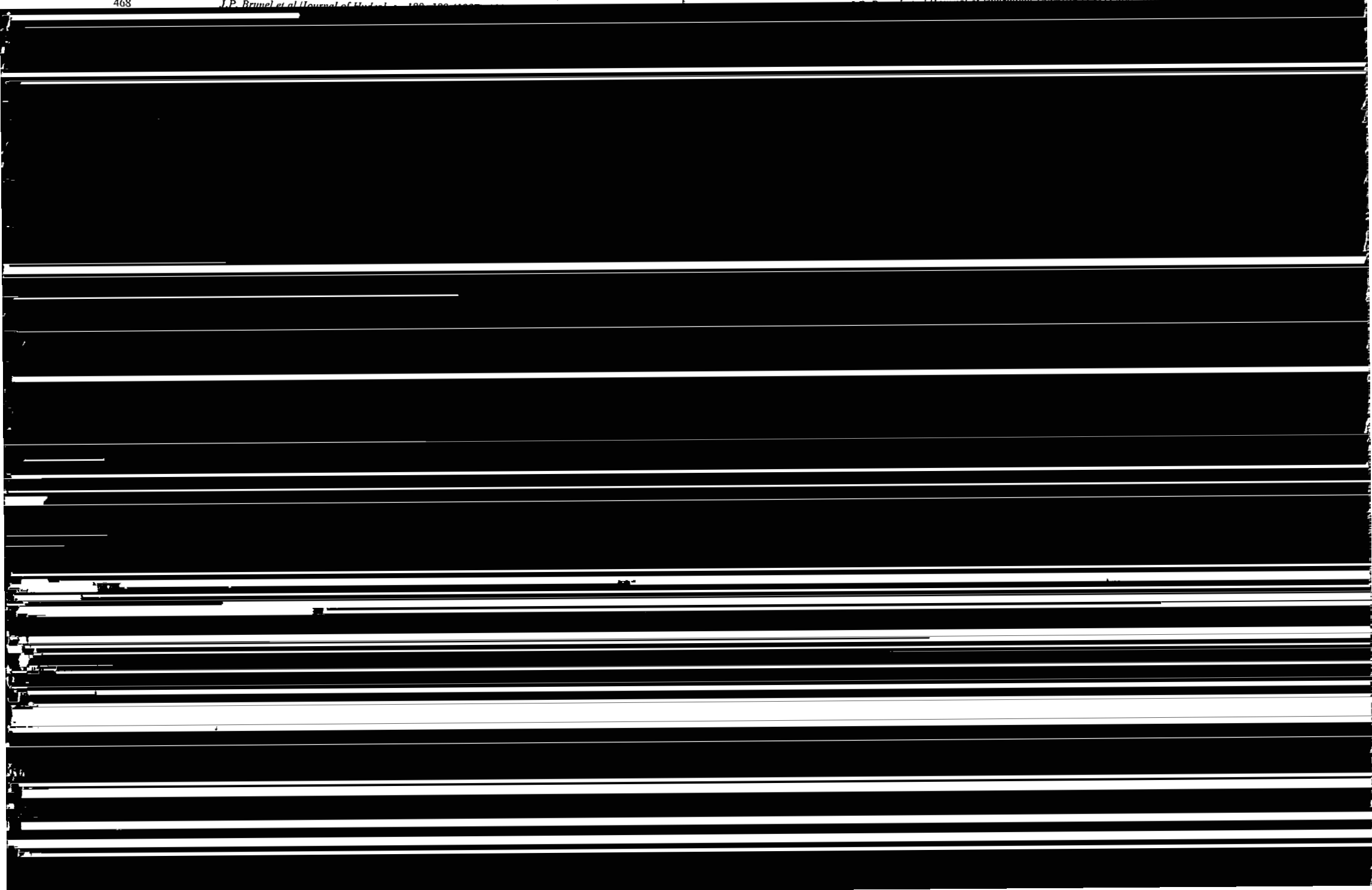




Use of stable isotopes of water to determine the origin of water
used by the vegetation and to partition evapotranspiration

Calder et al., 1992), large-scale evapotranspiration (Magaritz et al., 1990) and water balance (Gat and Matsui, 1991). Isotopic fractionation resulting from the change from liquid to vapour phase also provides a tool for studying evapotranspiration processes. This has been developed mainly to estimate long-term bare soil evaporation (Allison and Hughes, 1983; Barnes and Allison, 1988).

It is therefore surprising that isotopes have not been included in more classical studies of evapotranspiration. They would be expected to provide information on mixing processes on a different spatial and time scale from the normal instrumentation. This paper presents results that were obtained in the framework of the HAPEX-Sahel exercise (Goutorbe et al.,



rainfall events occurred, on 18, 22 and 27 July. All rainfall events from May to September 1992 were sampled at Samadey Village, 3 km from the field site.

3.2.2. Sap flow velocity measurements

To estimate the transpiration from *Guiera* using a heat-pulse technique (Swanson and Whitfield, 1981), four probes were set up in two trees at the main site. The averaged cross-section was 35.5 cm^2 . Spatial integration was done using the vegetation survey information of Karimou (1993), who found that the total cross-section for trees having a main branch diameter greater than 4 cm is $4.1 \text{ m}^2 \text{ ha}^{-1}$.

3.2.3. Atmospheric water vapour sampling

Water vapour samples were collected through segments of tubing attached to a mast at three heights above the ground (3, 6 and 12 m) by pumping air slowly at a flow rate of $10^{-3} \text{ m}^3 \text{ min}^{-1}$ through glass traps maintained at approximately -60°C with an electrical refrigeration unit. These traps were similar to that described by Schoch-Fischer et al. (1984). Sampling periods were generally from 08:00–09:00 h to 17:00–18:00 h. Water samples thus collected were then transferred into hermetically sealed 20 ml glass vials and were later analysed using conventional preparation and mass spectrometry techniques.

change in water content with time was measured below 50 cm (Fig. 3(a) and (b), below); (2) the soil matric potential vs. depth curve (Fig. 4(b), below) shows that there was almost no chance that the vegetation would extract water below 50 cm; (3) one can consider as negligible the contribution from soil layers below 50 cm depth to direct soil surface evaporation over a 1 week period. Integration over time has been done for the period 23–30 July.

4. Results and discussion

4.1. Rainfall

Daily precipitation from 24 May to 14 September 1992 and the corresponding isotopic compositions (J.D. Taupin, personal communication, 1993) are shown in Fig. 1. Two comments can be made: (1) low rainfall events are associated with enriched deuterium values, which indicate evaporative enrichment during the event; (2) rainfall is more depleted in heavy isotopes at the end of the rainy season, which, according to Taupin

Table 1
Rainfall characteristics

Day	Time ^a	$\delta^2\text{H}$ (‰)	$\delta^3\text{H}$ (‰)	$\delta^{18}\text{O}$ (‰)	$\delta^{18}\text{O}^b$ (‰)	P (mm)	P^b (mm)
18/7	01:10	-20.8	-22	-3.74	-3.8	23.0	16.2
22/7	15:45	-31.2	-32	-5.55	-5.3	26.5	38.2
27/7	17:10	-21.2	-28	-3.19	-3.0	15.5	5.2

^a Time when the rainfall event started at Samadey.

^b Values measured at the long-term station Samadey.

(1994), means that it formed from condensation processes at very high altitude, linked to strong convection at the time of the tropical monsoon.

The line of best fit for the ^2H – ^{18}O relationship, the local Meteoric Water Line, can be expressed as follows:

$$\delta^2\text{H} = 6.9\delta^{18}\text{O} + 1.5$$

During the exercise, three rainfall events occurred. The amount of rainfall and isotopic compositions measured at both the field site and the long-term station at Samadey are shown in Table 1 (expressed in ‰).

The previous rainfall (measured at Samadey) was on 13 July: $P = 8.8$ mm, $\delta^2\text{H} = -27$ ‰ and $\delta^{18}\text{O} = -4.5$ ‰. From the start of the rainy season on 24 May to 18 July, cumulative rainfall was 97.0 mm. Except for the rainfall recorded on 11 and 13 July with isotopic compositions being respectively -37 ‰ and -27 ‰ for ^2H and -6.3 ‰ and -4.5 ‰ for ^{18}O , all other events show a relatively enriched isotopic composition, -9 ‰ to $+9.6$ ‰ for ^2H and -1.93 ‰ to $+1.76$ ‰ for ^{18}O .

4.2. Gravimetric water content, soil matric water potential and isotopic composition of water in the soil at the main site (Site 2)

Soil was sampled for gravimetric water content, soil matric water potential and stable isotope analysis on six selected days according to the rainfall events which occurred between 18 and 30 July. These days were 18, 23, 24, 26, 28 and 30 July. Surface soil was sampled on 24, 27 and 30 July. Deep soil sampling was on 24 July.

In Fig. 2(a), the three curves represent the variation of gravimetric water content with depth within the 0–0.1 m depth interval (sampling every centimetre). One can see the effect of rainfall and the rapidity with which the soil surface is responding to the precipitation–infiltration–evaporation process. The corresponding profiles for deuterium, in Fig. 2(b), show a similar pattern for the 3 days, with high enrichment in heavy isotopes from 4 cm depth to the surface, representing soil evaporation.

Fig. 3(a) shows for selected days the gravimetric water content vs. depth within the 0–1.2 m depth interval (sampling every 10 cm), and illustrates the quick response of the top 40–50 cm of soil to infiltration–evapotranspiration. Below that depth, variations seem almost negligible, and gravimetric water contents remain low (less than 3%) and fairly stable. Corresponding deuterium profiles in Fig. 3(b) show an old evaporative front at

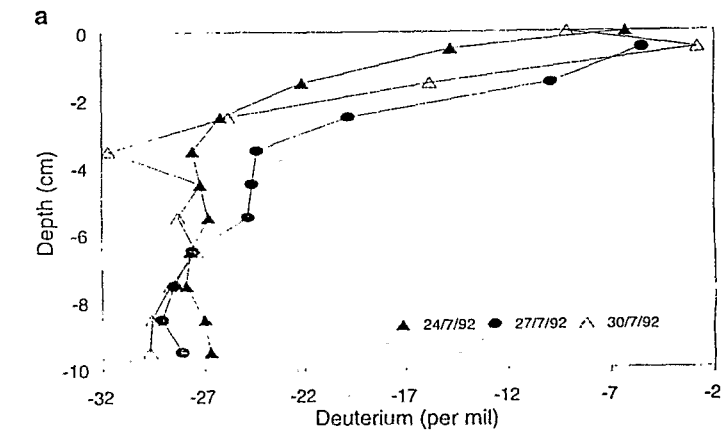
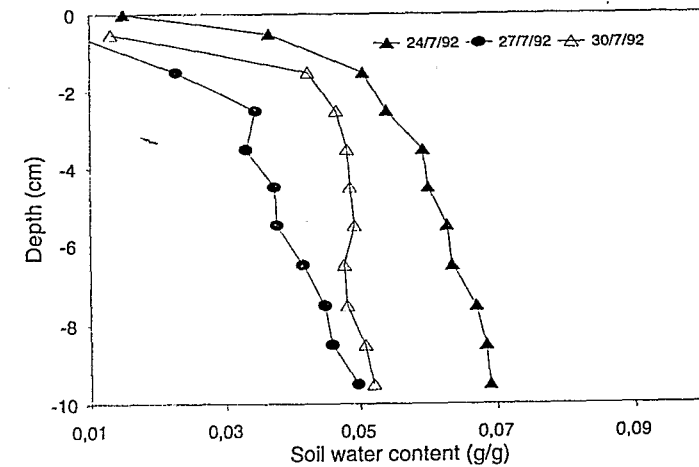


Fig. 2. (a) Surface gravimetric water content (0–10 cm) and (b) surface deuterium profiles (0–10 cm), at Site 2 on 24, 27 and 30 July.

50 cm depth. For the 0–3.5 m depth interval (sampling every 20 cm), data are shown in Fig. 4(a)–(c).

Fig. 5(a) and (b) give an example of the variation of gravimetric water content and deuterium composition of soil water with depth for Sites 2, 3 and 4, on 23 and 26 July. Spatial variability is not sufficient to influence the interpretation of the results.

4.3. Isotopic composition of sap water in trees

Twigs were sampled for isotopic analysis of sap water on 23, 26 and 30 July; the data are shown in Table 2. For each tree at Sites 2, 3 and 4, and for each time of sampling, twigs

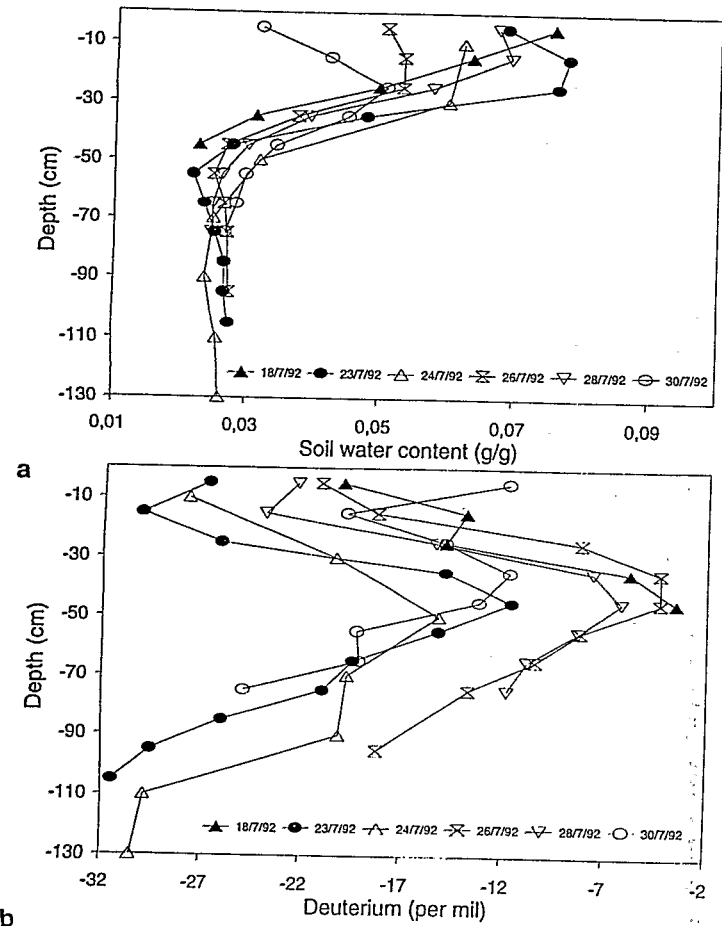


Fig. 3. (a) Gravimetric water content and (b) deuterium profiles at Site 2: time variability.

were generally sampled from the same two main branches denoted a and b. The numbers 1 and 2 denote replicates of the same twig. When there are two numbers in the $\delta^2\text{H}$ column, the second is the value for ^{18}O .

4.4. Determining the possible sources of water used by the *Guiera* trees

The principle of the method is as follows:

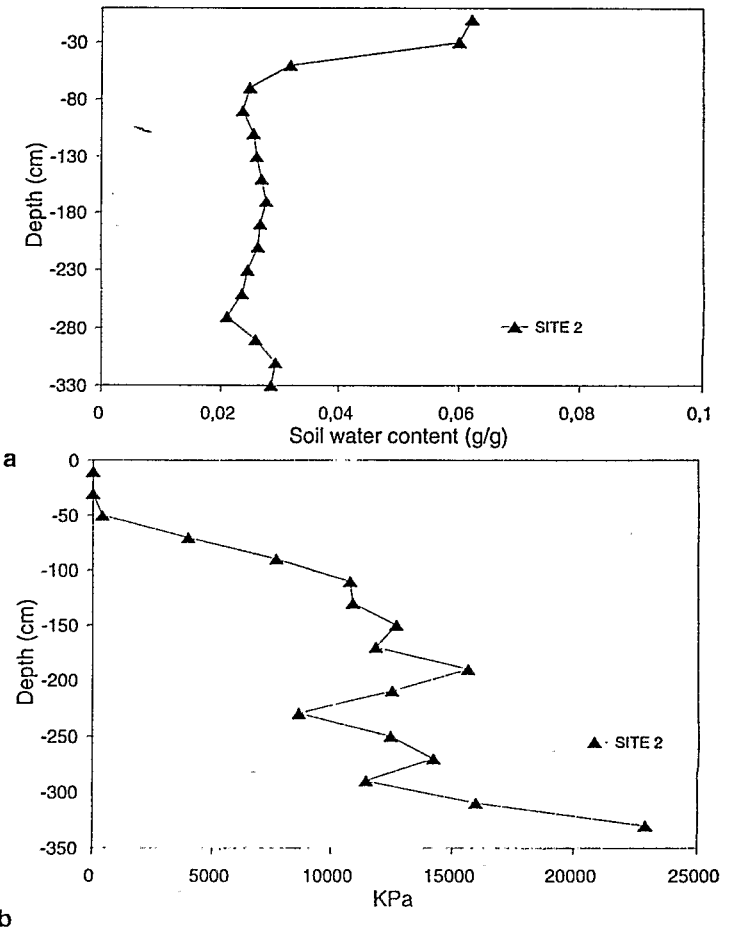


Fig. 4. (a) Gravimetric water content, (b) soil matrix water potential and (c) deuterium profile, for the deep soil sampling (24 July 1992).

groundwater, because the water table is at a considerable depth, generally 20-60 m from the surface and probably close to 40 m in the area of the field sites.

As regards the deuterium profiles from the deep soil sampling (0-3.5 m) at Site 2 (Fig. 4(c)), there are three zones in the soil where isotopic composition of soil water matches that of the sap water in the tree; these are at depths between 20 and 30 cm, around 1 m and between 1.9 and 2.5 m. However, the corresponding soil matrix water potential

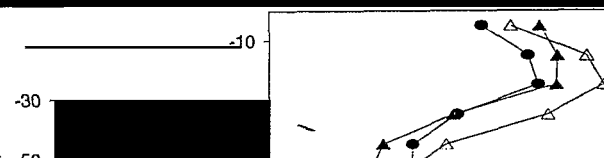
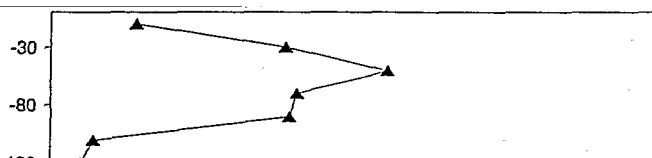


Table 2

Deuterium composition (oxygen-18) of sap water in the trees (in ‰)

Date-site-identity	$\delta^2\text{H}$	Date-site-identity	$\delta^2\text{H}$
23-2-a1	-24.1 (2.49)	26-2-a	-24.1 (3.3)
23-2-a2	-24.8	26-2-b	-28.2
23-2-b1	-26.5	26-3-a	-22.4
23-2-b2	-26.7	26-3-b	-23.2
23-3-a1	-22.1	26-4-a	-26.9
23-3-a2	-23.9		
23-3-b1	-21.1	30-2-a	-21.9 (1.81)
23-3-b2	-22.2	30-2-b	-28.2
23-4-a1	-22.6	30-3-a	-19.8
23-4-a2	-22.4	30-4-a	-21.8
23-4-b1	-23.4		
23-4-b2	-22.3		

density is negligible, as a change from 1.4 to 1.6 (the range of measured values for ρ) would lead to less than 1‰ change in $\delta^2\text{H}$.

Values of actual evapotranspiration for the study site are not available for the measurement period. Hence, the comparison of these results with those obtained by other methods

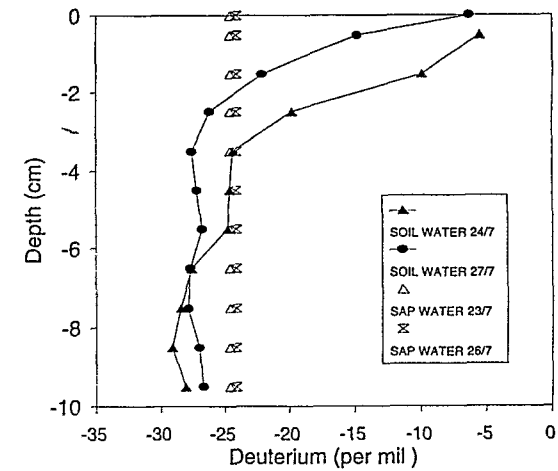


Fig. 7. Deuterium composition in soil (0-1 cm) and plant water (23-27 July 1992).

Table 3

Averaged values of the isotopic signatures of water in soil, plant and atmosphere, and calculated value of

Gat, J.R. and Matsui, E., 1991. Atmospheric water balance in the Amazon basin: an isotopic evapotranspiration model. *J. Geophys. Res.*, 96(D7): 13179-13188.

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