THE FATE OF ORGANIC MATTER IN A SUGARCANE SYSTEM IN BRAZIL

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Abstract

Our objective was to gain a better understanding of organic matter and nutrient turnover in the cultivation of sugarcane. Related processes that involve soil water content, soil bulk density and soil temperature, were included. A comparison was made between the traditional management practice of burning the cane trash before harvest, with the newly recommended practice of leaving the trash on the soil surface after harvest. Results showed great differences in surface-soil temperature and water content between the two management practices. Water balances were not affected, but the dynamics of nitrogen and organic matter in the soil-plant system differed significantly. The sugarcane productivity was, however, not affected by management practice, during the first 3 years of the study.

1. INTRODUCTION

Worldwide, Brazil is the largest producer of sugarcane producer. It is cultivated on over 4 Mha with a total yield of 240 Mt of cane, 9.5 Mt sugar, and 12 GL of alcohol. In general, the cropped area is submitted to straw burning before harvest, to facilitate cutting and transport operations. Recent emphasis on adopting agricultural practices, for greater sustainability of the system, is exerting pressure on this agroindustry to review management procedures, including consideration of harvesting without previous burning, called “raw-cane harvest” or “green-cane harvest.” With the new approach, straw and tips, jointly called trash, are chopped and left on the soil surface after harvest, thus mulching the next ratoon crop.

The practice of burning the cane straw presents mostly economic advantages, facilitating manual harvesting by cutters who are paid on a t day^{-1} basis. Furthermore, the maintenance of all organic matter in the system can lead to advantages for the soil, will reduce air pollution (CO_2 and wind-carried ash) and, probably, will reduce the need for mineral fertilizers.

The green-cane method was recently adopted in the main sugarcane-producing areas of Brazil. Therefore, it is fundamentally important to understand how this new practice will affect nutrient dynamics in order to maximize its positive aspects and improve sustainability. For these reasons, this agroindustrial problem was chosen to be part of the FAO/IAEA Co-ordinated Research Project on “The use of isotope techniques in studies on the management of organic matter and nutrient turnover for increased, sustainable agricultural production and environmental preservation.”

The main objectives of the project were:

- to review the state-of-the-art on soil organic matter studies,
- to discuss how the decomposition of organic matter in tropical soils affects nutrient release and soil physical/chemical properties,
- to determine factors that control nutrient losses from decomposing organic matter, and to seek management options to increase the use efficiency of the released nutrients by the crop, and
- to examine how computer-simulation models can play a role in predicting optimal organic matter levels.

These objectives fitted exactly the described sugarcane-management situation in Brazil.

2. DESCRIPTION OF THE EXPERIMENT

Sugarcane, a semi-perennial crop that is replanted every 5 to 8 years, belongs to the grass family (Gramineae). Cane stalks can reach 3 m height. It has a bulky rhizome, and the root system is confined mostly within the 0.5-m topsoil, although some roots grow more deeply than 1 m. It is planted in rows and harvested after 1 year or more. Stalks are used to manufacture sugar and/or alcohol. After each harvest, the rhizome sprouts, renewing the crop: the ratoon. After four to seven ratoons, the crop is renewed with stalk cuttings.

This experiment was started in October 1997, on a Dark Red Latosol (Rhodic Kandiudalf), locally called “Terra Roxa Estruturada,” at Piracicaba (22°42’ S, 47°38’ W) in the State of São Paulo, Brazil, at 580 m above sea level and 250 km inside the continent. The medium/late sugarcane variety SP 80-3280 was planted on 0.21 ha, i.e., fifteen rows 100 m long, spaced 1.4 m, as illustrated in Fig. 1. Four treatments with four replicates each were imposed on the central lines (7, 8 and 9), called upper, central and lower, due to a 7.4% slope, separated by borders, in such a way that each plot had three cane rows of 4 m, totalling 16.8 m^2. Figure 1 also shows three transects of 84 m each, consisting of 1-m plots used for geostatistical and state-space analysis [1]. The experimental scheme extended over a period of 5 years, as follows: (i) October 1997 to October 1998, planted crop; (ii) October 1998 to October 1999, first ratoon crop; (iii) October 1999 to October 2000, second ratoon; (iv) October 2000 to October 2001, third ratoon; (v) October 2001 to October 2002, fourth ratoon crop. This report presents data for the period 1997 to 2000.

During the first year (1997–1998), no treatments were imposed; the field was managed homogeneously according to traditional agricultural practices. After the October-1998 harvest, treatments were applied to the crop as indicated in Fig. 1.

Treatment T_1 consisted of “green-cane harvest” with mulching. At planting time (October 1997), the crop was fertilized with 63 kg ha^{-1} of ^{15}N-labelled ammonium sulphate, and after the first harvest (October 1998) received non-labelled trash from T_2.

Treatment T_2 also consisted of “green-cane harvest” with mulching. The same N application rate as T_1 was applied at planting time (October 1997), however it was not labelled. After the first harvest (October 1998) it received ^{15}N-labelled trash mulch from T_1.

Treatment T_3 consisted of “green-cane harvest with bare interrow.” All crop residues were exported, leaving bare interrow areas. All other management practices were the same as for T_1 and T_2.

Treatment T_4 consisted of “burning straw before harvest”. This treatment also received ^{15}N-labelled trash in October 1997, as for T_1.

Phosphorus and K fertilization, and all other management practices adopted during cane development, were the same for all treatments. Only one ^{15}N-labelled fertilizer pulse was applied, in October 1997, with the objective of following its fate over the 5-year period, in plant and soil, in order to better understand the organic matter flow in these management systems.

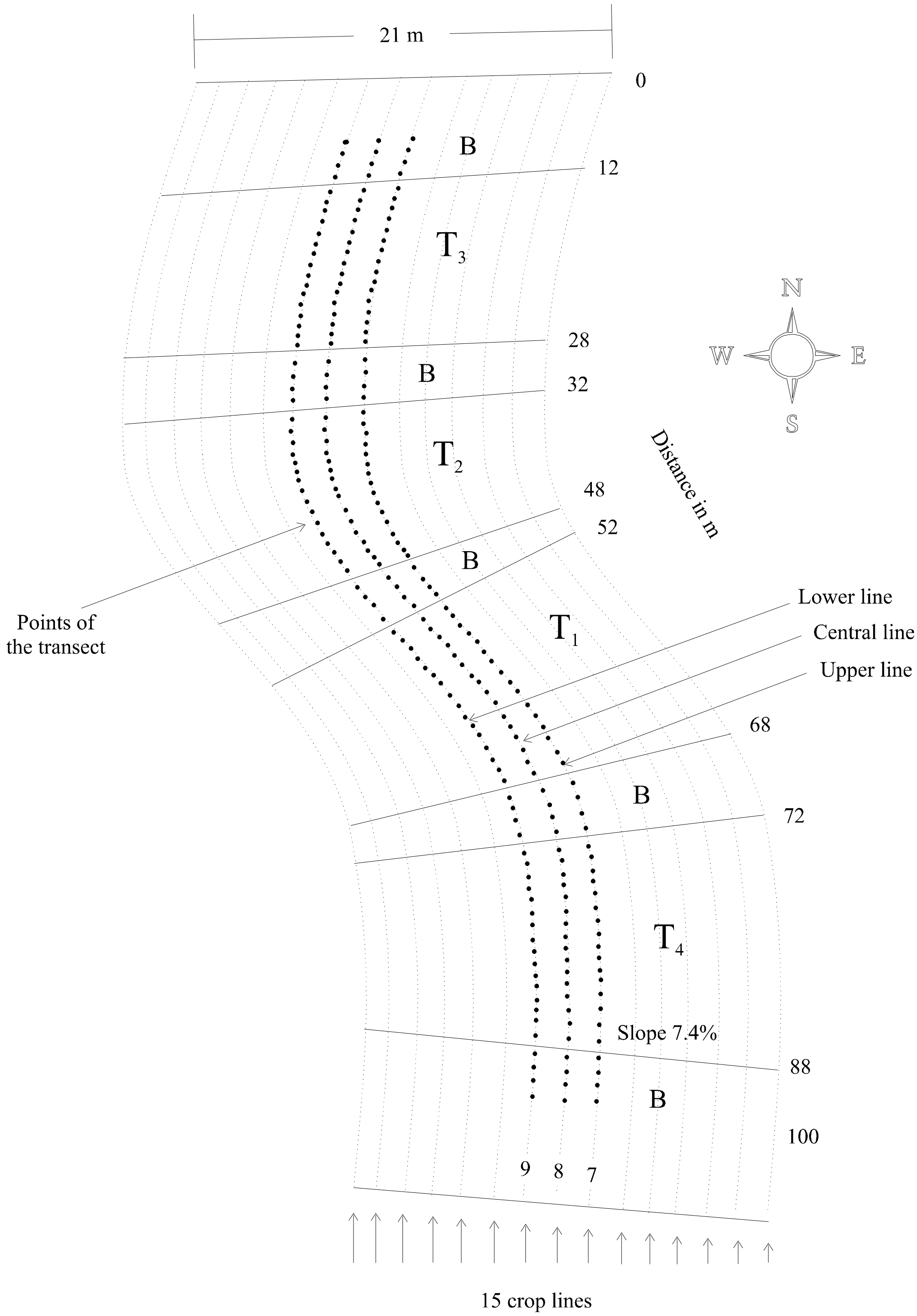

FIG. 1. Schematic view of the experimental area. Treatments T_1 and T_2 were mulched, T_3 had bare interrow, and T_4 had burned trash after harvest. B=borders.

The following aspects were studied:

- Soil Chemistry: soil organic matter (SOM) including its fractionation according to particle-size distribution, and respective ^{15}N enrichment. Soil properties: pH, SOM, P, K, Ca, Mg, H^+, Al, SB, T, and V;
- Soil Physics: temperature, water content, water storage, water-balance components, and compaction evaluated through bulk density measurements;
- Plant Development: plant ^{15}N enrichment during growth, and, at harvest, number of canes m^{-1}, weight of canes, weight of straw, weight of tips.

3. RESULTS AND DISCUSSION

3.1. Soil water content and temperature

A state-space approach was used [2] to investigate the effects of organic-matter mulching on soil water content and temperature. Water-content and temperature data were collected along the 84-point transect (Fig. 2). The temperature data reflect visually the effects of the treatments on the average soil temperature of the surface layer (0.03 to 0.09 m). Treatments T_1 and T_2 presented much lower temperatures (overall average of 23.2°C) due to the presence of the mulch (trash = tips + straw, 127 kg ha^{-1} of dry matter); T_3, with the soil surface bare, presented an average of 30.1°C; and T_4, the burned treatment, had an average of 28.3°C. These differences in temperature were due to the fact that they were measured two weeks after harvest of the first crop, when the ratoon crop was starting to sprout and the soil was exposed to sunshine (November 20, 1998, a late spring day) after six days without rainfall.

Soil water content data (0–0.2 m layer), collected on the same day, presented an inverse pattern. The mulched treatments, T_1 and T_2, showed higher water contents in relation to the bare T_3 and the burned T_4 treatments. This is demonstrated in Fig. 3, which shows a correlation (R^2 = 0.4491, significant at the 5% level) between soil temperature T and soil water content θ. The negative slope of the relation expresses the inverse relation between T and θ.

The state-space analyses applied to soil water content and temperature are presented in Figs. 4 and 5, respectively, after transforming the data according to [3]. The obtained matrix coefficients were:

$$\theta_i = 0.881\ \theta_{i-1} + 0.1148\ T_{i-1} + W_{\theta i} \quad (1)$$

$$T_i = 0.0615\ \theta_{i-1} + 0.9272\ T_{i-1} + W_{Ti} \quad (2)$$

The shaded area of Figs. 4 and 5 represent the fiducial limits considering ± one standard deviation. Analyzing Eqq. (1) and (2), it can be seen that θ at location i-1 contributed 88% to the estimate of θ in i, while T at i-1 contributed with 11.5%, showing that the contribution of θ of the first neighbour was more significant than that of T.

For the case of temperature estimation (Fig. 5), Eq. (2) shows that θ_{i-1} contributed with 6.2% in the estimate of the temperature at point i. On the other hand, T_{i-1} contributed with 93%. This state-space analysis is the first performed on soil spatial data in Brazil. One objective was its introduction into the Brazilian literature and, as already said, to contribute to a better understanding of the relation between θ and T.

Relating soil properties at sites i to properties at sites i-h is also of practical importance, mainly to farmers. In this study, the lag of 1 m was small for practical purposes, however it is very important to better understand how far one property is affected by its neighbour, and so recognize management practices that would lead to increased yield. Precision agriculture is one of the recent fields that contributes to these aspects.

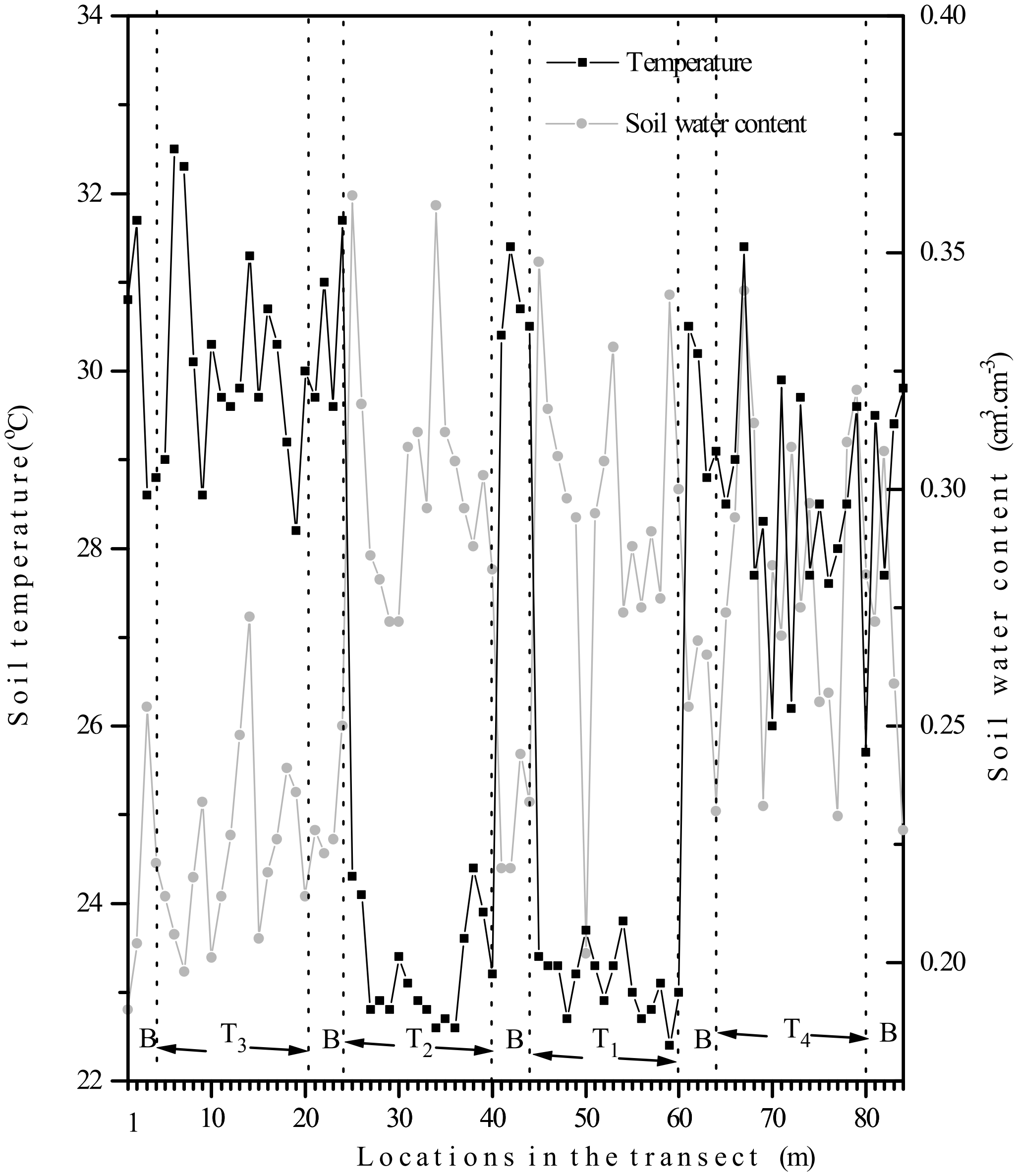

FIG. 2. Distributions of soil temperature (average of three depths: 0.03, 0.06, and 0.09 m) and water content (0–0.20 m) meter by meter along the 84-point transect, at noon (11:00 AM–12:00) on Nov. 20, 1998. B=border; T_1 and T_2=trash mulching; T_3=bare soil; T_4=burned trash.

Analysis of variance was used to compare average values of soil temperature. The differences between mulched (T_1 and T_2) and non-mulched (T_3 and T_4) treatments were significant for the average temperature at all measured depths (0.03–0.09 m layer), even at the greatest depth, as shown in Fig. 6. Between mulched treatments (T_1 and T_2) the difference was not significant (Table I, November 18, 1998).

For this early date, when the crop covered no more than 10% of soil surface, the burned trash in T_4 significantly affected soil temperatures as compared to the bare soil of T_3 The situation on December 12, 1998, was very similar but there was no difference between T_3 and T_4, indicating that there was no more effect of the residues of the burned trash. On December 18, 1998, a cloudy day, the significant differences shown in Table I have no physical meaning since the average values are very close.

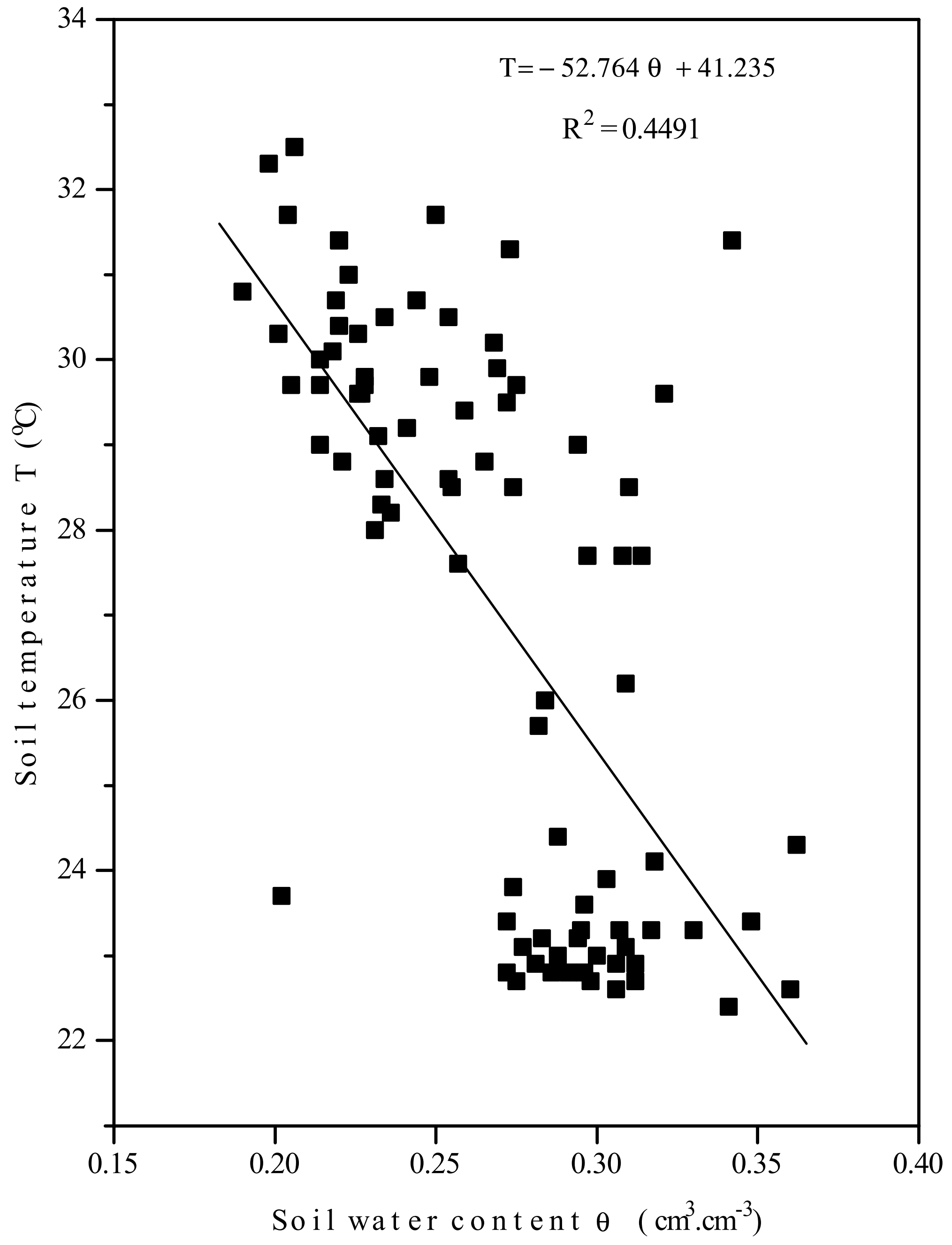

FIG. 3. Correlation between soil-temperature and water-content data of Fig. 2.

The data of January 12, 1999, were collected when the plants were about 1-m tall. Although Table I indicates no differences among T_1, T_2 and T_3, the average temperature of the bare treatment T_3 was slightly higher than that of the mulched treatments, T_1 and T_2, at least for depths of 0.06 and 0.09 m. The greater difference between these treatments and T_4 is likely due to a delay in plant growth for the burned trash treatment. On February 5, 1999 (also a cloudy day), the differences shown in Table II had no physical significance. The same can be said for the other dates (March 4, April 7, May 14 and June 29), which were not cloudy. On the last date, the plant canopy completely shaded the interrows, therefore treatments no longer affected soil temperature. The slightly higher temperatures at the beginning of the transect (0–15 m) on June 29 were due to clearings from wind-fallen canes.

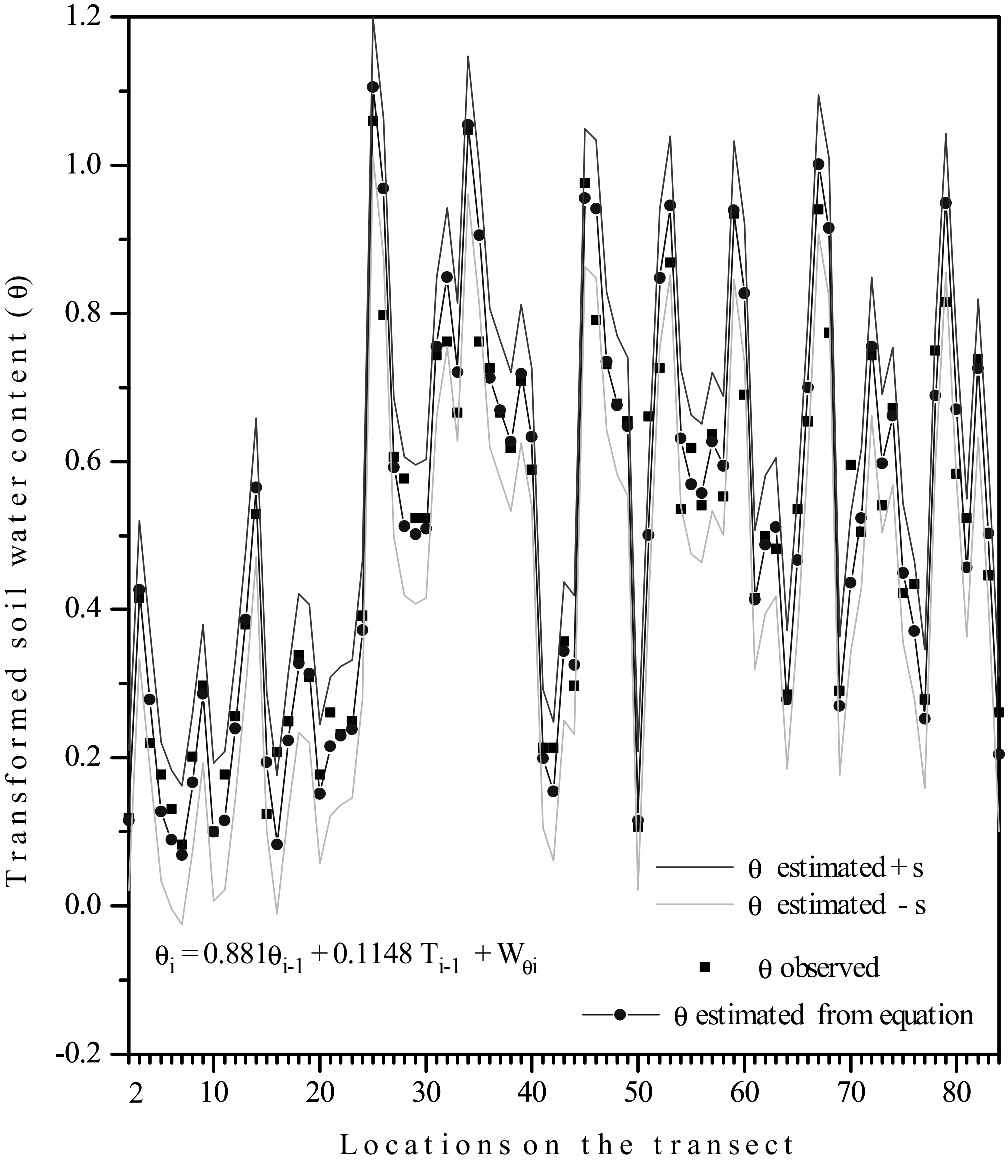

FIG 4. State-space analysis of transformed soil water content θ data of Fig. 2, using the transformation: $x_i = [X_i - (m - 2s)]/4s$.

The temperature differences between the non-mulched treatments (T_3 and T_4) and the mulched (T_1 and T_2) reached 7°C in November, decreasing to almost zero in February (Table I). Peak values, at the shallow depth (0.03 m), reached 37°C, and, since soil-temperature profiles, are, in general, exponential, the soil surface must have reached much higher temperatures. The spring-summer period is very important for the establishment of ratoon crops, and it was expected that lower soil temperatures due to mulching would favour development. During this relatively short period in the crop cycle, the young rhizome is more sensitive to high temperatures. Yield data (Table II) show, however, a negative effect of the mulch on growth, since at harvest (October 1999) T_1 and T_2 had significantly lower values for wet mass and number of stalks per meter of row, in relation to T_3 and T_4, except for the number of stalks in T_4. A humid microenvironment in the straw layer, which had a thickness, initially, of 0.20 to 0.30 m, may have promoted the growth of fungi and microorganisms, affecting rhizome sprouting and stalk development.

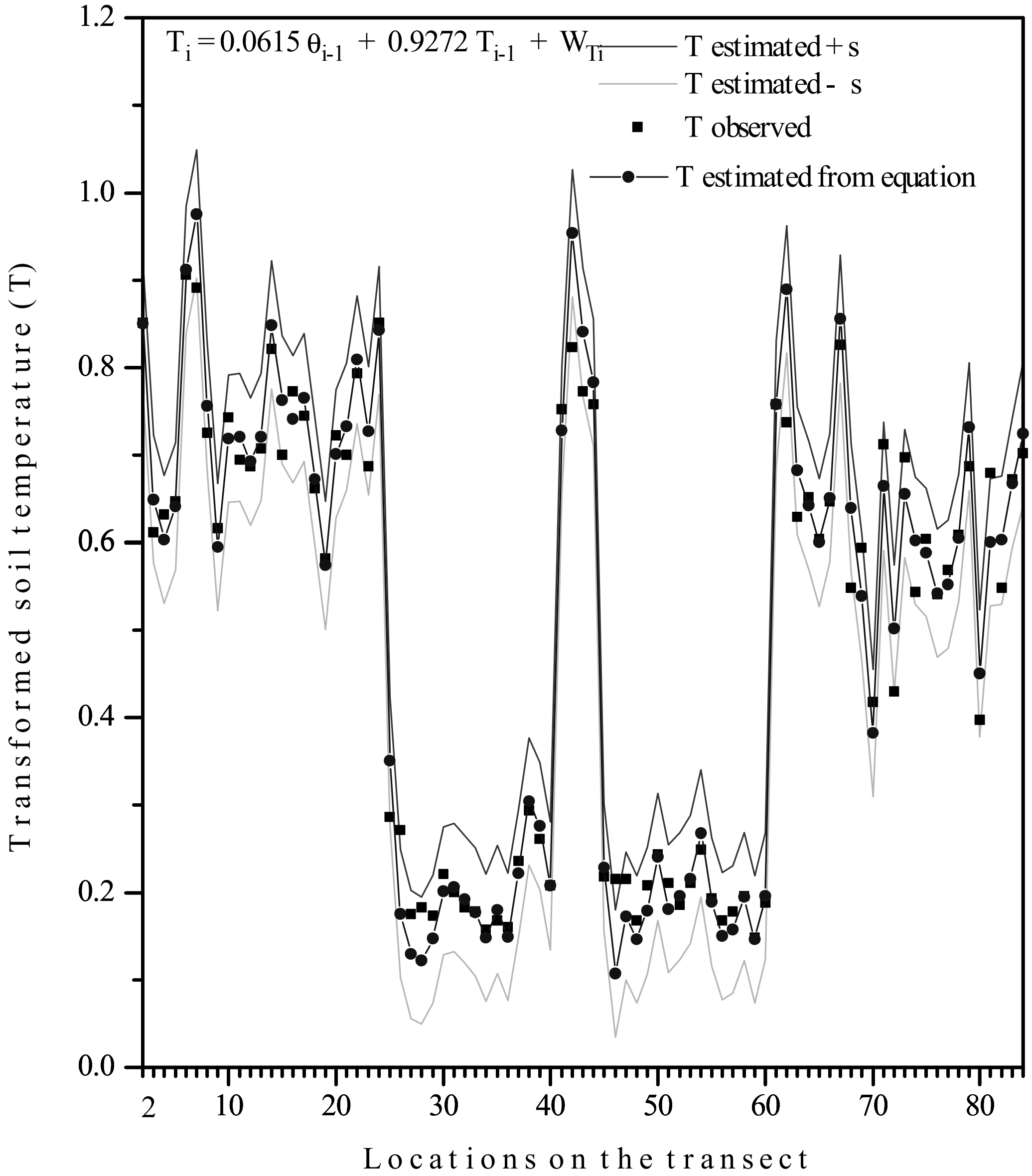

FIG. 5. State-space analysis of transformed soil-temperature data of Fig. 2, using the transformation: $x_i = [X_i - (m - 2s)]/4s$.

3.2. Soil water content and bulk density

Soil bulk density was monitored on rows 7, 8 and 9, along the 84-point transect, using a surface gamma-neutron gauge, Model CPN MC-3. It has to be pointed out that the experimental field was not machine harvested, and that the observed soil bulk density changes were due to foot traffic on interrows to make measurements and take instrument readings. The calibration of the surface gamma-neutron gauge in Ref. [4] presented an improvement in relation to the manufacturer's method. A new calibration equation was established for the probe shown in Fig. 7 using several materials, among them soils and sand, at various levels of moisture and density, pure tap water, and including results with the materials employed by the manufacturer. The density range for the used materials was 0.995 to 2.632 Mg m^{-3}. Figure 8 illustrates the changes of the calibration equation, when points of lower density were included. The lowest value used by the factory was 1.717 Mg m^{-3}, which, in some cases, is high for agronomic purposes. Figure 8 shows the calibration for the 0.05-m depth. A similar pattern was found for the other investigated depths.

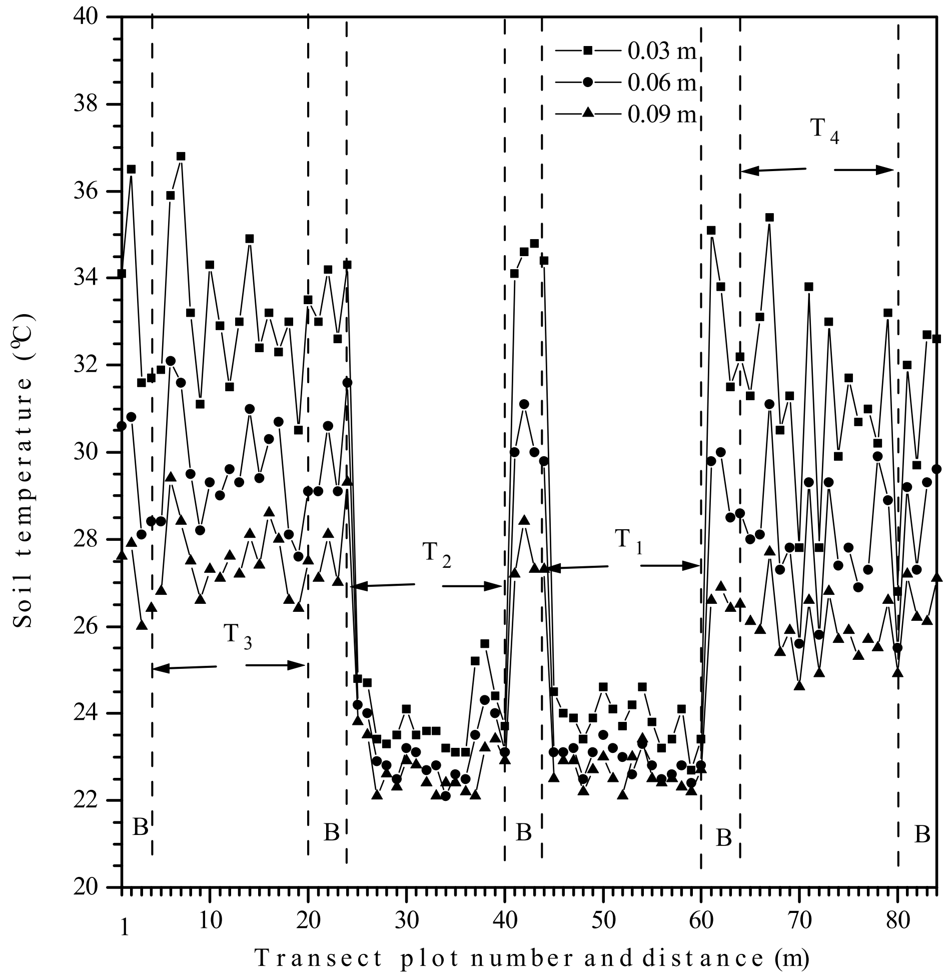

FIG. 6. Soil temperature transect for 18 November 1998. T1=mulched; T2=mulched; T3=bare; T4=burned residues; B=borders.

Table I. Average soil temperatures (four replicates, each with four sampling points) for the 0.03- to 0.09-m layer, at selected dates (T_1=mulched; T_2=mulched; T_3=bare; T_4=burned. Maximum, minimum, and mean air temperatures are also shown)

Date	Average soil temperature				Air temperature		
	T_1	T_2	T_3	T_4	Max	Min	Mean
	(°C)						
November 18, 1998	23.1c[a]	23.3c	30.1a	28.3b	32.8	19.7	26.3
December 2, 1998	23.1b	22.8b	29.8a	30.2a	35.0	18.0	26.5
December 18, 1998	23.9bc	23.8c	24.5a	24.4ab	27.6	20.8	24.2
January 12, 1999	23.1b	23.3b	23.8b	28.3a	29.8	20.0	24.9
February 5, 1999	23.8a	23.8a	23.5b	23.4b	33.7	19.8	26.8
March 4, 1999	22.7a	22.9a	22.7a	22.3b	32.0	18.4	25.2
April 7, 1999	22.3b	22.6a	22.6a	22.1c	32.2	18.4	25.3
May 14, 1999	17.4a	17.4a	17.7a	17.6a	22.5	9.0	15.6
June 29, 1999	15.5b	15.6b	16.3a	15.3b	27.8	14.2	21.0

[a]Averages within dates followed by the same letter do not differ significantly at the 5% level by Tukey.

Table II. Plant growth evaluation at harvest (October 1999) (averages of sixteen replicates per treatment)

Treatment	NS[a] (per m)	WS[b] ($kg\ m^{-1}$)
T_1	39.7b[c]	51.1b
T_2	40.3b	55.3ab
T_3	47.8a	63.2a
T_4	45.2ab	58.1ab

[a]Number of stalks. [b]Weight of stalks. [c]Averages in a column followed by the same letter do not differ at the significance level of 5% by Tukey.

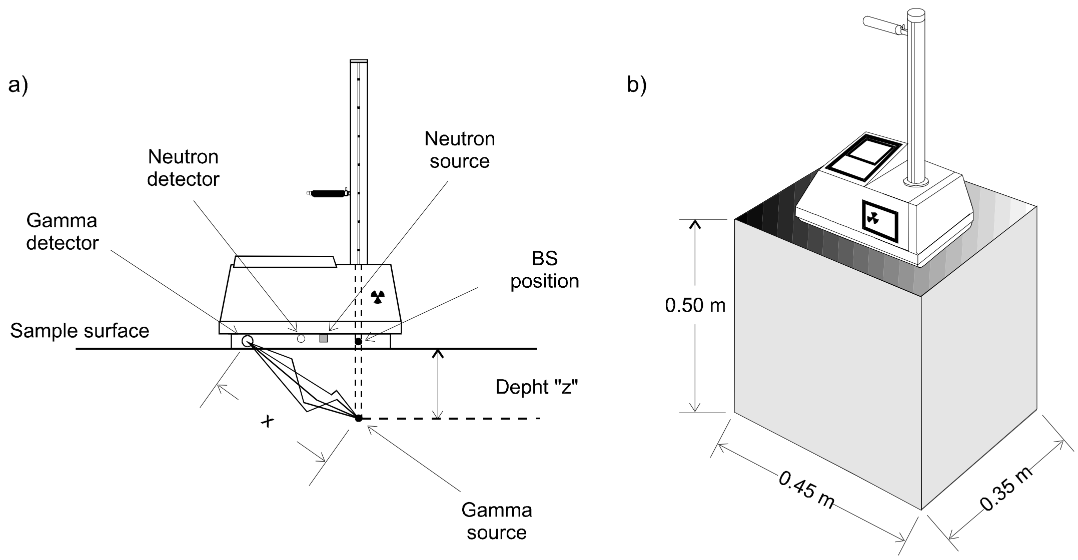

FIG. 7. Schematic diagram of the neutron probe: (a) measuring position, (b)with container for artificially packed samples.

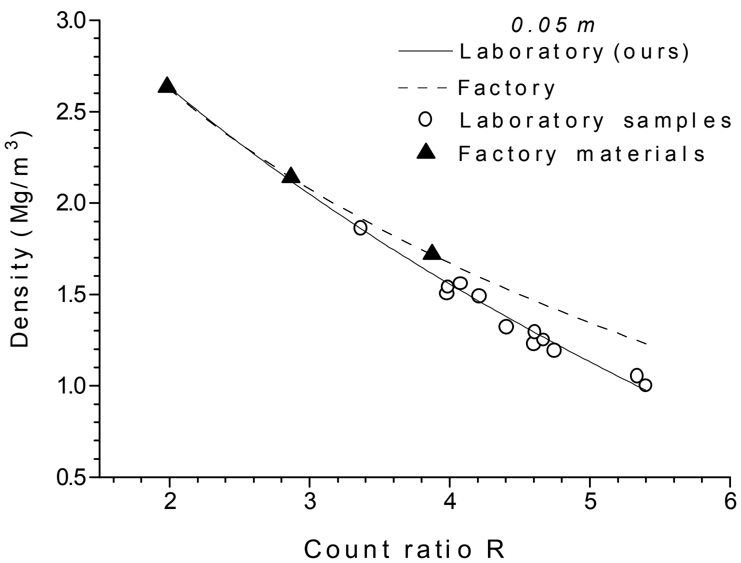

FIG. 8. Factory calibration as compared to our own laboratory calibration, for the 0.05-m position.

It can clearly be seen that the factory calibration, which was obtained from three high-density materials, coincides with our calibration curve only for a specific range of densities, more specifically for materials of high and intermediate densities. For low-density values, like those found in most soil profiles, for which the factory calibration should be extrapolated, it can be seen that deviations can reach values up to 16% higher, in relation to gravimetric measurements.

Along with the calibration efforts, an algorithm was developed [5] to explore soil layers. It was shown that using single-probe surface neutron-gamma gauges it is possible to detect compacted layers at depths in the range 0 to 0.30 m. The comparison between densities measured gravimetrically and with the aid of the gauge indicates that the density value obtained by the gauge represents a mixture of the densities crossed by the gamma-ray beam along its path. When compacted layers present a large difference of density in relation to the surrounding medium, it is possible to reproduce gravimetric data using gauge data and the proposed algorithm. The analysis showed that the probe yields less-exact and more-disperse values for shallow depths.

The relationship between soil-water content and bulk density is presented in [6]. Figure 9 shows the temporal evolution of soil-water contents, comparing the mulched-soil content θ_m with the bare-soil content θ_b. For all 300 days of measurements during the first ratoon crop cycle, the mulched rows presented 0.04 m^3 m^{-3} higher soil-water contents in relation to the bare rows, which corresponds to an increase of about 15%. A very good correlation was obtained between θ_m and θ_b:

$$\theta_m = 0.14 + 0.64\theta_b \quad (r=0.93;\ P < 0.01) \tag{3}$$

and, in terms of average values, the following relation was found:

$$\bar{\theta}_m = 0.04 + \bar{\theta}_b \tag{4}$$

where

$\bar{\theta}_m$ and $\bar{\theta}_b$ are the time averages of θ for the mulched (T_1 and T_2) and bare (T_3) rows, respectively.

Similar behaviour was observed when comparing the mulched rows (T_1 and T_2) with the burned residuals (T_4), however in a lower intensity, showing only 0.01 $m^3.m^{-3}$ higher θ values in relation to T_4. The following relations were found:

$$\theta_m = -0.03 + 1.1\theta_b \quad (r=92;\ P < 0.01) \tag{3a}$$

and

$$\bar{\theta}_m = 0.01 + \bar{\theta}_r \tag{4a}$$

where

θ_r is the soil water content of the burned residual rows, and

$\bar{\theta}_r$ is the time average.

Average dry bulk density data along the three rows are presented in Fig. 10 for two depths, 0.15 and 0.30 m. ANOVA was applied to all available data in order to verify differences among treatments. Table III shows the average D_b values for each treatment at depths of 0.15 and 0.30 m and for the three lines. Results indicate that the 0- to 0.30-m layer was denser than the 0- to 0.15-m layer for all treatments. For both depths, the bare-soil treatment (T_3) and the burned-residue treatment (T_4) presented higher densities in relation to those that were straw-mulched, T_1 and T_2, a fact that could be explained by the protective effect of the mulch on soil compaction.

It is concluded that the change of sugarcane management practice of burning trash in the field after harvest, to the practice of leaving trash as a mulch for the next ratoon crop, increased soil water content only slightly (about 4%) in the 0- to 0.15-m layer. In comparison to bare interrow, the increase in soil water content was significantly higher (about 15%). It was observed that, in terms of soil bulk density, the mulching of soil with harvest trash mitigates compaction.

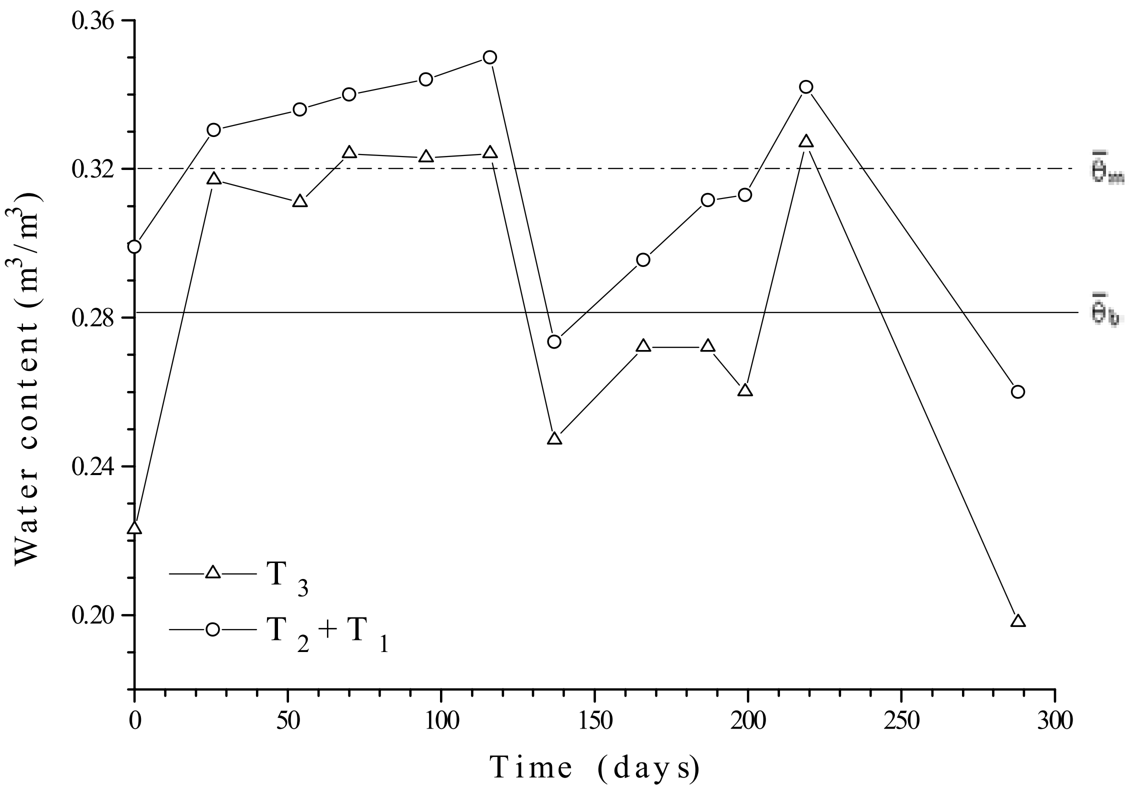

FIG. 9. Time evolution of average soil-water content, comparing mulched treatments (T_1 and T_2) with bare interrow (T_3).

Table III. Average soil dry bulk density as a function of depth, for the three rows of treatments T_1 and T_2 (straw mulch), T_3 (bare soil) and T_4 (burned residues), for three dates

Treatment	Dry bulk density	
	0.15 m	0.30 m
	(kg m^{-3})	
T_1	1,385d[a]	1,458d
T_2	1,415c	1,487c
T_3	1,470b	1,553b
T_4	1,512a	1,571a

[a]Means within a column followed by the same letter do not differ significantly at the 5% level.

3.3. Water balance

To follow the dynamics of the water, a water balance was carried out [7] using the 0- to 1.0-m soil layer as the volume element. Rainfall was measured at the site, evapotranspiration was estimated from atmospheric parameters, soil water fluxes at the 1.0-m depth were calculated from Darcy's equation, and run-off was measured by difference. Results did not reveal significant differences among treatments.

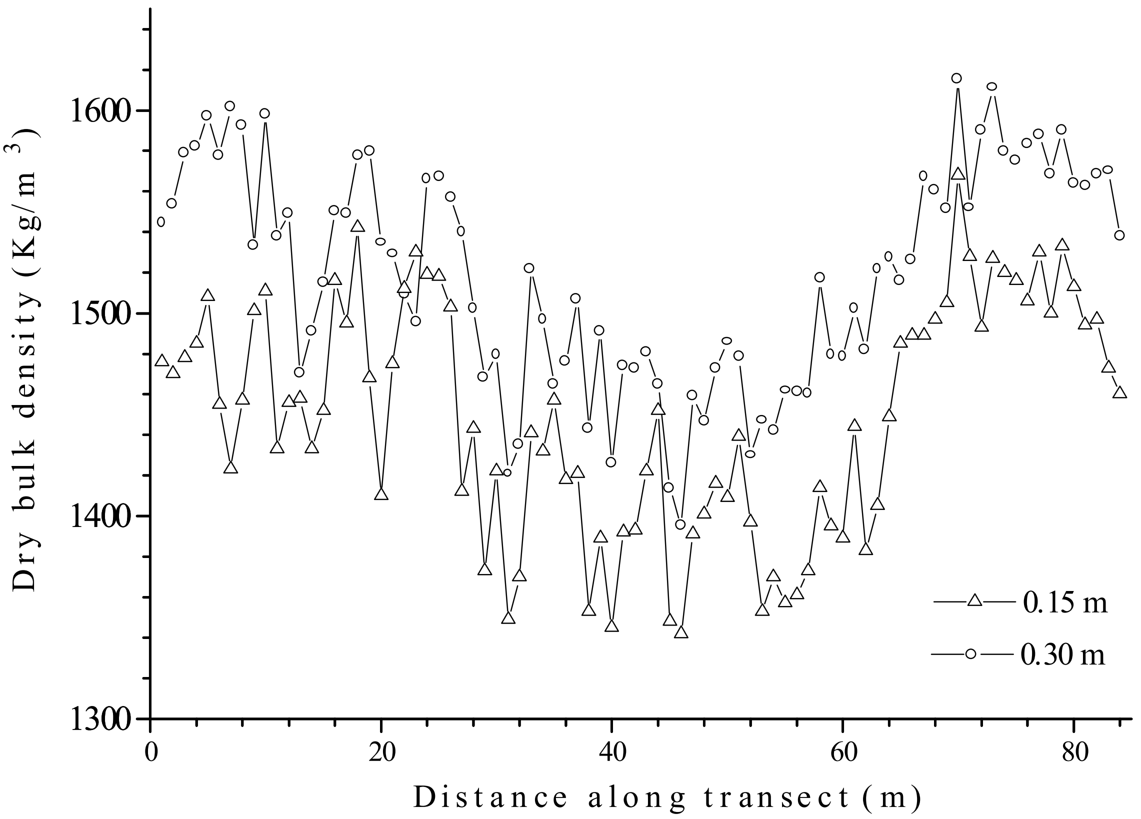

FIG. 10. Spatial variability of average (three lines) dry soil bulk densities, for two depths.

Table IV. Soil (Rhodic Kandindox) chemical characteristics (0–0.2 m layer) of the sugarcane field

Replicate	pH in $CaCl_2$	SOM (g dm^{-3})	P (mg dm^{-3})	K	Ca	Mg
				($mmol_c$ dm^{-3})		
T_1R_1	5.1	26.0	35.8	4.3	59.5	15.8
T_1R_4	5.0	22.3	26.5	3.1	62.0	15.8
T_1R_2	4.9	22.8	32.5	3.0	58.5	14.8
T_1R_3	5.0	23.0	51.8	3.2	73.0	15.8
T_4R_1	4.8	24.5	31.3	3.7	66.0	15.3
T_4R_2	4.7	25.5	22.8	3.6	65.0	15.0
T_4R_3	4.7	23.5	19.5	3.0	58.3	13.8
T_4R_4	4.7	23.0	20.8	2.8	63.5	15.3
Mean	4.9	23.8	30.1	3.3	63.2	15.2
SD	0.16	1.35	10.53	0.50	4.91	0.68
CV (%)	3.3	5.7	34.9	14.8	7.8	4.5

$\rho = 1.374$ $g.cm^{-3}$.

3.4. Soil chemical characteristics

Some soil chemical characteristics of part of the transect (points 45 to 60), corresponding to the labelled treatments T_1 and T_4, of samples collected before planting (October 1997) are presented in Table IV (pH in $CaCl_2$, OM, P, K, Ca and Mg). The analysis of these data indicated that the chosen area is relatively isotropic for crop production. There were no significant differences between replicates.

3.5. Nitrogen and soil organic matter

3.5.1. Materials and methods

For each replicate, composite soil samples were taken at depths of 0 to 0.15, 0.15 to 0.30, and 0.30 to 0.50 m for determinationsof total N (TN), ^{15}N, and soil organic carbon (SOC). By means of successive dry and wet sievings, at 2,000, 200 and 50 µm, of air-dry soil samples (<2mm), the following soil fractions (SFs) were obtained: 1, light SF_1, floating in water (200–2,000 µm), with coarse crop residues; 2, heavy SF_2 (200–2,000 µm), mineral fraction related to sand particles; 3, SF_3 (50–200 µm), organo-mineral fraction with plant residues at different stages of decomposition associated with fine sand particles; 4, heavy SF_4 (0–50 µm), organo-mineral fraction with humidified plant materials associated with clay and silt-sized particles and clay (precipitated by centrifugation); 5, solution SF_5 (0–50 µm), organo-mineral fraction that remain suspended in water after centrifugation. Non-fractionated samples were also used for SOC determination, to check the efficiency of the fractionation procedure.

In plants, composite (twelve sub-samples) leaf 3^+ samples per replicate were collected in February, May, and October 1998 for ^{15}N analysis. At the last date (harvest time), crop yields were determined measuring the number of canes, weight of canes, and weight of straw and tips (trash). After drying at 65°C the fresh weights were transformed into dry-matter (DM) yield data. Total N and ^{15}N enrichment values were measured with a mass spectrometer (ANCA–SL, Europe Scientific, Crewe, UK).

Nitrogen derived from fertilizer (Ndff), for any compartment[1] in the system was calculated from:

$$Ndff = \frac{atom\ \%^{15}N\ excess\ of\ compartment}{atom\ \%^{15}N\ excess\ of\ fertilizer} \tag{5}$$

Total amounts of N in any compartment of the plant or soil of the system, derived from fertilizer or residue (TNdff, kg ha^{-1}), were calculated according to:

$$\mathrm{TNdff} = \mathrm{Ndff}\,.(\mathrm{DMyield\ of\ compartment}).(\mathrm{total\ \ N\ content\ of\ compartment}, \%)/100 \tag{6}$$

where DM is expressed in kg ha^{-1}.

Leached N was estimated measuring the concentration (C_N) of total N, and the enrichment in ^{15}N of the soil solution, using porous-cup extractors, one per replicate, installed at the depth of 1.0 m. The total amount of leached N, Q_N (kg ha^{-1}), was estimated as follows:

$$Q_N = \int_{ti}^{tf} q_W . C_N . dt \tag{7}$$

where

t	is the time, and
q_w	is the soil water flux density at z=1.0 m, estimated from Darcy´s equation.

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[1]Compartment: plant [stalk, tip and straw]; soil [SF_1, SF_2, SF_3, SF_4, SF_5]; Losses and Nitrogen in Other Compartments [LNOC].

The hydraulic conductivity of the soil was measured at the field site [8]. With the ^{15}N enrichment of the soil solution, Q_N values were transformed into leached N derived from fertilizer, using Eqq. (5) and (6).

4. RESULTS AND DISCUSSION

Figure 11 shows the values of ^{15}N atom % excess, measured for leaf 3^+, for the part of the transect that received labelled fertilizer in October 1997, on 10 February 1998, 13 May 1998, and on 15 October 1998 (harvest time). These data indicate the rate of fertilizer N uptake during the first year of the sugarcane crop, and also the data variability. In terms of means, Fig. 12 shows the evolution of the ^{15}N label in leaf 3^+ for the 3 years 1997–1998, 1998–1999, and 1999–2000 for all treatments. For the first year the fertilizer-N uptake increased up to May, and, thereafter, the increasing uptake of soil N decreased ^{15}N enrichment in the leaves. For the subsequent years, the label became distributed in the various compartments, and decreased steadily, being still readily measurable in the third year (2000). Treatment T_2 received the labelled straw of T_1, with an enrichment of 11.7% a.e. ^{15}N, and therefore, the evolution of the label in leaf 3^+ of T_2 was a measure of the cane uptake of mineralized N coming from T_1 trash (straw and tips).

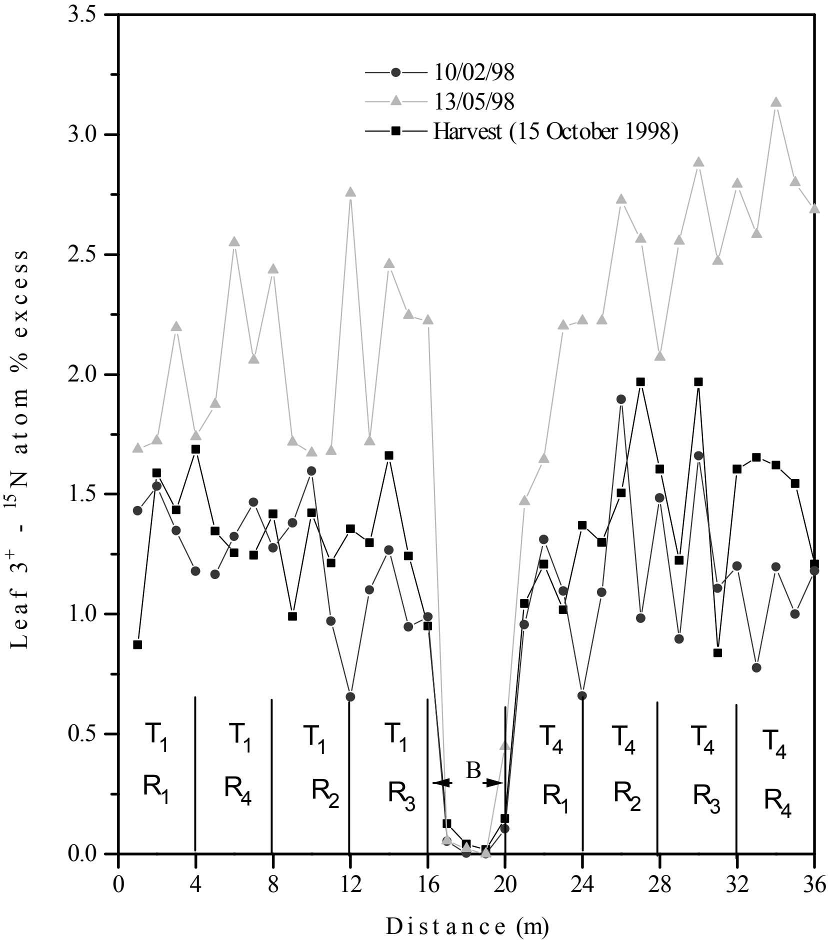

FIG. 11. Distribution of ^{15}N atom % excess in leaf 3^+ for three dates in 1998, covering the labelled part of the transect, which includes treatments T_1 and T_4.

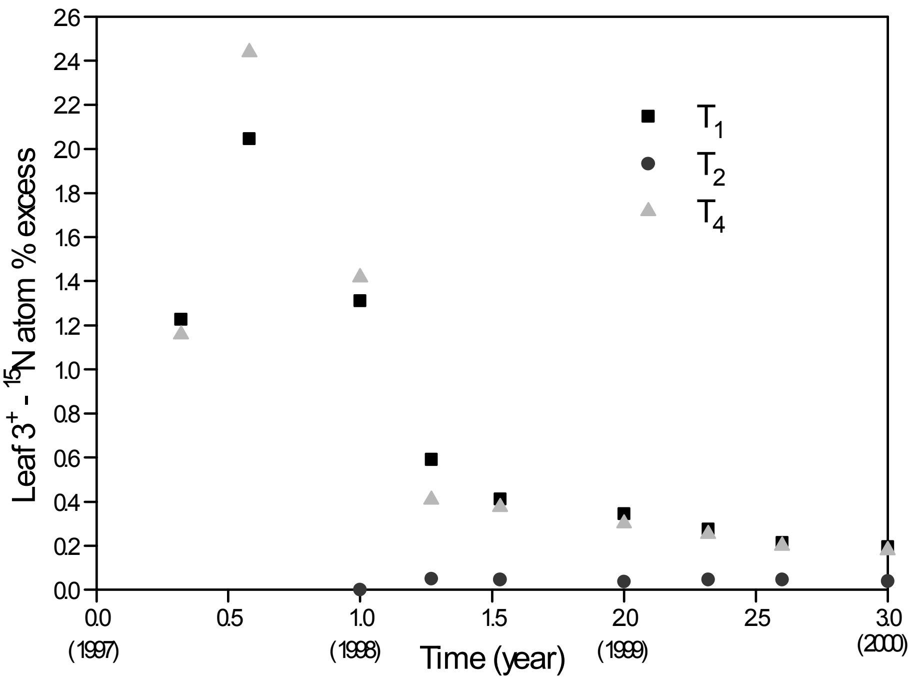

FIG. 12. Evolution of the ^{15}N label in leaf 3^+ samples for the period October 1997 to October 2000.

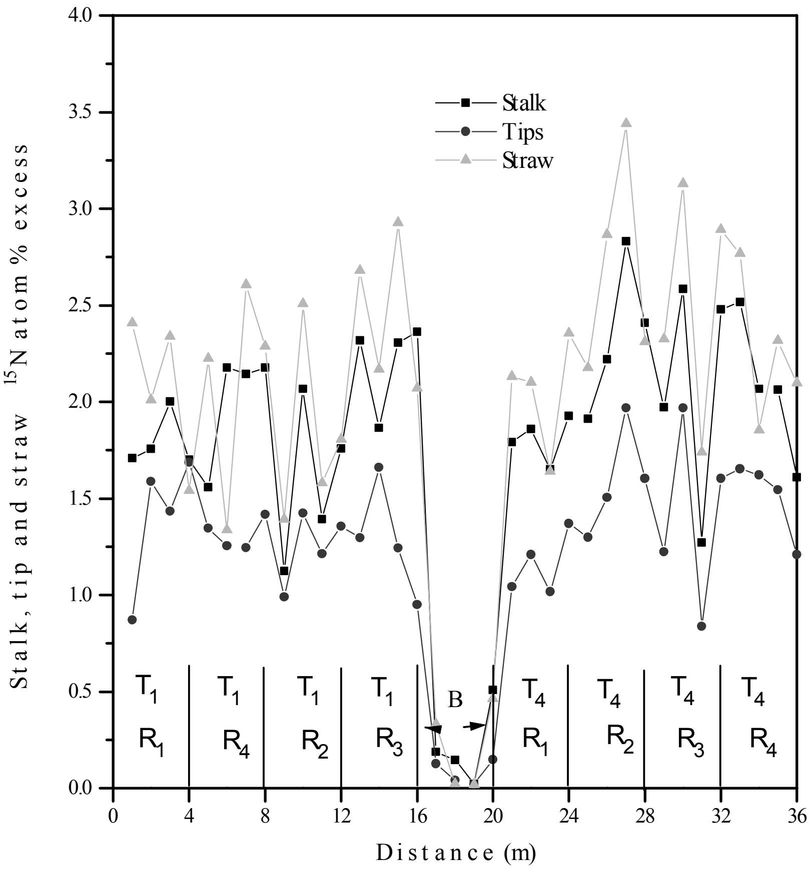

FIG. 13. Distribution of ^{15}N enrichment in stalk, tip (leaf 3^+) and straw at the October 1998 harvest.

Figure 13 gives an overview of the label distribution at the first harvest (October 1998), in the three chosen plant compartments (stalk, tip and straw) along the labelled part of the transect. Table V presents the overall N balance at the first harvest, taking into account soil and plant compartments. Soil fractionation data presented high coefficients of variation, mainly in the case of the mineral fraction SF_2, which was negligible in terms of amounts of total N. Plant-N variability was, in general, less than soil-N variability. It is important to note that the soil used in this experiment is very rich in N, presenting, on average, 7,667 kg ha^{-1}. Soil fertilization with N is, however, very important even at the relatively low rate of 63 kg N ha^{-1}, since it results in improved growth. Table VI presents the balance of the N derived from fertilizer (Ndff) at the first harvest (October 1998), showing the distribution of the ^{15}N-labelled fertilizer (63 kg ha^{-1}) applied at the beginning of the experiment (October 1997).

Table V. Distribution of total N content in all measured compartments, after 1 year, in October 1998

Compartment		T_1				T_4				Mean	SD	CV (%)
		R_1	R_2	R_3	R_4	R_1	R_2	R_3	R_4			
		(kg N ha^{-1})										
Soil	SF_1	89	40	88	65	74	52	79	63	68.8	17.2	25
(0–0.5 m)	SF_2	9	15	39	6	20	4	0	12	13.1	12.1	93
	SF_3	1,593	1,565	1,681	1,216	1,575	1,343	1,084	1,272	1,416	215.6	15
	SF_4	6,286	4,212	4,270	5,307	4,549	4,262	4,867	4,215	4,746	734	16
	SF_5	921	2,102	1,446	1,968	1,328	1,391	1,018	1,208	1,423	419	30
Soil total		8,898	7,934	7,524	8,562	7,546	7,052	7,048	6,770	7,667	755	9.8
Plant	Stalk	144	118	149	131	125	146	104	117	129	16.2	13
(Shoot)	Tip	79	77	75	80	77	74	73	69	75.4	3.5	4.7
	Straw	51	52	47	48	42	44	42	43	46.2	4.2	9.2
Plant total		274	247	271	259	244	264	219	229	251	20.0	8.0

Table VI. Distribution of the N derived from fertilizer in all measured compartments, after 1 year, October 1998

Compartment		T_1				T_4				Mean	SD	CV (%)
		R_1	R_2	R_3	R_4	R_1	R_2	R_3	R_4			
		(kg ha^{-1})										
Soil	SF_1	1.6	0.5	1.1	1.5	0.6	0.6	0.7	1.1	0.9	0.4	44
(0–0.50 m)	SF_2	0	0	0	0	0	0	0	0	0.0	0.0	0.0
	SF_3	1.7	1.3	1.5	1.3	1.2	1.1	0.9	1.4	1.3	0.2	19
	SF_4	5.0	3.4	4.0	4.8	3.5	3.4	3.6	4.2	4.0	0.6	16
	SF_5	0.6	1.7	1.3	1.5	0.7	1.0	0.5	0.9	1.0	0.4	41
Soil total (S)		8.9	6.9	7.9	9.1	6.0	6.0	5.7	7.6	7.2	1.3	18
Plant	Stalk	22.1	16.0	28.2	22.6	19.5	29.3	18.5	20.7	22.1	4.6	21
(Shoot)	Tip	9.4	8.2	8.2	9.0	7.6	10.0	8.8	8.9	8.8	0.8	8.6
	Straw	9.1	8.2	9.8	8.8	7.4	10.2	9	8.3	8.9	0.9	10
Plant total (P)		40.6	32.4	46.2	40.4	34.5	49.5	36.3	37.9	39.7	5.8	15
LNOC[a]		13.5	23.8	8.9	13.7	22.7	7.6	21.1	17.6	16.1	6.2	39

[a]Losses (denitrification, volatilization, leaching and erosion) and N in Other Compartments (0.5–1.0 m soil layer, rhizome, residual trash from last harvest, and other possible sinks), calculated as LNOC = F_N – (S + P).

To close the balance, Table VI provides the LNOC (Losses and Nitrogen in Other Compartments), which includes the losses (denitrification, volatilization, leaching and erosion), the 0.50- to 1.0-m soil layer, the rhizome, and the residual trash from the last harvest, which were not sampled.

Although not having sampled the rhizome completely, part of the N of the rhizome and of the root system are in the SF_1. This light organic fraction has, however, the least amount of ^{15}N, indicating that very little of the trash was incorporated by the soil at the 1998 harvest.

As expected, SF_2 did not present ^{15}N, since it is a mineral fraction constituted mostly of sand. The SF_3 and SF_5 fractions, the former related to sand particles and the latter to suspension, after centrifugation, presented similar amounts of ^{15}N, however about one third less than SF_4, related to clay and silt-sized particles precipitated by centrifugation. There are very few data in the literature, for tropical soils, that provide comparison with the soil-fraction data of Table VI.

Figure 14 presents the Ndff flow during the first 3 years of the experiment (1997–2000), for the mulched sugarcane treatments (T_1+T_2), showing N recovery. At this point, it is important to recall that at the harvest of 1998 the trash collected from T_1 and T_2 were interchanged, and that, in terms of amounts of Ndff or N recovery, the sum of both represents the mulched treatment.

Following the mass conservation principle, Fig. 14 presents the distribution of Ndff year after year, always summing up to the 63 kg ha^{-1} of labelled N applied to the crop in October 1997. “Exports” represent the Ndff of the stalks, used for sugar and alcohol production.

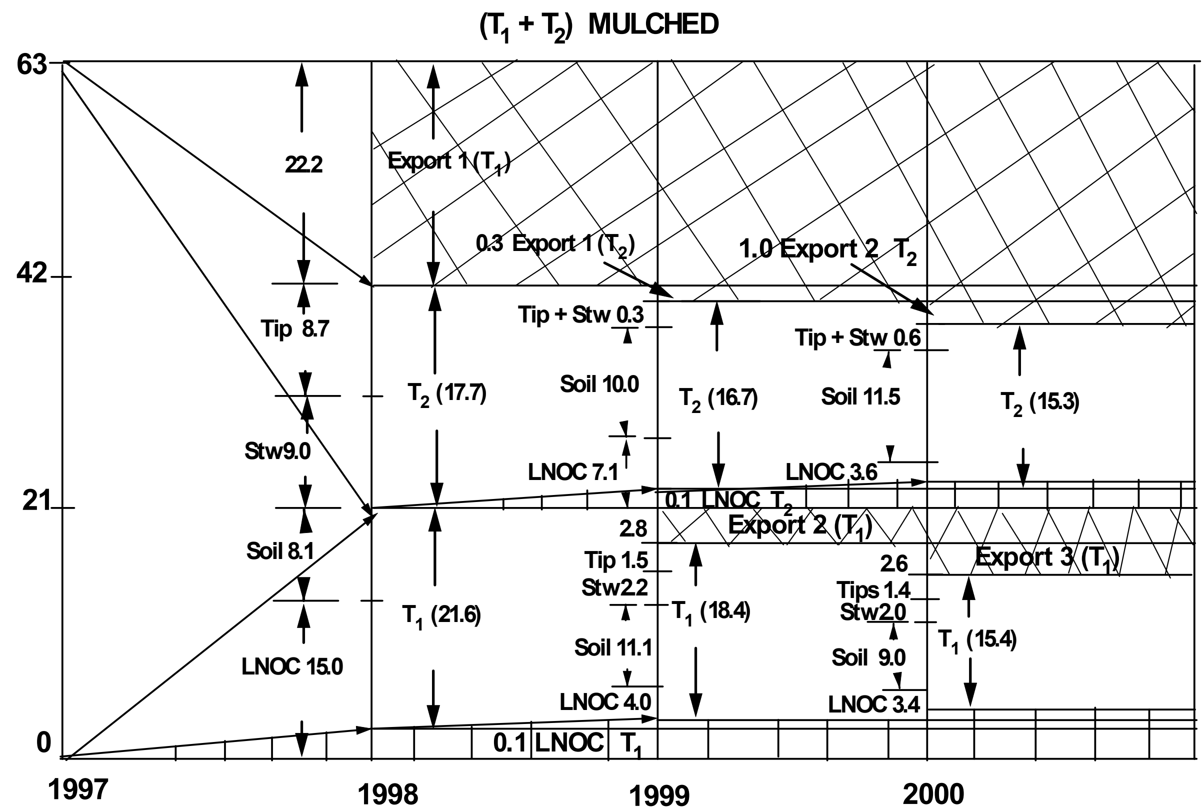

FIG. 14. Flow of N derived from fertilizer (Ndff) in different compartments for the mulched plots: T_1—^{15}N label in the soil; T_2—^{15}N label in trash.

As already defined, LNOC represents the amount of Ndff necessary to close the balance. Although the soil N content was 7.6 t ha^{-1} (Table V), it is mainly in immobile organic forms, since the amount of leached NO_3^- measured during the first year was very low, of the order of 1 kg N ha^{-1}, with negligible contribution of Ndff.

Other studies [9] carried out under similar conditions confirm the very low percentage of leached fertilizer. The 15.0 kg N ha^{-1} of the LNOC at the first harvest of 1998 consisted mostly of labelled N in the sugarcane rhizome, which was not quantified due to the crop's semi-perennial characteristics, thus retaining the labelled plots.

Ratoon sugarcane crops renew the rhizome yearly, the old one contributing to soil organic matter. Only a small part of the rhizome and root system N is included in the SF_1 fraction. As a result of rhizome renewal, the soil Ndff of T_1 increased from 1998 to 1999. Figure 14 also assumes that the lost part of LNOC Ndff was 10%. For T_2, the LNOC Ndff increased from 0 in 1998 to 7.1 kg ha^{-1} in 1999. Part of LNOC was the remainder of the labelled straw that came from T_1 in 1998, and the old rhizome, which absorbed part of the decomposed straw N. For treatment T_1, soil Ndff increased from 8.1 in 1998 to 11.1 in 1999. This increase could also be explained by rhizome decomposition.

Figure 15 is similar to 14, but presents data for the burned residues of treatment T_4, and it should be analyzed in a comparative way. Exports also represent Ndff of the stalks. During burning, the straw is completely carbonized and it is assumed that 100% is lost to the atmosphere. Tips having mainly green leaves are only partially burned. After harvest they are left on the ground, become drier due to insolation and, before sprouting of the ratoon crop, they are burned again. This second burning is not total, and partially burned tips are left on the ground. Therefore, the exported N in tips as a result of burning was assumed to be 50% (Fig. 15). Table VII presents details of the Ndff after 2 years, October 1999.

Table VII. Distribution of the N derived from fertilizer in all measured compartments, after 2 years, October 1999

Treatment		T_1					T_2					T_4				
Compartment		R_1	R_2	R_3	R_4	mean	R_1	R_2	R_3	R_4	mean	R_1	R_2	R_3	R_4	mean
Fertilizer (F_N)					21.6	21.6	17.7	17.7	17.7	17.7	17.7	26.2	26.2	26.2	26.2	26.2
							(kg N ha^{-1})									
Soil	SF_1	2.0	1.4	1.1	2.3	1.7	4.2	3.3	4.2	3.1	3.7	3.4	2.6	2.5	1.9	2.6
(0–0.5 m)	SF_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SF_3	2.6	2.5	2.0	2.9	2.5	1.3	2.2	1.4	2.6	1.9	3.3	3.8	4.0	2.3	3.4
	SF_4	6.0	5.3	6.2	4.5	5.5	3.1	3.2	2.7	3.3	3.1	7.7	9.4	8.7	6.7	8.1
	SF_5	1.7	1.8	1.0	1.2	1.4	0.7	2.0	1.8	0.9	1.4	2.7	1.8	1.8	1.3	1.9
Soil total (S)		12.3	11.0	10.3	10.9	11.1	9.3	10.7	10.1	9.9	10.1	17.1	17.6	17.0	12.2	16.0
Plant	Stalk	2.5	3.1	2.5	3.0	2.8	0.30	0.28	0.29	0.21	0.27	2.5	3.9	3.3	3.3	3.2
(Shoot)	Tip	1.4	1.6	1.6	1.6	1.5	0.16	0.19	0.13	0.10	0.14	1.3	1.3	0.95	1.3	1.2
	Straw	2.1	2.3	1.8	2.4	2.2	0.19	0.22	0.13	0.13	0.17	1.6	1.5	1.5	1.5	1.5
Plant total (P)		6.0	7.0	5.9	7.0	6.5	0.65	0.69	0.55	0.44	0.58	5.3	6.7	5.8	6.0	5.9
LNOC[a]		3.2	3.7	5.4	3.7	4.0	7.7	6.3	7.1	7.3	7.1	3.9	2.0	3.3	8.0	4.3

[a]Losses (denitrification, volatilization, leaching and erosion) and N in Other Compartments (0.5–1.0 m soil layer, rhizome, residual trash from last harvest, and other possible sinks). Calculated as LNOC = F_N – (S + P).

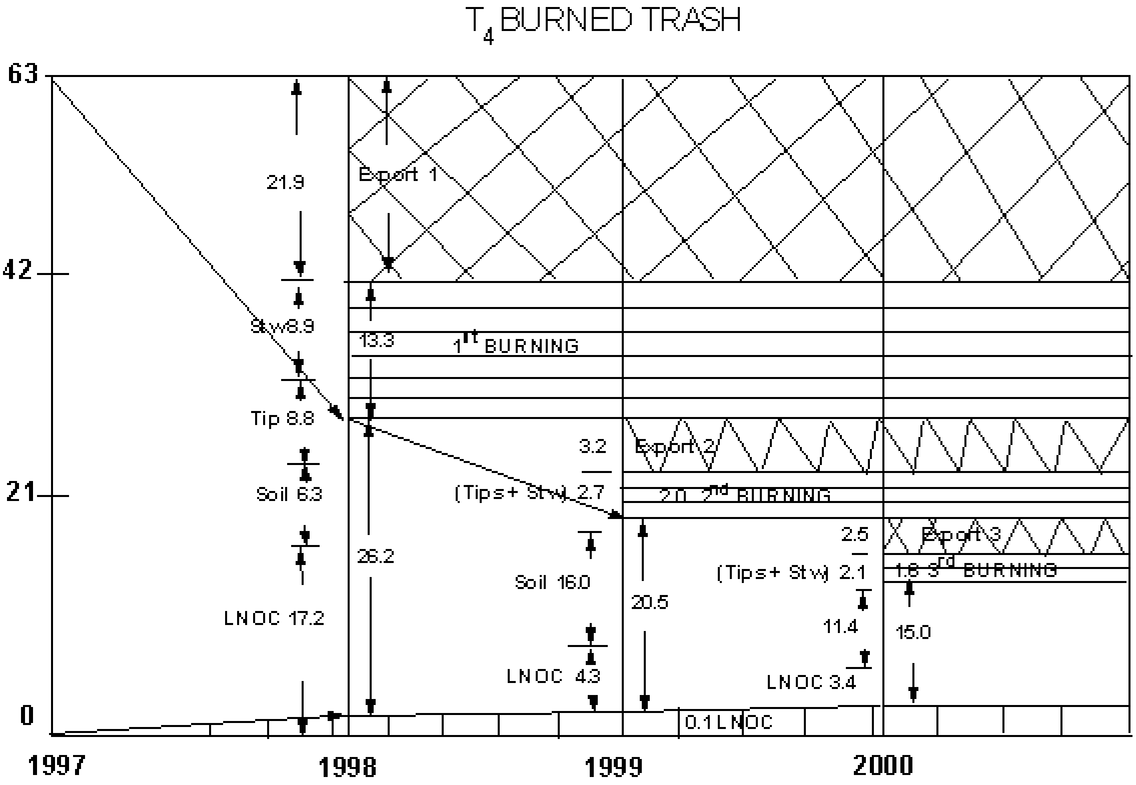

FIG. 15. Flow of N derived from fertilizer (Ndff) in different compartments for the burned trash treatment.

Table VIII. Evolution of exported and burned N derived from fertilizer for treatments T_1, T_2 and T_4, at harvests in 1998, 1999 and 2000

Harvest	T_1	T_2	(T_1+T_2)	T_4	Bur[a]	(T_4+Bur)
	(kg N ha^{-1})					
1998	22.2	0	22.2	21.9	13.3	35.2
1999	2.8	0.3	3.1	3.2	2.0	5.2
2000	2.6	1.0	3.6	2.5	1.6	4.1
			total: 28.9			total: 44.5

[a]Burned Ndff.

Table IX. Nitrogen derived from fertilizer available for sugarcane ratoon crops, immediately after harvests in 1998, 1999 and 2000,

Harvest	T_1	T_2	(T_1+T_2)	T_4
	(kg N ha^{-1})			
1998	21.6	17.7	39.9	26.2
1999	18.4	16.7	35.1	20.5
2000	15.4	15.3	30.7	15.0

Tables VIII and IX compare the traditional practice of trash burning before harvest (T_4) with the new management practice of leaving the trash on the soil surface as a mulch, in terms of N flow. During the 3 years of the experiment, the mulched plots had an export of Ndff equal to 28.9 kg ha^{-1}, whereas the burned plots lost 44.5 kg ha^{-1} of Ndff (export + burning), which was 53% more loss. As a consequence, the Ndff available for the ratoon crops was significantly higher for the mulched plots, as compared to the burned. However, this gain in Ndff did not affect sugarcane productivity, which was similar for non-burned (T_1+T_2) and burned T_4 treatments.

In relation to soil C, no significant differences were found between treatments since the period (2 years) of the study was too short. Yearly SOM measurements will be performed and it is expected that after 5 years differences between mulched and burned plots will be detected.

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