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サツマイモ塊根の初期肥大と土圧の関係

Relationship Between Soil Pressure and Initial Enlargement of Sweet Potato Root Tuber.

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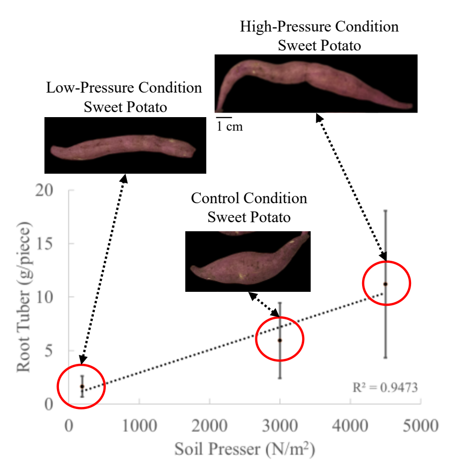
Abstract: Space agriculture has attracted attention as a solution to logistical and psychological challenges of long-term missions, such as those planned under the Artemis program. We investigated the effect of soil pressure on the early-stage enlargement of sweet potato root tubers, a promising crop for space agriculture. Growing experiments were conducted under three soil pressure treatments—low, high, and control—in planters filled with different media. Sweet potatoes were grown in a controlled environment, and growth parameters, including fresh weights of shoots, roots, and root tubers, were measured after 40 days of transplant. Root lengths were analyzed using WinRHIZO software. The results showed a negative correlation between soil pressure and the fresh weight of shoots and roots, whereas root tubers indicated a positive correlation. Total root lengths decreased under the high pressure, while the mass of fine-diameter roots remained relatively unchanged. These findings suggest that moderate soil pressure may be beneficial for storage root development, although it may suppress the growth of other organs. Our study highlights the importance of maintaining suitable soil pressure in microgravity environments for promoting successful root crop growth.



Keywords: space agriculture, microgravity, moon base, Mars base, human-crewed space mission

1. Background

In the context of long-duration space missions like NASA's Artemis program, maintaining life support - including food, oxygen, and water - while managing transport costs, waste processing, and crew mental health is a major challenge[1)2)]. Space agriculture could address these issues by producing food and oxygen, recycling waste, and offering psychological benefits. Sweet potato (*Ipomoea batatas*) is a promising crop due to its high nutritional value, ease of virus-free propagation, and adaptability for genetic modification[3)]. However, soil-based cultivation in microgravity faces problems because reduced gravity lowers soil pressure, potentially disrupting root architecture and tuber development. Previous studies in other crops show that mechanical impedance from soil can promote root thickening, but its specific effect on sweet potato storage root enlargement is unclear[4)5)6)]. This study investigates how different soil pressures affect early-stage tuber growth, aiming to inform cultivation system design for extraterrestrial environments.

2. Materials and Methods

To investigate the effects of soil pressure on sweet potato storage root development, sweet potatoes were grown under three soil pressure conditions: low, high, and control.

2.1.1 Soil Pressure Theory

Horizontal soil pressure soil pressure σ_h at depth h can be calculated using the following equation[7]:

$$\sigma_h = K_0 \rho g h \tag{1}$$

Where ρ denotes the dry density, g the gravitational acceleration, and K_0 the coefficient of soil pressure at rest.

2.1.2 Low-Pressure Condition (Fig. 1(a))

To simulate microgravity-like low soil pressure, a medium with reduced dry density was used. Microbeads (MB) with a dry density of 0.024 g/cm³ served as the growth medium, filled to 34 cm depth. A 5 cm layer of granular rockwool (RW) was added at the bottom for water retention and root support. The surface was covered with black mulch (BM) to reduce evaporation. A pressure sensor (PS) was installed 15 cm from the base on the inner wall.

2.1.3 High-Pressure Condition (Fig. 1(b))

The same MB and RW setup as the low-pressure condition was used. Additional pressure was applied by placing an acrylic board (AB) on the MB and adding weights. A pressure sensor was placed in the same location as in the low-pressure setup.

2.1.4 Control (Medium-Pressure Condition, Fig. 1(c))

Commercial potting soil (dry density: 0.50 g/cm³) was used as the medium. The planter was filled to the same depth with 5 cm of RW at the bottom. The surface was also covered with BM, and a PS was placed 15 cm from the base.

2.2 Cultivation Procedure

The cultivar used was Kokei No. 14. On May 16, 2023, seedlings were pre-grown in Wagner pots filled with commercial soil to induce root growth. After 40 days of rooting in a greenhouse at Meiji University Ikuta Campus, seedlings with root lengths of 30–40 cm were transplanted on June 23 into planters (3 plants per planter), with roots embedded in the RW layer.

Planters were kept in a natural-light-type gas exposure chamber (27°C). Liquid fertilizer was prepared by mixing Tank Mix A and B, resulting in 140 ppm N, 70 ppm P, 200 ppm K, and 40 ppm Mg. Peristaltic pumps delivered 15 mm/day of irrigation for low and high-pressure treatments, and 3.4 mm/day for the control.

2.3 Measurements

All plants were harvested. Fresh weights of shoots, root tubers, and roots were measured. Root length and diameter distribution were analyzed using WinRHIZO. Roots with a diameter of 5 mm or more were classified as storage roots.

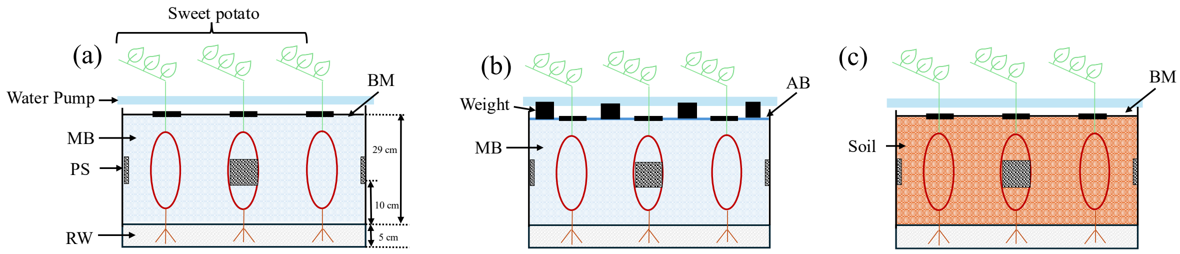


Fig 1. Cultivation system

(a) Low-Pressure Condition, (b) High-Pressure Condition, (c) Soil Condition

3. Results and Discussion

High soil pressure reduced shoot and fibrous root biomass but promoted storage root enlargement. Compared with low pressure, high pressure reduced shoot fresh weight by 41%, total root biomass by 66%, and total root length by 74%. However, storage root fresh weight under high pressure was 6.8 times greater than under low pressure (Fig 2.).

Root diameter (RD) distribution showed that most roots across all treatments fell within the 0.3–0.4 mm range, with roots ≤0.5 mm in diameter accounting for more than 50% of the total root length. Statistical analysis revealed a significant difference only in the 0.8–0.9 mm diameter range between high- and low-pressure conditions, while other diameter classes showed no notable differences. This suggests that the observed reduction in root fresh weight and length was due to a general decrease in total root biomass rather than selective suppression of specific root sizes (Fig 3.).

4. Discussion

This study showed that soil pressure affects different sweet potato organs in distinct ways—negatively impacting shoot and fibrous root biomass while positively promoting storage root growth. These results align with earlier studies on upland rice and barley, which found that soil compaction reduces shoot biomass and that mechanical resistance increases root cross-sectional area via mechanosensory responses[5)6)8)].

In contrast to Chowdhury et al. (2002), who found that excessive soil compaction and poor oxygen supply reduced sweet potato tuber size, this study used porous microbeads that ensured adequate aeration, ruling out oxygen deficiency as a limiting factor[9)].

Overall, the findings emphasize that both proper irrigation and moderate soil pressure are essential for storage root development. In the context of space agriculture, applying controlled soil pressure through engineered systems could enable effective root crop cultivation, even under reduced gravity.

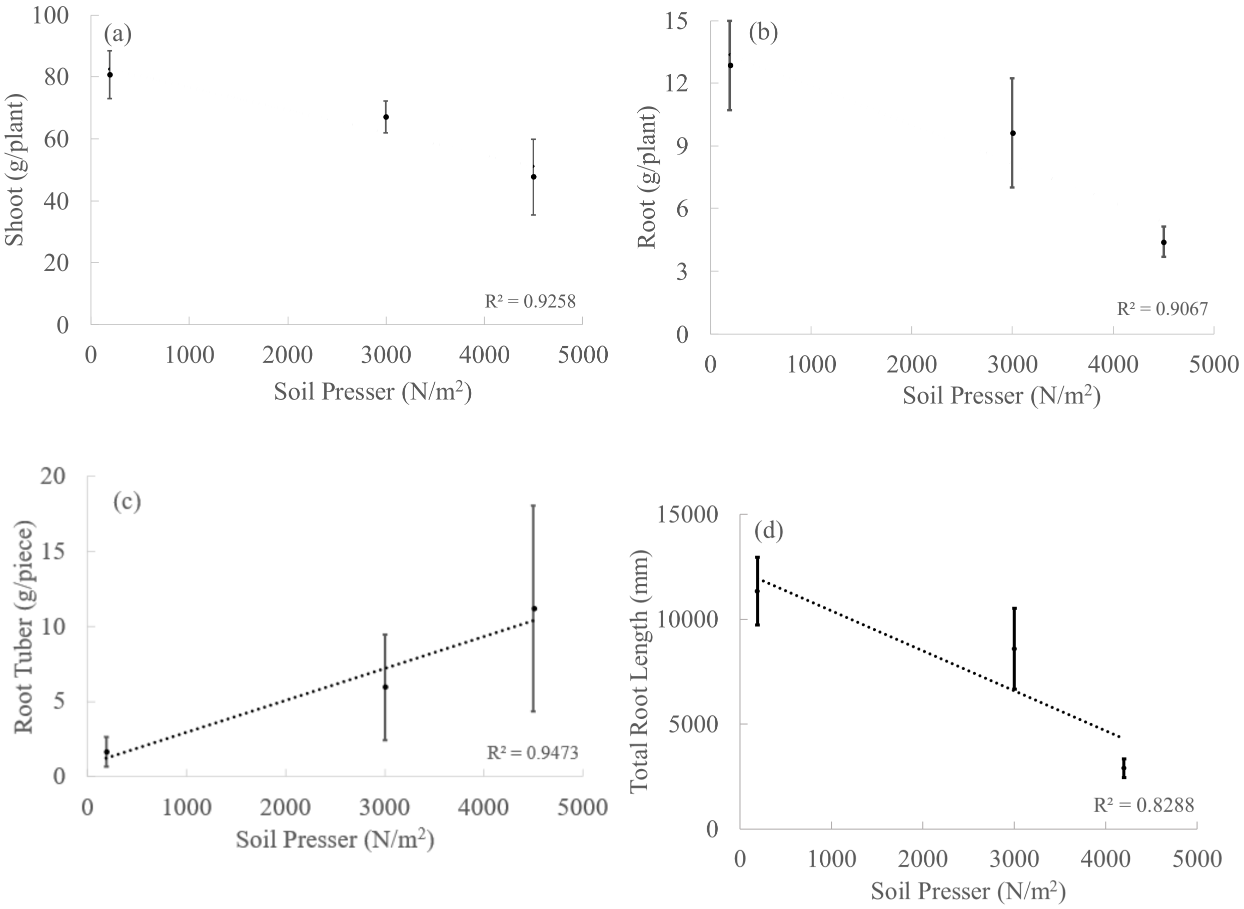


Fig 2. Relationship Between Soil Pressure and Fresh Weight or Length

(a) Shoot, (b) Root, (c) Root Tuber, (d)Total Root Length

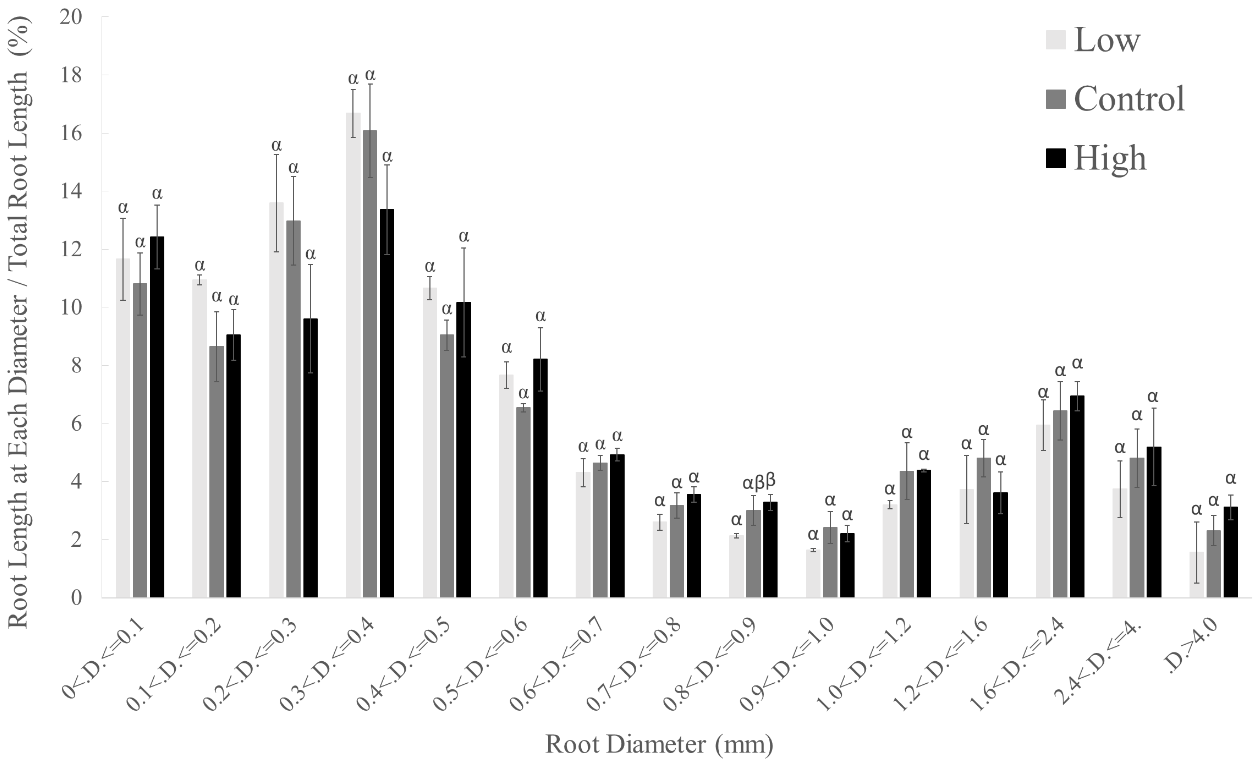


Fig 3. Root Length Distribution by Diameter

References

1) NASA: The Artemis Plan – NASA's Lunar Exploration Program Overview, NASA, Washington, D.C. (2020). Available at: https://www.nasa.gov/sites/default/files/atoms/files/artemis_plan-20200921.pdf (accessed on June 30, 2025).

2) G.D. Massa, R.M. Wheeler, R.C. Morrow and H.G. Levine: Growth chambers on the International Space Station for large plants., 1134 (29) (2016) 215.
DOI: https://doi.org/10.17660/ActaHortic.2016.1134.29

3) Lunar Farming Concept Study Working Group: Report of the Lunar Farming Concept Study Working Group, JAXA Special Publication (2019) 1-101.

4) S. Terabayashi, T. Yomo and T. Namiki: Root Development of Root Crops Grown in Deep Flow and Ebb & Flood Culture. Environ. Control in Biol., 35 (1997) 99–105.
DOI: **https://doi.org/10.2525/ecb1963.35.99**

5) M. Iijima and Y. Kono: Interspecific Differences of the Root System Structures of Four Cereal Species as Affected by Mechanical Impedance. Jpn. J. Crop Sci., 60 (1991) 592–603.
DOI: https://doi.org/10.1626/jcs.60.130

6) R.S. Russell and M. J. Goss: Physical aspects of soil fertility - the response of roots to mechanical impedance. Neth. J. Agric. Sci., 22 (1974) 305–318.
DOI: https://doi.org/10.18174/njas.v22i4.17215

7) K Ishihara: Soil Mechanics (土質力学), Maruzen, Tokyo (2018) pp. 219–242.

8) M.J. Goss: Effects of Mechanical Impedance on Root Growth in Barley (*Hordeum vulgare* L.): I. Effects on the Elongation and Branching of Seminal Root Axes. *J. Exp. Bot.*, 28 (1977) 96–111.
DOI: https://doi.org/10.1093/jxb/28.1.96

9) S. R. Chowdhury, R. Singh, D. K. Kundu, E. Antony, A. K. Thakur, and H. N. Verma: Growth, Dry-Matter Partitioning and Yield of Sweet Potato (*Ipomoea batatas L.*) as Influenced by Soil Mechanical Impedance and Mineral Nutrition under Different Irrigation Regimes. Adv. Hortic. Sci., 16 (2002) 25–29.