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宇宙 CELSS での人の長期生存を可能とする物質循環型植物生産

Material-circulating plant production enabling long-term human survival in space CELSS

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1. Introduction

Life support of crew in long-duration space missions will be highly dependent on the supply of food, O2, and clean water regenerated by plants in the Closed Ecological Life Support System (CELSS). The space farming system with circulating materials and obtaining a high yield with a rapid turnover rate will be important in the CELSS.

2. Necessity of plant production systems

For example, in a manned space flight to Mars, it takes about 17 months only to make a round-trip to Mars. According to NASA's estimate, the food required for ingestion of one day's energy (2,800 kcal) when one adult male performs normal activities is 0.62 kg in dry weight, 3.08 kg of water, and 0.84 kg of O_2 necessary for respiration, and 0.11 kg of solid materials, 3.42 kg of water and 1.0 kg of CO_2 to be discharged. The total amount of substances that one person takes into the body per day is about 4.5 kg and the total amount of substances to be discharged is the same. The amount of substances for maintaining life, such as food, water, and oxygen for life support, including the period of staying on Mars for waiting for the chance for returning to the Earth, becomes enormous, and it is physically impossible to bring it from the Earth. Therefore, when humans stay long on the moon and Mars, it is necessary to create a survival environment resembling the Earth. Also, in the long-term manned space exploration planned before the migration, a life support system is indispensable in the aircraft when human goes out into space.

CO_2 emitted by the respiration of animals including humans is absorbed and fixed by the photosynthesis of plants, and O_2 is generated at the same time and used for the respiration of animals. Also, since the excrement of animals and non-edible parts of plants are oxidized and converted into water and CO_2 and other minerals, the supply of O_2 necessary for its oxidation and simultaneously generated CO_2 is also absorbed by photosynthesis. Furthermore, absorption and removal of trace gases harmful to humans and unpleasant odors can also depend on plants. Evaporated and transpired water from cultivated plants is condensed and used for drinking water. Furthermore, physical and mental stress suffered by astronauts will be mitigated by ingesting fresh vegetables and contacting living plants. Therefore, in CELSS, it is important to construct a multifunctional plant culture system having gas treatment, water treatment, amenity function, etc. in addition to the food production function.

Therefore plant growth and reproduction in space have recently been of greater concern as the possibility of realizing manned space flight over a long term increases. Life support of crew in long-term space missions is dependent on the amount of food and atmospheric O_2 produced by plants grown at a high density. The feasibility of achieving long-term manned space missions is entirely dependent on crops in controlled ecological life support systems (CELSS) or space farming that will play important roles in food production, CO_2/O_2 conversion, and water purification. In space farming, scheduling of crop production, obtaining high yields with a rapid turnover rate, and converting atmospheric CO_2 to O_2 efficiently can be established with precise control of environmental variables around plants.

3. Problems of environmental control under micro- or low-gravity conditions in space

Gas exchanges between leaves and the atmosphere will be restricted under micro- or low-gravity conditions. On Earth, free convection can easily occur with uneven temperature distribution. Air movements are induced by convection even in a closed chamber with no forced ventilation system. However, very little free convection would occur under a microgravity condition in space. The limited free convection would reduce plant growth by limiting heat and gas exchanges on plants.

Possible disorders of plant vegetative and reproductive growth are, therefore, expected in space. The temperatures of reproductive organs, such as anthers and stigmas, could rapidly increase to significantly high levels due to limited convection under micro- or low-gravity conditions. This temperature rise could cause reproductive disorders such as sterile seed production in space.

4. Advantages of sweetpotato culture in material-circulating plant production in Space

Sweetpotato has been one of the candidate crops in space farming, which can produce food without vegetative growth. Sweetpotato also has a high yield of edible biomass because it can be utilized for the leafy vegetable as well as the root crop.

Tuberous roots of sweetpotato contain relatively high chemical energy, and higher contents of various vitamins, minerals, and protein than other crops. Stems and leaves of sweetpotato are recently beginning to be known as a healthy foodstuff with high contents of various nutrition components and antioxidant elements such as beta-carotene, ascorbic acid, and tocopherol that protect against heart disease and cancer.

I propose a plant culture facility for supplying nutritional food, O_2, and clean water for a person as shown in Fig. 1. One person can survive in a total plant culture area of 54 m^2 when culturing nutritious sweetpotatoe plants that can eat not only potatoes but also leaves and stems. The facility also improves human mental health by relaxing mental stress.

5. Conclusion

Restricted free air convection under micro- or low-gravity conditions in space would limit plant growth by retarding heat and gas exchanges between plants and the ambient air. Proper air movement is, therefore, essential to promote plant growth in space. Considerable effort must be directed toward the development of an adequate environmental control system to establish plant production systems for enabling material circulation and thus long-term human survival in space.

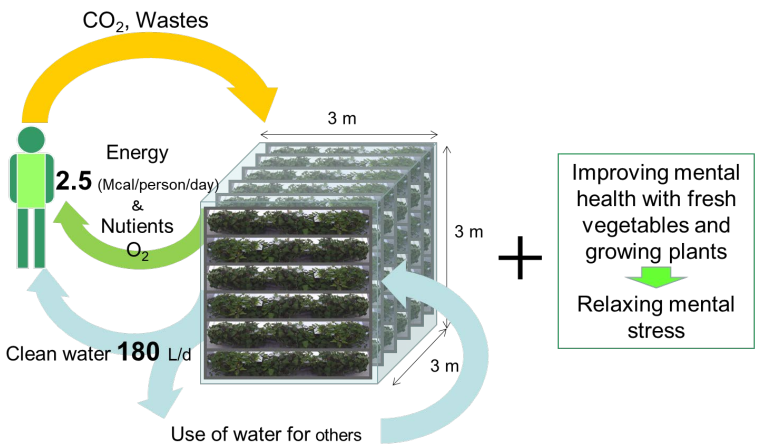

Figure. 1. Mulch-beneficial functions of the space plant culture system