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Growth of sweetpotato cultured in the newly designed hydroponic system for space farming

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Abstract

Life support of crews in long-duration space missions for other planets will be highly dependent on amounts of food, atmospheric O_2 and clean water produced by plants. Therefore, the space farming system with scheduling of crop production, obtaining high yields with a rapid turnover rate, converting atmospheric CO_2 to O_2 and purifying water should be established with employing suitable plant species and cultivars and precisely controlling environmental variables around plants grown at a high density in a limited space. In this study, we developed a new hydroponic method for producing tuberous roots and fresh edible leaves and stems of sweetpotato. In the first experiment, we examined the effects of water contents in the rooting substrate on growth and tuberous root development of sweetpotato. The rooting substrates made with rockwool slabs were inclined in a culture container and absorbed nutrient solution from the lower end of the slabs by capillary action. Tuberous roots developed on the lower surface of the rockwool slabs. The tuberous roots showed better growth and development at locations farther from the water surface on the rockwool slabs, which had lower water content. In the second experiment, three sweetpotato cultivars were cultured in a hydroponic system for five months from June to November under the sun light in Osaka, Japan as a fundamental study for establishing the space farming system. The cultivars employed were ‘Elegant summer’, ‘Kokei-14’ and ‘Beniazuma’. The hydroponic system mainly consisted of culture containers and rockwool slabs. Dry weights of tuberous roots developed in the aerial space between the rockwool slab and the nutrient solution filled at the bottom of the culture container were 0.34, 0.45 and 0.23 kg/plant and dry weights of the top portion (leaves, petioles and stems) were 0.42, 0.29 and 0.61 kg/plant for ‘Elegant summer’, ‘Kokei-14’ and ‘Beniazuma’, respectively. Young stems and leaves as well as tuberous roots of ‘Elegant summer’ are edible and palatable. Therefore ‘Elegant summer’ would be a promising crop to produce large amounts of food with high nutritional values in the present hydroponic system in space farming.

Keywords: Aeration; Hydroponic culture; Space farming; Sweetpotato

1. Introduction

Plant growth in space has recently been of greater concern as the possibility of realizing manned space flight over a long duration increases. The feasibility of achieving long-duration manned space missions for other planets will be highly dependent on crops in bioregenerative life support systems (BLSS) or space farming that will play important roles in food production, CO_2/O_2 conversion and water purification (e.g., Nitta, 1987; Salisbury, 1991; Gitelson, 1992). In space farming, scheduling of crop production and obtaining high yields with a rapid turnover rate are important.

Sweetpotato is a candidate food crop for crews and an important feed for domestic animals in space. Sweetpotato culture has many advantages over the culture of other crops, i.e., it grows more rapidly, has a high yield, and requires less fertilizer (Kozai et al., 1996). Recirculating hydroponic systems were recommended in space farming

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to allow efficient crop production and conservation of nutrients and water (Bugbee, 1995; Wheeler et al., 1999). However, the tuberous root growth of sweetpotato in hydroponic systems is generally poor mainly due to poor aeration in the root zone because of waterlogging or excess moisture content in the rooting substrate.

Hydroponic techniques for sweetpotato production have been developed by Loretan et al. (1989), Uewada (1990), Mortley et al., 1991, Uewada et al. (1992) and Hill et al. (1992) as well as for potato production (Wheeler et al., 1990) and peanut production (Mackowiak et al., 1998) in bioregenerative life support systems. Although the growth rate of sweetpotato in hydroponic systems was greatly fluctuated by environmental conditions (e.g., Loretan et al., 1989, 1994; Uewada et al., 1992; Bonsi et al., 1994; Eguchi et al., 2003), the yields were generally less than those under conventional field conditions. We are developing a new hydroponic method for culturing sweetpotato with a fibrous rooting substrate in order to ensure high yield with a simple system compared with previous studies. We employed rockwool slabs as the rooting substrate.

In this study, we developed a method for producing large amount of sweetpotato tuberous roots in a hydroponic system. In the first experiment, we examined the effects of water contents in the rooting substrate on growth and tuberous root development of sweetpotato as a preliminary experiment. After deciding the appropriate planting location on the rockwool slabs, three sweetpotato cultivars were cultured in a newly developed hydroponic system and the yield and growth performance of the cultivars were compared in the second experiment.

2. Materials and methods

Plastic containers containing rooting substrates were used to culture sweetpotato (*Ipomoea batatas* (L.) Lam.) hydroponically. The rooting substrates made with rockwool slabs were inclined in the container and absorbed nutrient solution from the lower end by capillary action. Sweetpotato plants were cultured using stem cuttings, which were inserted into the rooting substrate. Cuttings were 0.25–0.28 m long and had 9–11 nodes with 7–9 leaves each. Tuberous roots of sweetpotato were developed in the aerial space between the rockwool slab and the nutrient solution filled at the bottom of the culture container. The nutrient solution used was modified Hoagland solution. Water depth was kept at 0.05 m throughout the experimental period.

Dry weights of leaves, stems and tuberous roots were determined after drying each plant part for more than 48 h at 80 °C in an oven. The tuberous root biomass ratio was evaluated from the expression, (tuberous root dry weight)/(whole plant dry weight). All the data were analyzed statistically and differences in mean values were evaluated by Fisher's t test at a 5% level of significance, and showed with means and least significant differences.

2.1. Experiment 1: Growth of sweetpotato planted on the rooting substrate at different distances from the water surface

A sweetpotato cultivar, 'Elegant summer', was employed for this experiment. The rockwool slabs were inclined in the culture container (0.6 × 0.45 × 0.35 m high) (Fig. 1). The stem cuttings were located at 0.05, 0.15 and 0.25 m above the water surface. We focused on tuberous root formation at different locations on the substrate in this experiment. Terminal and lateral buds of each cutting were, then, removed for suppressing top growth and promoting tuberous root growth. Plants were cultured under greenhouse conditions without CO_2 enrichment in a summer season. Six plants were cultured for 32 days in each location.

Temperatures of the ambient air, the aerial space between the rooting substrate and the nutrient solution layer were measured every hour for the growing period. Temperatures of rooting substrates were also measured at 0.05, 0.15 and 0.25 m above the water surface. Relative humidity was measured in the ambient air and the aerial space between the rooting substrate and the nutrient solution layer. Temperatures and relative humidity in the air were measured with thermo-hygrometer (TR-72, T&D Inc., Japan) and temperatures in the substrate and the solution were measured with thermocouples. The water content at each location in the rooting substrates was measured with a soil moisture meter (HYDRO SENSE, Decagon Devices Inc., USA) at a depth of 5 cm in the substrate after making calibration with a weighing method.

2.2. Experiment 2: Growth characteristics of three sweetpotato cultivars in a hydroponic system

Three sweetpotato cultivars, 'Beniazuma', 'Elegant summer' and 'Kokei-14' were cultured in the hydroponic system mainly consisted of culture containers (1.9 × 0.55 × 0.25 m high, each) (Fig. 2a) and rockwool substrates. A growing space for tuberous roots was made

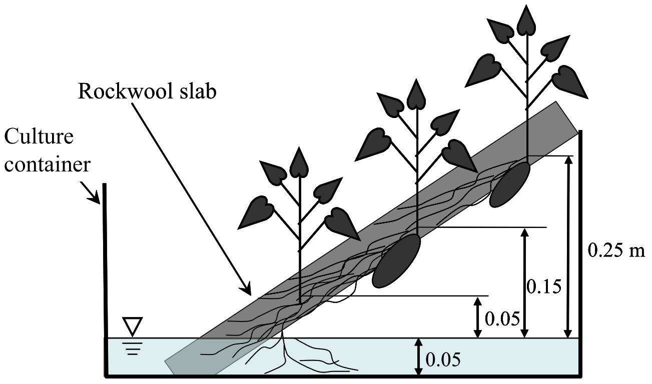

Fig. 1. Cross-section of the hydroponic system mainly consisted of a culture container and a rockwool slab in the first experiment.

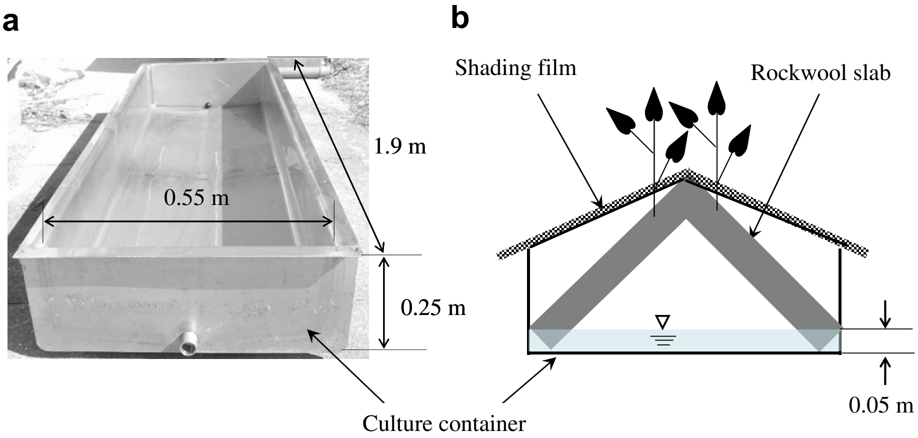

Fig. 2. A photograph of the culture container (a) and a diagram showing a cross section of the hydroponic system with the inclined rockwool slabs (b) used in the second experiment.

under inclined rockwool slabs and above the water surface in the culture container (Fig. 2b). The stem cuttings were planted at 0.2 m above the water surface. Sixteen plants of each cultivar were cultured for 150 days from June to November in 2005 under an open field condition. Mean daily integrated solar radiation was 13.2 MJ m^{-2} during the culture period.

3. Results and discussion

For the growing period in the first experiment, average temperatures in the ambient air, in the aerial space between the rooting substrate and the nutrient solution layer, and in the nutrient solution was 36.3, 32.6 and 31.3 °C, respectively, at 06:00–18:00, and 27.6, 29.5 and 29.2 °C, respectively, at 19:00–05:00. The root zone temperature was lower in the daytime and higher in the nighttime than atmospheric air temperature. Average temperatures of rooting substrates at 0.05, 0.15 and 0.25 m above the water surface were 32.9, 31.6 and 32.0 °C, respectively, at 06:00–18:00, and 28.6, 26.5 and 26.6 °C, respectively, at 19:00–05:00. There was no significant difference among the locations. Average values of relative humidity in the ambient air and the aerial space between the rooting substrate and the nutrient solution layer were 48% and 98%, respectively, at 06:00–18:00, and 75% and 99%, respectively, at 19:00–05:00. The aerial space between the rooting substrate and the nutrient solution layer was mostly saturated with moisture.

The rooting substrate became drier as the distance from the water surface increased. Volumetric water contents decreased from 75% to 42% with increasing the distance from the water surface from 0.05 to 0.25 m (Fig. 3).

The upper and middle portions of the root system developed to tuberous roots in the aerial space between the rockwool slab and the nutrient solution layer, and fibrous roots mainly developed in the nutrient solution layer at the bottom of the culture container.

Fig. 4 shows dry weights of total biomass, top biomass (leaves, petioles and stems), tuberous roots and fibrous roots of sweetpotato plants planted at different distances from the water surface. Dry weights of total, top and fibrous roots were greater at the location nearer to the water surface. Tuberous roots, on the other hand, did not develop at the location nearest to the water surface. Tuberous roots showed almost the same dry weight at 0.15 and 0.25 m above the water surface.

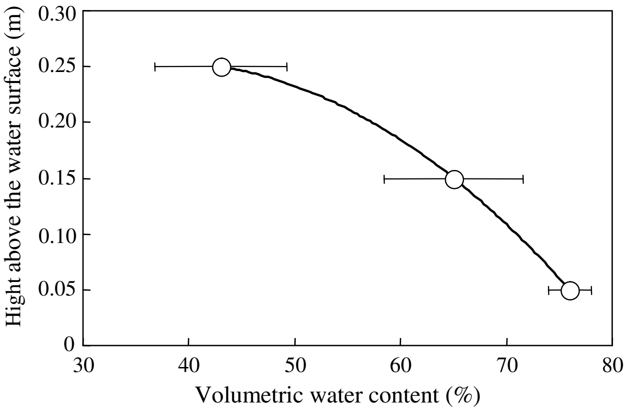

Fig. 3. The profile of volumetric water contents in the rooting substrate.

Growth of sweetpotato was affected by the water content in the rooting substrate (Fig. 5). Dry weights of total, top and fibrous roots were greater at higher water contents in the rooting substrate. The dry weight of tuberous roots was mostly constant at 40–65% of volumetric water contents in the rooting substrate and decreased significantly at around 75% of the volumetric water content. The tuberous root biomass ratio was affected significantly by the water content in the rooting substrate (Fig. 6). The ratio was higher at lower water contents in the rooting substrate.

In the second experiment, stem cuttings were planted on the inclined rockwool slabs at 0.2 m above the water surface. The planting location lied in the region between 0.15 and 0.25 m above the water surface, which was the location suitable for tuberous root growth in the first experiment. Fig. 7 shows tuberous roots of sweetpotato

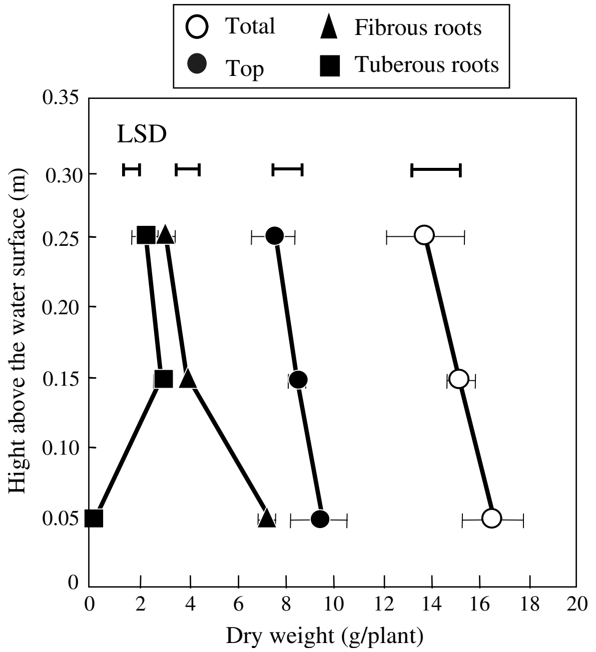

Fig. 4. Effects of the planting location on the rooting substrate on dry mass partitioning in sweetpotato ('Elegant summer') plants cultured for 32 days in a hydroponic system. Mean ± standard deviation and least significant difference (LSD, $p < 0.05$) in each part are also shown.

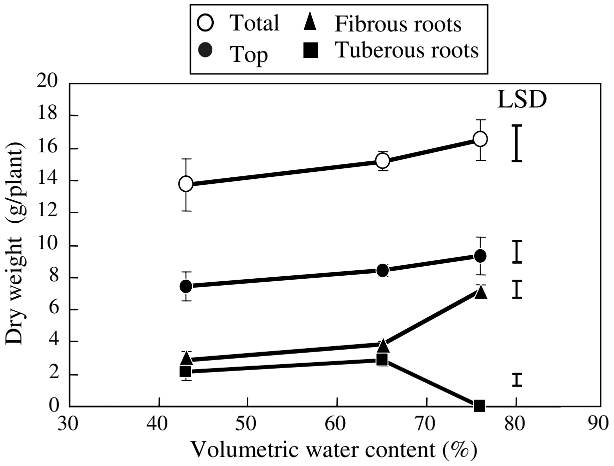

Fig. 5. Effects of volumetric water contents in the rooting substrate on dry mass partitioning in sweetpotato ('Elegant summer') plants cultured for 32 days in a hydroponic system. Mean ± standard deviation and least significant difference (LSD, $p < 0.05$) in each part are also shown.

cultured for 150 days in the hydroponic system in the second experiment. The final harvest produced large yields of normal shaped, tuberous roots. Total yields (sum of top and tuberous root dry weights) of three cultivars were almost the same (Fig. 8). 'Kokei-14' produced greatest tuberous roots biomass while the top biomass of 'Kokei-14' was least of all the cultivars. The tuberous root biomass ratios were 0.27, 0.45 and 0.60 for 'Beniazuma', 'Elegant summer' and 'Kokei-14', respectively. 'Elegant summer' showed middle yield for tuberous roots, leaves, petioles and stems among three cultivars.

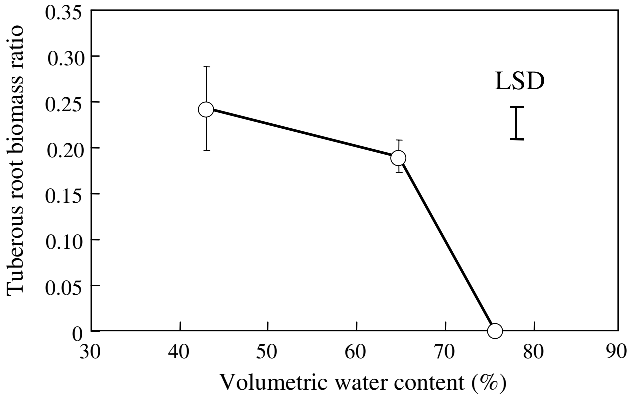

Fig. 6. Effects of volumetric water contents in the rooting substrate on tuberous root biomass ratio of sweetpotato ('Elegant summer') plants grown in a hydroponic system. Mean ± standard deviation and least significant difference (LSD, $p < 0.05$) are also shown.

Leaves, petioles and stems of 'Elegant summer' are edible and palatable as well as tuberous roots and can be utilized as a fresh leafy vegetable (Komaki, 1997). Sweetpotato leaves contain relatively high values of nutritional compounds and also polyphenolic compounds (Yoshimoto et al., 2005; Ishiguro and Yoshimoto, 2005), which have potential antioxidant properties. Therefore 'Elegant summer' can be utilized as fresh vegetable food for nutritional source as well as crop food for an energy source for crews, and would be a promising plant producing large amounts of food with small amount of inedible biomass in long-duration space missions.

Inadequate oxygen concentration results in a retardation of tuberous root formation in sweetpotato and this partly accounts for the poor performance of sweetpotato on waterlogged soils (Watanabe et al., 1968). Increasing the CO_2 concentration to about 1–2% in soil also retarded tuberous root formation in sweetpotato (Kitaya et al., 1992). CO_2 concentration in soil increased with increasing the soil water content (Yabuki and Kitaya, 1984). The tuberous roots showed better growth and development with lower water content in the rooting substrate in this study. On the other hand, the stems, leaves and roots except tuberous roots showed poorer growth with lower water content in the rooting substrate. In the previous study (Islam et al., 1997) in which plastic porous tubes were placed into the soil ridges for soil aeration, the tuberous root biomass ratio increased to four times that without porous tubes. These results show that soil aeration can considerably affect the tuberous root formation of sweetpotato.

In conclusion, sweetpotato production can be performed successfully in the hydroponic system, if sufficient air space is provided. The culture method developed in the present study can be applied to other root zoon crops such as carrot, radish, etc. as well as sweetpotato in space farming. The yield from this method can be expected to increase by elevating atmospheric CO_2 concentration and by implementing more precise control of the light intensity,

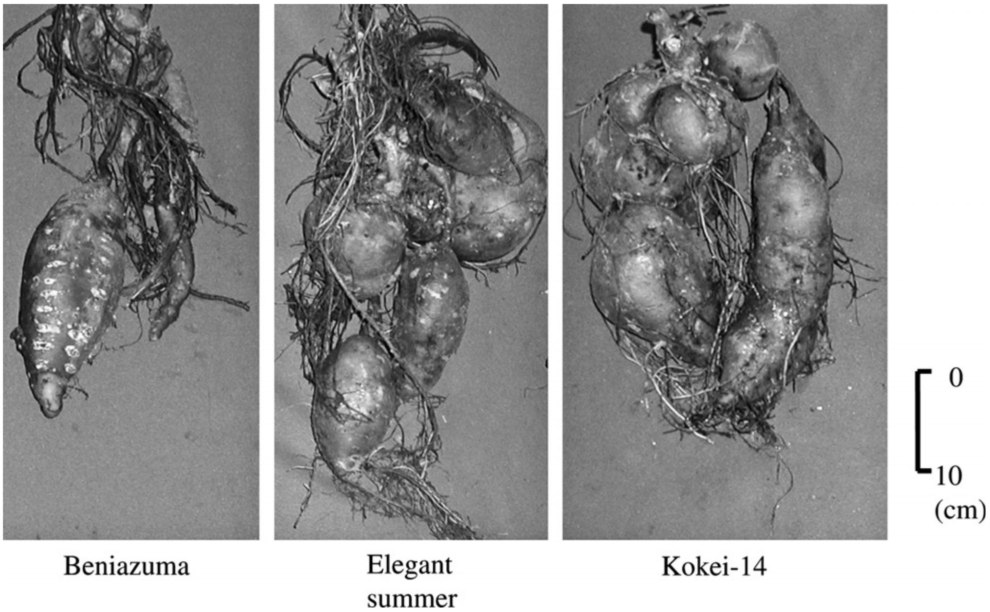

Fig. 7. Tuberous roots of three sweetpotato cultivars, ‘Beniazuma’, ‘Elegant summer’ and ‘Kokei-14’, cultured for 150 days in a hydroponic system.

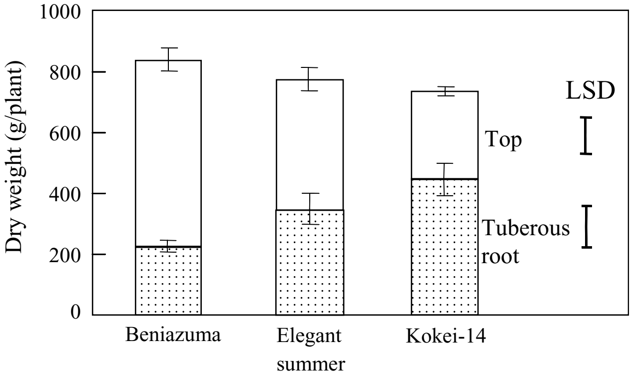

Fig. 8. Top and tuberous root dry weights of three sweetpotato cultivars, ‘Beniazuma’, ‘Elegant summer’ and ‘Kokei-14’, cultured for 150 days in a hydroponic system. Mean ± standard deviation and least significant differences (LSD, $p < 0.05$) are also shown.

photoperiod and temperature conditions. Although the rockwool substrate was used for several times, reuse of the rockwool material is restricted because of its fragile property. In order to reuse the substrate for numerous cycles, we need to develop stable materials for rooting substrates that can keep water and air optimum in the same manner as the rockwool substrate.

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