NMR Imaging for Measuring Root System
and Soil Water Content

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An attempt was made using a nuclear magnetic resonance (NMR) computed tomography (CT) system to measure spatial distributions of soil water and main roots of broad bean and Japanese radish plants growing in the soil without destroying the plants and the soil environment.

Computed tomography (CT) is a technique to reconstruct from a set of projection data a cross-sectional distribution of some physical property of a test object without destroying it. This technique has been widely utilized in medicine and industry since the first development of a commercial X-ray CT scanner by Hounsfield.[1] Recently, the X-ray CT scanner was applied to detect rots and annual rings in a living tree.[2]

Nuclear magnetic resonance (NMR) CT is the newest technique in the medical CT family.[3-5] It yields not only morphological information but also such physiological information as metabolic process and mass transfer. Especially, the distribution of proton, which is abundant in water, in any section is easily provided by the NMR CT.[4,5]

In order to study the growth of seedling and root system it is necessary to measure them without destroying the plant itself and the soil environment. Rhizotrons are the most elaborate installation devised for the direct, sustained observation and measurement of roots growing in soil.[6] However, rhizotrons permit observation only through transparent walls or windows abutting on the soil. Gordon *et al.*[7] recently observed a sunflower seedling growing in a rectangular cuvette containing 1% agar using a TV camera system. However, this system cannot directly observe seedling and root growing in soil.

The growth of seedling and root system is greatly influenced by the soil environment.[8] The soil moisture is a major factor affecting the growth. The common methods for measuring soil water content are neutron probes and capacitance meters. Electrical resistance blocks and tensiometers can also be used to estimate soil water content as well as matric potential.[8] However, these devices affect the growth of root system and cannot measure spatial distribution of water in soil abutting on the spreading roots.

We, therefore, examined NMR imaging for measuring water content of soil and root systems growing in a pot. Broad bean (*Vicia fava* L. cv. Otafuku) and Japanese radish (*Raphanus sativus* L. cv. Minowase) plants were used. Broad
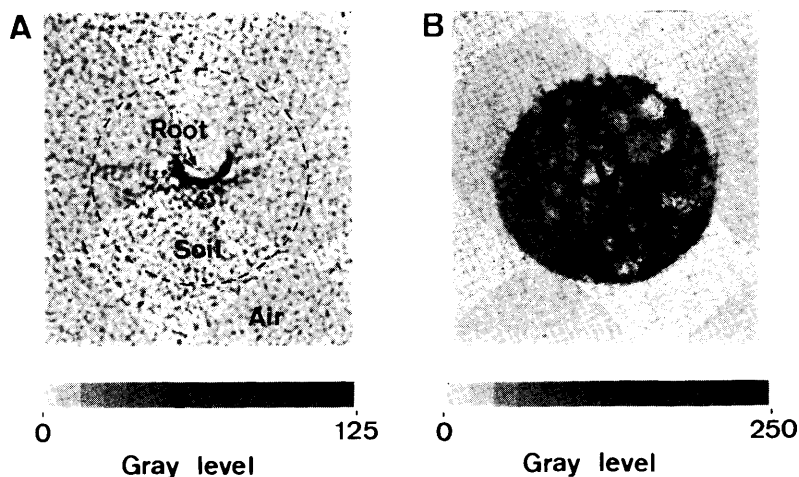
Fig. 1 NMR images of dry and wet soils with broad bean roots in horizontal sections of pots. A, air-dried soil; B, wet soil. The gray level indicating with numerals under the gray scale means the intensity of NMR signal.

bean was grown in a pot (10 cm in diameter and 20 cm in height) in a controlled-environment greenhouse at 20/15°C day/night temperature and 70% RH (Relative humidity) under natural lighting for 2 to 3 weeks. Radish was grown at 25/20°C day/night temperature and 70% RH for 4 to 5 weeks. The pot was filled with a 1 : 1 (v/v) mixture of perlite and peat moss. The saturation recovery (SR) image in any section of the pot was measured by an NMR CT system (Toshiba, Model MRT–15A). This system had magnet coils of 0.15 T in the intensity of the basic magnetic field and of 400 Hz/cm (center frequency; 6.39 MHz) in the spatial gradient of the magnetic field. The reconstructed matrix of this CT system was 512 (H)×512 (V) and the spatial resolution was within 2 mm. The repetition time for obtaining the SR image was 525 ms. Air temperature and humidity in a space (60 cm in diameter and 120 cm in length) setting the pot in the NMR scanner were maintained at 25°C and 60% RH.

Figure 1 shows NMR images of dry and wet soils with broad bean roots in horizontal sections of pots. The gray level indicated by the numerals under the gray scale shows the intensity of NMR signal. NMR signal from air-dried soil (ca. pF 5.5) in A was very weak except that from the root in the center, and the background noise was observed as black-and-white spots. Therefore, we could not separate the soil from the surrounding air. The wet soil (ca. pF 2) in B showed high gray level although the level differed from region to region in the pot. Since the bulk of protons in soil is water, the gray level represents its water content.

Figure 2 shows an NMR image of a broad bean and its main root in a vertical section of a pot with wet soil. Since the gray level of the bean and root was higher than that of soil, we could easily discriminate the bean and its main root from the soil. However, roots finer than 2 mm could not be seen by this CT system. The ununiformity in the soil water content was probably influenced by the water uptake of roots as well as by the spatial distribution of soil struc-
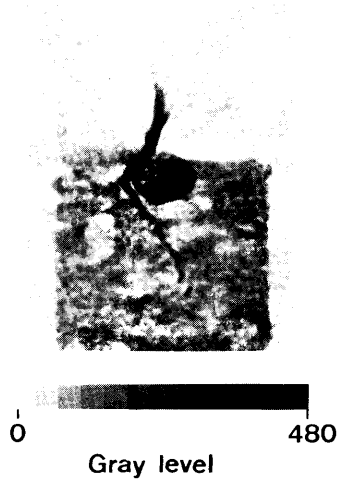
0   480
Gray level

0   1360
Gray level

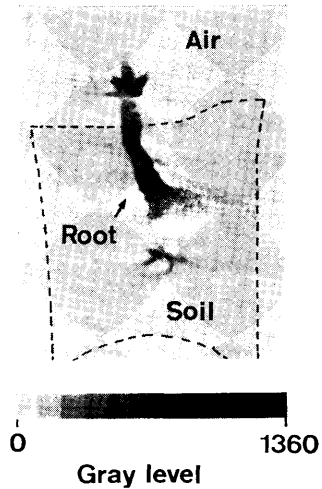**Fig. 2** NMR image of a broad bean and its main root in a vertical section of a pot with wet soil.

Fig. 3 NMR image of a main root of Japanese radish with the injury in a vertical section of a pot with wet soil.

ture. Figure 3 shows an NMR image of a main root of Japanese radish in a pot with wet soil. When the gray scale extended to wide level, we could detect the ununiformity in the root in addition to that in the soil. This ununiformity may be caused by the unknown injury.

The results suggest that the NMR imaging is an effective method for measuring spatial distributions of water in soil and roots growing in the soil. By analyzing the image the information about the growth in seedling and root and the water uptake of root may be provided without destroying the plant itself and the soil environment. Since NMR signal, especially transverse relaxation time (T_2), relates to water potential as well as water content in plants,[9,10] the CT system also may used to measure spatial distributions of water potential. Although the CT system used in the experiment could not detect roots finer than 2 mm, this problem will be improved by increasing the gradient of magnetic field and the sampling density. NMR CT is more suitable for making three-dimensional image in comparison with X-ray CT.

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⟨和文抄録⟩

根系と土壌水分の測定のための NMR イメージング

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NMR-CT を用いて,ポット栽培の植物(ソラ豆,大根)の根系と土壌水分の非破壊計測を試みた.最初に,SR 法で得た NMR 信号の強度と土壌水分との関係を調べたところ,風乾土壌では信号強度が非常に小さく,ノイズレベルにあったが,土壌が湿ると大きくなった.しかし,その空間分布は,不均一であった.次に十分に湿った土壌中での根系の分布を計測したが,根からの信号強度は土壌に比べて十分大きく,実験に用いた CT の解像度の範囲内ではあるが,土壌と根を容易に分離することができた.また,根系の障害部位は,信号強度が小さく,CT を根の障害診断に用いることができることがわかった.