, 1977). This inhibition has been partly attributed to suppression of root respiration caused by low oxygen concentration (Glinski and Stepniewski, 1985) and high carbon dioxide concentration (Yabuki and Kitaya, 1984; Kitaya *et al.*, 1992). Generally, root damage in excess moisture environments has been attributed to the lack of oxygen (Williamson and Kriz, 1970). White and Strandberg (1979) reported that carrot root growth can be depressed by water-saturated conditions during early growth but growth continues if the root tips are not damaged. The carbon dioxide concentration was shown to increase considerably with increased water content (Yabuki and Kitaya, 1984; Kitaya *et al.*, 1984 and 1987 and Islam *et al.*, 1998). In the present study, the lower carbon dioxide concentration and higher carbon dioxide gas diffusion coefficient in the rockwool blocks with holes containing vermiculite were helpful in promoting better growth and development of storage root of carrots. Eavis (1972) reported that under compacted conditions, the effect of mechanical impedances and aeration deficiency on root growth was more apparent. In the rockwool blocks without holes, it would be expected that the storage roots of carrots would have had to exert a high pressure to penetrate the medium for growth as indicated by the greater hardness (Fig. 6). Under these conditions, carrot growth was restricted presumably because of the high mechanical impedance resulting in shorter, forked and poor storage root growth.

Therefore, better aerating conditions and looseness of the growing media around the roots would partly account for the better growth and development of storage roots of carrot in the rockwool blocks with holes containing vermiculite than in the rockwool blocks without holes.

The hydroponic method is applicable for carrot cultivation using loose growing media capable of providing sufficient aeration in the root zone. The method developed in the present study can be applicable to other vegetable crops as well.

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