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Not light or gravity but water guiding root to grow

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ABSTRACT

The plant root elongation and growth-oriented mechanism is the research focus. The main viewpoints are three, which are the growth of backlight, to gravity and to water and fertilizer. This paper believes that the viewpoint of the root growth to water and fertilizer is more reasonable. The random structured soil model, and the soil water evaporation model in weightlessness and gravity environment are established. The numerical simulation is performed. The phenomena, that root faster grows on the earth's gravity than in weightless environment, the root near the surface soils is more disorderly in weightless environment, the main root is more taproot growing faster in both environments than the lateral roots, and the roots have some bifurcation and tilt, are explained. The water evaporation near the surface causes the water gradient, and the water gradient drives root elongation and growth, which shows the illusion of the root elongating to gravity. This study can be referred in the subsequent root growth-oriented, random structured soil, soil cracking, and soil water seepage/evaporation.

1. Hypothesis of root to water and fertilizer

About the elongation of plant roots in the soil, there are three viewpoints: one is that roots elongate opposite to the plant stem, which extends in the direction of the light source, while the roots grow opposite to the light. The second one is that the expansion of plant roots on the direction toward the earth gravity [1], namely growing toward downward. Some molecular biology experts support this viewpoints, and believe the gravity-sensing columella cells in roots can orient the root elongation [2,3]. These cells contain amyloplasts that function as statoliths and move in response to the direction of the gravity (toward bottom). The third one is that the plant roots extend in the direction of the water and fertilizer in the soil, namely the roots grow to direction where there are more water and fertilizer, as shown in Fig. 1.

The above three viewpoints and hypothesis seem to be reasonable, and the plant roots seem to extend to the three hypotheses growth direction.

In Fig. 1, (A) Garlic vertically placed, (B) Garlic horizontally placed, (C) Garlic inverted, (D) Garlic vertically placed, (E) Garlic vertically placed. The center of garlic in A, B, C is regularly dropped water on. One side of garlic in D is regularly dropped water on. One side of garlic in E is regularly dropped water on, and at the same time the other side of garlic is regularly dropped fertilizer on. Phenomenon: after some time of the rooting, the root system of the garlic A extends to the bottom; the roots of the garlic B twistedly extend to the bottom; the roots of the garlic C stretch back to the bottom; the roots of the garlic D expand to the water drip side; the roots of the garlic E expand to the fertilizer drip side. Description: the growth of Garlic A, B, C root may explain roots elongate to the earth center direction, and to the backlight; Garlic D illustrate roots extend to the water direction; Garlic E describes roots grow more likely to the fertilizer direction than to the water direction.

Experiment shown in Fig. 1 cannot deny the three hypothesis about the root growth: away from the light, to gravity, in the direction of more water and fertilizer. Therefore, many scientists do many significant root growth experiments [4,5]. But it is difficult to conduct the experiments the independent factor affecting on the earth. A lot of scientists expand the related root extension study by the experiments in space [6], as shown in Fig. 2.

These Phenomena can be found: (1) the roots grows to the bottom of soil; (2) On the earth, root growth speed is more than in space; (3) roots near surface in weightless environment are more disorderly; (4) The taproot grow fast and is thick, while the lateral root slow grows and is small; (5) the root has some bifurcation and tilt.

Many researchers have tried to explain such phenomena by the plant biological mechanism [4,7,8]. Brown and Chapman [9]

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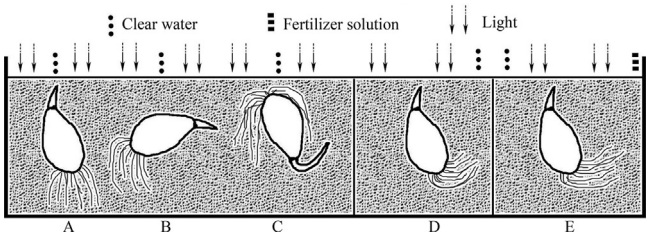

Fig. 1. Garlic rooting experiment.

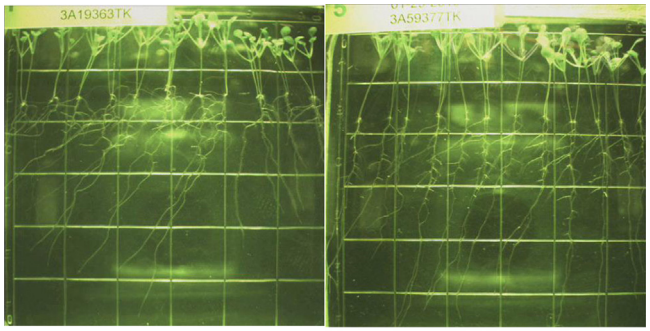

Fig. 2. Different extension of root on ground and space. (A) Flight experiment in space. (B) Root growth patterns from the ground control [6]. Part (A) shows the root growing in space. Part (B) shows the root growing on the earth.

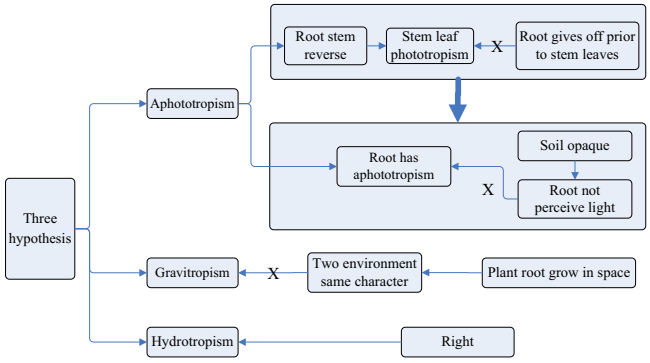

Fig. 3. Argumentation about three hypothesis.

found the circumnutation in weightless environment, so Brown and Chapman [9] drew the conclusion that the phenomenon of plant growth is not related to gravity. But they ignore the fact that the plants growing in space is also in fertilizer and water soil, and therefore the water seepage in both environmental soil need to be fully considered.

As shown in Fig. 3, the argument is expanded about the three hypothesis.

The first hypothesis (as shown in Fig. 3): the roots extending is depart from the plant stems and leaves growth. Is it right? From Fig. 1, garlic roots send forth prior to the stems and leaves. So the first hypothesis introduction is not appropriate. Root system shown in Fig. 2 was carried out in the agar, which is translucent. Is the conclusion drawn that the root growth of self-directed away from the light source? The root on the ground is grown in the soil, and the soil is opaque (as shown in Fig. 1). It is not appropriate, that roots grow away from the light, namely the light does not orient the root growth.

Therefore, we can say, the direction roots extending in is not directly related to the light, namely the first hypothesis is not appropriate. By the comparative experiments in the weightless and gravity environment (as shown in Fig. 2), the same phenomenon of the roots extending to the bottom of soils is found. Therefore root growth direction, we can say, is not connected with the gravity.

By comparing the three hypothesis, following conclusions are drawn: (1) Root growth is not directly connected with the gravity; (2) Roots extending to water and fertilizer may exist. The main aim of this paper is to explain based on the root growing to the water and fertilizer.

2. Seepage model of root absorbing water

The water seepage equation in the unsaturated soil is as follows [10–14]:

$$\frac{\partial\theta}{\partial t}+\frac{\partial v_x}{\partial x}+\frac{\partial v_y}{\partial y}+\frac{\partial v_z}{\partial z}=0 \tag{1}$$

In the formula, θ represents the volumetric water content, which is the volume of water contained in unit volume of soil (soil, pore and water); v_x, v_y, v_z are flow velocities in three directions, $v_i=-K(\theta)\partial\phi/\partial i$, i represents the x, y or z direction; $K(\theta)$ represents for permeability coefficient as a function of water content θ; ϕ is soil matric potential in the face of the earth when considering the acceleration of gravity, $\phi=z-h_c$; h_c is water pressure height (pore water pressure), z is the coordinate in z direction of the studied point. Because at this time, it is unsaturated soil, h_c *in* ϕ takes "−"; at the time without considering the acceleration of gravity, namely flying in space, $\phi=-h_c$. Furthermore, according to the $D(\theta)=-K(\theta)\partial h_c/\partial\theta$. In the two-dimensional space on earth, Y axial direction is for positive, $v_x=-D(\theta)\partial\theta/\partial x$, $v_y=-K(\theta)-D(\theta)\partial\theta/\partial y$; in space flight, $v_x=-D(\theta)\partial\theta/\partial x$, $v_y=-D(\theta)\partial\theta/\partial y$. $D(\theta)$ is the water diffusivity of unsaturated soil.

2.1. Soil water seepage equation in weightlessness and gravity environment

There is water and pores in soils, and water is transported in pores, at last the water movement gets the balance. In space, there is no other external force, so water can run by the diffusion. On the earth, there is the gravity, so water can be influenced by the gravity. When the gravity is considered on the earth [15],

$$v_x=-D(\theta)\frac{\mathrm{d}\theta}{\partial x} \tag{2}$$

$$v_y=-D(\theta)\frac{\mathrm{d}\theta}{\partial y} \tag{3}$$

$$v_z=-K(\theta)-D(\theta)\frac{\partial\theta}{\partial z} \tag{4}$$

where, $v_i=-K(\theta)\partial\phi_x/\partial i$, i is the x, y and z. ϕ_x, ϕ_y, ϕ_z are $z-h_c$. $D(\theta)=-K(\theta)\partial h_c/\partial\theta$.

Therefore, Eq. (1) is simplified to,

$$\frac{\partial\theta}{\partial t}=\frac{\partial}{\partial x}\left[D(\theta)\frac{\partial\theta}{\partial x}\right]+\frac{\partial}{\partial z}\left[D(\theta)\frac{\partial\theta}{\partial z}\right]\pm\frac{\partial k(\theta)}{\partial\theta}\frac{\partial\theta}{\partial z} \tag{5}$$

Eq (5) is the water seepage equation on the earth. If the Z-axis positive direction is upward, '+' is taken, otherwise '−' is taken.

Without the gravity in space, Eq. (4) is changed into,

$$v_z=-D(\theta)\frac{\partial\theta}{\partial z} \tag{6}$$

Eq. (2), (3), (6) into Eq. (1),

$$\frac{\partial\theta}{\partial t}=\frac{\partial}{\partial x}\left[D(\theta)\frac{\partial\theta}{\partial x}\right]+\frac{\partial}{\partial z}\left[D(\theta)\frac{\partial\theta}{\partial z}\right] \tag{7}$$