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Field Crops Research 96 (2006) 477–480

Field Crops Research
www.elsevier.com/locate/fcr

Short communication

# Hydrogen isotope composition of soil water above and below the hardpan in a rainfed lowland rice field

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Received 2 February 2005; accepted 13 September 2005

## Abstract

In rainfed lowland rice fields, developing hardpan soil layers must be important to pool rainfall, but during drought that also restricts water movement from below it. We investigated whether the hardpan can maintain a contrast of deuterium/hydrogen isotopic composition ($\delta$D) in soil water under field condition. The experimental site was at Rajshahi in north-west Bangladesh. The hardpan soil layers had developed around 0.2 m soil-depth in the field. Soil water from either above or below the hardpan was collected non-destructively with porous cups installed into the field. Using an isotopic ratio mass spectrometer, $\delta$D value of each water sample was determined. During the sampling period, the field surface varied from water-saturated to unsaturated status with rainfall event. While the $\delta$D values fluctuated by the influence of rainfall, significant differences in the $\delta$D values were always detected between above and below the hardpan, revealing heterogeneity in the $\delta$D values persisted with the hardpan. The effect of hardpan on retention of the $\delta$D signature was further confirmed in a laboratory experiment using intact soil columns collected from a paddy field at Nagoya University. The natural $\delta$D signature in rainfed lowland rice field may be useful to identify certain genotypes that demonstrate in situ capability of water acquisition from below the hardpan through $\delta$D analysis of the xylem sap.

*Keywords:* Deep root system; Drought avoidance; Isotope discrimination; Natural abundance; Soil heterogeneity; Water uptake

## 1. Introduction

Analysis of stable hydrogen isotope composition ($\delta$D) of xylem water is a powerful tool to determine the water sources utilized by plants in the field, since $\delta$D values of xylem water reflect those of the water sources utilized, except in halophytes (Ehleringer and Dawson, 1992; Dawson, 1993; Sekiya and Yano, 2002a). Previously, the $\delta$D method was mainly applied in natural ecosystems. But recently, Sekiya and Yano (2002b) have applied the method in an agricultural ecosystem, detecting an interspecific difference in groundwater dependency between *Cajanus cajan* and *Sesbania sesban.* Both species developed deep roots to more than 2 m in soil depth, but *C. cajan* showed less dependency on groundwater from the permanent water table. Interestingly, *C. cajan* was found to cause ‘hydraulic lift’, that is water movement between soil layers via the plant root system, thereby supplying the groundwater to adjacent maize plants (Sekiya and Yano, 2004).

Rainfed lowland rice is grown in bunded fields, accounting for about 25% of the rice production area worldwide, with an average grain yield of only 2.3 t ha$^{-1}$ (IRRI, 1997). Of the constraints to grain yield in rainfed lowland rice, drought is considered the major problem (Sharma and De Datta, 1994). In land preparation, the process of soil puddling produces a smeared layer at the depth of cultivation, with higher penetration resistance

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doi:10.1016/j.fcr.2005.09.011

(Samson et al., 2002). When rains fail, however, the hardpan hinders both root penetration to depth and the movement of water between soil layers. Because root systems of rainfed lowland rice tend to be shallow and mainly distributed above the hardpan (Wade et al., 1999), the crop may encounter remarkable fluctuations in soil water from flood to drought during a single growing season. During drought, it should be beneficial for roots to penetrate the hardpan and extract water from deeper soil layers.

Several attempts have been made to identify genotypes displaying deeper root systems that penetrate the hardpan (Clark et al., 2002; Samson et al., 2002). We consider that measuring δD values of xylem water may assist the identification of genotypes with an enhanced ability to extract soil water from below the hardpan. For this approach to be successful, however, it is essential that δD values of soil water from above and below the hardpan should differ considerably. Therefore, in the current report, we investigate how the hardpan can affect hydrogen isotope ratio of soil water in a rainfed lowland rice field, in order to know whether the δD signature can be applicable in this agricultural ecosystem. On the basis of the field investigation, an experiment was conducted in the growth chamber to confirm the effect of the hardpan on retention of the δD signature.

## 2. Materials and methods

### 2.1. Field experiment

The investigation was conducted at Rajshahi in north-west Bangladesh (latitude 24°21′N, longitude 88°18′E). The soil was a dark gray clay (40.8–44.2% clay) of the Ammura series, aeric haplaquepts, a montmorillonitic clay with poor internal drainage (UNDP/FAO/Pakistan, 1968). Between saturation and wilting point, the maximum capacity of plant available water in the top 30 cm of soil ranged from 50 mm at high to 73 mm at low topographic positions on this soil. More detail information was presented in Samson et al. (2004).

Soil water samplers (DIK-8390; Daiki Rika Kogyo Co., Ltd., Tokyo) were installed in the field at approximately 0.1 and 0.4 m soil depth, between puddling and transplanting of rice seedlings. Ten samplers at each depth were placed at a distance of 10 m from each other, at high, mid and low topographic positions. Samples were taken on September 21, 26 and October 3, 2001. In later sampling attempts, however, we could not collect sufficient soil water for measurement, as soil water content declined to tensions greater than those supported by the samplers.

The water sampled was reacted in a chromic water-reducing reactor (H/Device, Finnigan, Germany) at 800 °C. The hydrogen gas resulting from the combustion was analyzed for its isotopic composition in an isotope ratio mass spectrometer (Delta plus, Finnigan, Germany). δD values were expressed in delta notation relative to standard (SMOW) as,

$$\delta\mathrm{D}\,(‰) = \left[\frac{\mathrm{R}_{\mathrm{sample}}}{\mathrm{R}_{\mathrm{standard}}} - 1\right] \times 1000$$

where $\mathrm{R}_{\mathrm{sample}}$ and $\mathrm{R}_{\mathrm{standard}}$ refer to the hydrogen stable isotopic composition (D/H ratio) of sample and standard, respectively (Dawson, 1993).

### 2.2. Growth chamber experiment

Intact soil columns (50 mm in diameter, 300 mm in height) were taken from a paddy field at Nagoya University, where a hardpan developed between 0.1 and 0.2 m below the soil surface. Each of the intact columns was fixed into PVC tubes (50 mm in diameter, 500 mm in height), placed upright in a container (450 mm in length, 300 mm in width, 300 mm in height) filled to a depth of 150 mm with tap water (δD = 10.77‰). Distilled water (δD = −52.16‰) was subsequently supplied into the top of each of the columns until the level of water became 100 mm above the soil surface.

All the columns in the containers were placed into an environment-controlled chamber (60%RH, 25–25 °C, 12-h day:12-h night, 180 mmol $\mathrm{m}^2\,\mathrm{s}^{-1}$ day light). Water was sampled from the top and the bottom of each column using a syringe. Water samples were taken at 10, 15 and 20 days. The δD values of each sample were determined as described above.

## 3. Results and discussion

We confirmed the presence of a hardpan at around 0.2 m soil depth by measurement of soil penetration resistance at Rajshahi (Samson et al., 2002). δD values were plotted for each sampling date in Fig. 1. ANOVA detected significant effects of soil depth for δD values of soil water ($P < 0.001$), with lower values obtained from above the hardpan than below the hardpan, implying that water recently supplied into the field by rainfall had a lower δD value than the previous soil water. The contrasts in δD values by soil depth were retained throughout the sampling period, as the interaction between soil depth and sampling date was not significant ($P = 0.471$). This result showed that the development of a hardpan could consistently affect δD values, probably through impeded movement of soil water.

Further, ANOVA detected a significant variance of another main effect, the sampling date, on the δD values (Fig. 1). This was mainly caused by lower δD values on October 3, but with a wider variance, compared with those from September 21 and 26. Rainfall ceased on September 15 and free water disappeared from the soil surface on September 29. A further 78 mm of rain was received on October 1–3, and free water reappeared at the soil surface on October 3, when the third sample was taken. These observations suggest that the rainfall events of 1–3 October just before the sampling reduced the δD values of the soil