NITROGEN DYNAMICS IN A SOIL-SUGAR CANE SYSTEM

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ABSTRACT: Results of an organic matter management experiment of a sugar cane crop are reported for the first cropping year. Sugar cane was planted in October 1997, and labeled with a ^{15}N fertilizer pulse to study the fate of organic matter in the soil-plant system. A nitrogen balance is presented, partitioning the system in plant components (stalk, tip and straw), soil components (five soil organic matter fractions) and evaluating leaching losses. The ^{15}N label permitted to determine, at the end of the growing season, amounts of nitrogen derived from the fertilizer, present in the above mentioned compartments.
Key words: fertilizer, nitrogen, ^{15}N label, soil, sugar cane

DINÂMICA DO NITROGÊNIO EM UM SISTEMA SOLO-CANA-DE-AÇÚCAR

RESUMO: São apresentados resultados de um experimento sobre matéria orgânica em cultura de cana-de-açúcar, relativos ao primeiro ano (cana planta). A cultura foi instalada em outubro de 1997 e marcada com um pulso de fertilizante ^{15}N, para estudar o destino da matéria orgânica no sistema solo-planta. É apresentado um balanço de nitrogênio, subdividindo o sistema em componentes de planta (colmo, ponteiro e palha), componentes de solo (cinco frações de matéria orgânica do solo) e estimando perdas por lixiviação. O ^{15}N permitiu a determinação das quantidades de nitrogênio provenientes do fertilizante nos compartimentos acima mencionados, no final do ciclo da cultura.
Palavras-chave: fertilizante, nitrogênio, ^{15}N, solo, cana-de-açúcar

INTRODUCTION

Sugar cane is the most important crop for the sugar industry, Brazil having today 5 million hectares cultivated with this crop. The understanding of nitrogen dynamics in this soil-plant system will, therefore, contribute for the establishment and improvement of management practices, mainly now when the traditional practice of straw burning before harvest will be substituted by machine harvest, which leaves on the soil surface a considerable amount of trash, corresponding to an organic fertilization. Abramo Filho et al. (1993), Trivelin et al. (1995;1996) present a detailed study on sugar cane trash dry-matter and its nutrient content, specially in relation to nitrogen.

Sugar cane belongs to the family of the grasses, presents a sigmoid growth curve (Brzesowsky, 1986) with a pronounced phytomass production in response to nitrogen availability (Bolton & Brown, 1980), and being a C_4 cycle plant it presents twice as much dry matter per unit weight of leaf nitrogen, as compared to C_3 cycle plants (Black et al., 1978). Reports of Lima Júnior (1982);

Sampaio et al. (1984), and Bittencourt et al. (1986), indicate, however, that the potential of converting fertilizer N into phytomass is very variable and relatively low for the first crop cycle. This fact is attributed to non symbiotic nitrogen fixation (Döbereiner et al., 1972), soil N mineralization; plant residue mineralization, and the use of the nitrogen of the stalk that originated the new plant. Lima et al. (1987) and Urquiaga et al. (1992) report that sugar cane grown in Brazil receive, in general, low nitrogen rates, in the range 60 to 120 kg ha^{-1}, having stalk yields of 65 to 70 kg ha^{-1} of N , and the whole plant accumulates 100 to 120 kg ha^{-1} of N. This indicates that the non symbiotic nitrogen fixation might play an important role as a nitrogen source, since soils cultivated with sugar cane for long periods do not suffer significant yield reduction. Although gradual and slow, organic matter mineralization is of significant importance to the crop, since it is through this process that part of the needed nutrients reach the plant. Sampaio et al. (1995) evaluated the soil supply capacity and the fertilizer response of sugar cane, and concluded that the main N source for the crop is the native soil organic

matter and the maintenance of crop residues on the field.

This study has the intention to collaborate for a better understanding of the fate of a N fertilizer application, after one year, on a newly established sugar cane crop, in different soil and plant compartments, using the ^{15}N label, in a similar way as reported by Vanlauve et al. (1998).

MATERIAL AND METHODS

In a sugar cane field variety SP80-3280 medium/late of fifteen rows 40 m long, spaced 1.4 m, totalizing 924 m^2 (Rhodic Kandiudalf called "Terra Roxa Estruturada"), located in Piracicaba, São Paulo State, Brazil (22^0 42' S; 47^0 38' W), eight plots R_i were chosen along the three central cane rows, to apply the ^{15}N fertilizer pulse. Figure 1 presents a simplified scheme of the experimental arrangement, showing three central sugar cane rows, for ^{15}N labeling, which received ammonium sulfate with 11.7 % a.e. ^{15}N, at a N rate of 63 kg ha^{-1}, and 44.4 kg ha^{-1} of P and 83 kg ha^{-1} of K, all at planting (November 1997). These 8 plots, 4 m long each, represent replicates, since no treatment was tested. The rest of the field received the same fertilization, however, without label. At harvest (October 1998), the fate of this ^{15}N pulse was studied in several plant and soil compartments.

For each replicate, 3 composite soil samples were take at the depths 0-0.15; 0.15-0.3 and 0.3-0.5 m,

processed according to Anderson & Ingram (1993) and Feller (1978), for soil organic matter (SOM) fractionation. By means of successive dry and wet sievings at 2000, 200 and 50 μm, OM was separated in organic, mineral and organo-mineral fractions. Air dry soil samples (< 2 mm) were separated in five fractions by wet sieving: 1. light SOM$_1$, floating in water (200 – 2000 μm), essentially organic, mostly plant debris; 2. heavy SOM$_2$ (200 – 2000 μm) related to sand, and therefore considered mineral; 3. SOM$_3$ (50 – 200 μm) related to silt, considered organo-mineral; 4. heavy SOM$_4$ (0 – 50 μm) related to the clay precipitated by centrifugation, also organo-mineral; 5. solution SOM$_5$ (0 – 50 μm) also related to clay, remaining in solution after centrifugation, and also organo-mineral. Non fractionated samples were also used for SOM determination to check the efficiency of the procedure.

Plants were always sampled meter by meter, four composite samples per replicate, collecting leaf 3[+] samples for ^{15}N analysis, in February, May, and at harvest in October 1998, when crop yield was evaluated measuring the number of canes, weight of canes, weight of trash and weight of green leafs (cane tips). After drying at 65 °C the fresh weights were transformed into dry matter (DM) yield data. Total nitrogen and ^{15}N enrichment 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:

$$Ndff = \frac{(atom \ \%^{15}N excess \ of \ compartment)}{(atom \ \%^{15}N excess \ of \ fertilizer)} \qquad (1)$$

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

$$TNdff = Ndff \ . \ (DM yield \ of \ compartment) . (total \ N \ content \ of \ compartment, \%) / 100 \qquad (2)$$

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

Nitrogen leaching 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 was estimated as follows:

$$Q_N = \int_{ti}^{tf} q_w . C_N . dt \qquad (3)$$

Where t is the time in days and q_w is the soil water flux density at z=1.0 m, estimated from Darcy´s equation, in mm.day^{-1}. With the ^{15}N enrichment of the soil solution, Q_N values were transformed into leached nitrogen derived from fertilizer, using equations 1 and 2.

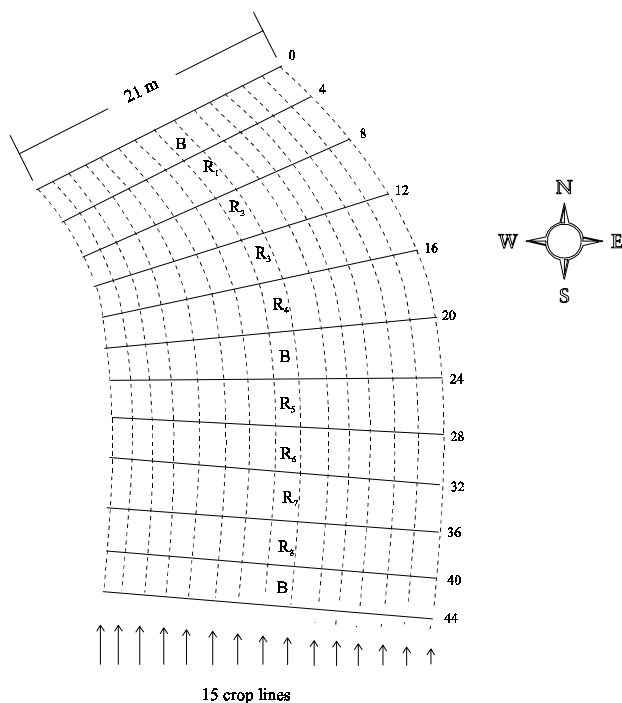Figure 1 - Experimental design, indicating the 8 plots (replicates) placed within the sugar cane field. R=replicates; B=border.

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[1]Compartment: plant stalk (cane), straw, tip, rhizome, root]; soil (SOM$_1$, SOM$_2$,.... SOM$_5$); fertilizer; leacheate; other losses. In the case of sugar cane, the sum of straw (old dry leaves) and tips (green leaves and apical gem) is called trash.

RESULTS AND DISCUSSION

Some chemical characteristics of the soil along the transect, for soil samples collected before planting (October 1997) are presented in TABLE 1 (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 was no significant difference between replicates.

Figure 2 shows the values of ^{15}N atom % excess, measured for leaf 3[+], for the 8 replicates, which received labeled fertilizer in October 1997, for three dates: 10 February 1998, 13 May 1998, and at harvest, 15 October 1998. This data give an idea about the rate of fertilizer N uptake, during the first year of the sugar cane crop, and also of the variability of the data. In terms of average, Figure 3 shows the evolution of the ^{15}N label in the plant during the first year. It can be seen that the uptake of

fertilizer N increased up to May, and that, thereafter, the increasingly uptake of soil N decreased the ^{15}N content in the leafs.

At harvest (October 1998) plant and soil were sampled in more detail. Figure 4 gives an overview of the label distribution in the three chosen plant compartments [stalk, tip and straw] along the eight replicates. TABLE 2 presents the overall N balance, in kg ha^{-1} of N, taking into account soil and plant compartments. Soil fractionation data present high coefficients of variation (CV), mainly in the case of the mineral fraction SOM_2. Plant N variability was, in general, smaller than soil N variability. It is important to note that the soil used in this experiment is very rich in N, presenting on the average 7660 kg ha^{-1}. Soil fertilization with N is, however, very important even at the relatively low fertilization rate of 63 kg ha^{-1}, since the crop does respond to these applications (Lima et al., 1987).
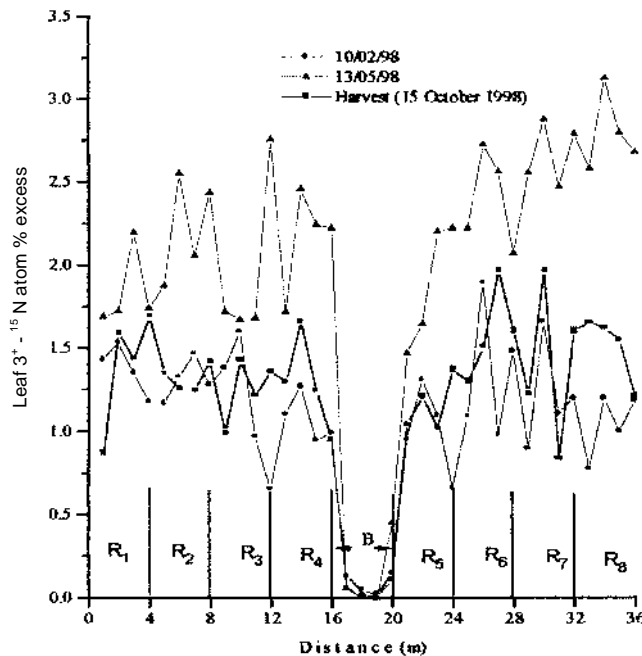

Figure 2 - Distribution of ^{15}N atom % excess in leaf 3[+] for strips 3 and 4 during 1998.
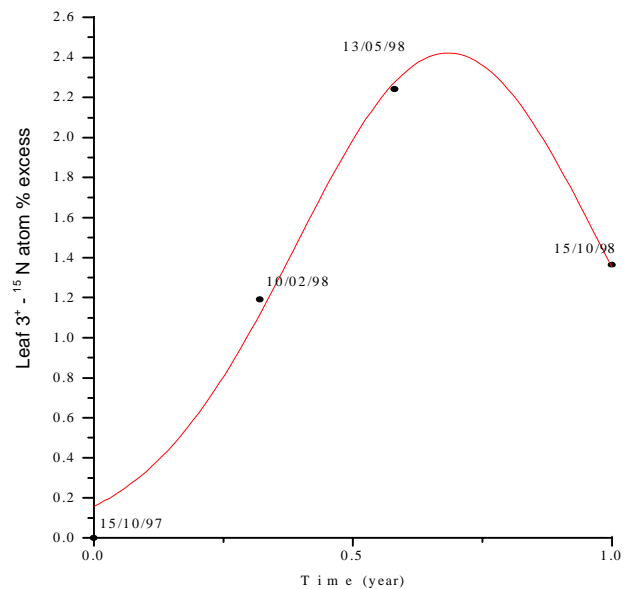

Figure 3 - Average evolution of ^{15}N atom % in leaf 3[+] during the first cropping year. Time zero= planting, time 1= harvest.

TABLE 1 - Soil (Rhodic Kandiudalf) chemical characteristics of the sugar cane field.

Replicate	pH in $CaCl_2$	OM	P	K	Ca	Mg
		g dm^{-3}	mg dm^{-3}	----------------------------mmol$_c$ dm[-3] -------------------------		
1	5.1	26.0	35.8	4.3	59.5	15.8
2	5.0	22.3	26.5	3.1	62.0	15.8
3	4.9	22.8	32.5	3.0	58.5	14.8
4	5.0	23.0	51.8	3.2	73.0	15.8
5	4.8	24.5	31.3	3.7	66.0	15.3
6	4.7	25.5	22.8	3.6	65.0	15.0
7	4.7	23.5	19.5	3.0	58.3	13.8
8	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

TABLE 3 presents the balance of the labeled nitrogen, applied at the rate of 63 kg ha^{-1} with a ^{15}N enrichment of 11.7 atom % excess. This is a commonly applied N rate for this type of soil. Due to all variabilities which contribute in the calculation of these final values of Ndff, in three of the eight replicates we found more than 63 kg ha^{-1} of N in plant and soil (R_3, R_4 and R_6). On the average, however, the balance seems reasonable. The line NOC (TABLE 3) represents the amounts of N needed to close the balance. NOC includes also the 50-100 cm soil layer and the rhizome, which were not sampled. However, part of the N of the rhizome and of the root system are in the SOM_i (SOM_4 >SOM_5 >SOM_3 >SOM_1) fractions. The light organic fraction SOM_1 presents the least amount of

[15]N, indicating that very little of the fresh organic matter was present in the soil after harvest. SOM_2 did not present ^{15}N, as expected since it is constituted mostly of sand. SOM_3 and SOM_5, the first related to silt and the second to solution after clay centrifugation, present similar amounts of ^{15}N, however about one third less than SOM_4, related to the clay precipitated by centrifugation. There is very little data in the literature, for tropical soils, to be compared with the SOM_i data of TABLE 3. Feller & Beare (1997) discuss some of these, and state that the "organo-clay complex" that corresponds to SOM_5, has a predominance of amorphous OM, which acts cementing the clay matrix, being, therefore, a very strongly bound form of OM.

TABLE 2 - Distribution of total nitrogen content in all compartments, for the first year (October 1997 – October 1998).

Compartment		R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	mean	SD	CV %
Fertilizer		63	63	63	63	63	63	63	63	63		
		---------------------------------- kg ha^{-1} ----------------------------------										
	SOM_1	89	40	88	65	74	52	79	63	68.8	17.2	25.0
Soil	SOM_2	9	15	39	6	20	4	0	12	13.1	12.2	93.1
(0 - 0.5 m)	SOM_3	1592	1565	1680	1216	1575	1343	1084	1272	1415.9	215.3	15.2
	SOM_4	6241	4211	4269	5306	4549	4261	4866	4215	4739.8	720.4	15.2
	SOM_5	921	2101	1446	1968	1328	1390	1018	1208	1422.5	419.1	29.5
Total		8855	7932	7522	8561	7546	7050	7047	6770	7660.4	745.1	9.7
	Stalk	144	119	151	133	126	148	105	119	130.6	16.3	12.4
Plant	Tip	79	77	75	80	77	74	73	69	75.5	3.5	4.7
(Shoot)	Straw	51	52	47	48	42	44	42	43	46.1	4.0	8.6
Total		274	248	273	261	245	266	220	231	252.3	19.8	7.8
Leached (100cm)		1	1	1	1	1	1	1	1	1	0	0

TABLE 3 - Distribution of the nitrogen derived from fertilizer in all compartments, for the first year (October 1997 - October 1998).

Compartment		R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	overall mean	SD	CV %
Fertilizer (FN)		63	63	63	63	63	63	63	63	63	0	0
		---------------------------- kg ha^{-1} ----------------------------										
	SOM_1	2.4	1.4	3	4	1.7	1.6	2	2.9	2.4	0.9	37.2
Soil	SOM_2	0	0	0	0	0	0	0	0	0.0	0.0	0.0
(0 - 0.5 m)	SOM_3	2.8	3.6	4.1	4.8	3.4	3	2.5	3.9	3.5	0.8	21.4
	SOM_4	10.9	9.5	11.2	18.1	9.6	9.4	10	11.6	11.3	2.9	25.5
	SOM_5	3.4	4.6	3.5	5.9	2	2.6	1.5	2.4	3.2	1.4	44.8
Total (S)		19.5	19.1	21.8	32.8	16.7	16.6	16	20.8	20.4	5.4	26.6
	Stalk	22.1	16.1	28.6	22.8	19.5	29.6	18.7	20.9	22.3	4.7	21.1
Plant	Tip	9.4	8.2	8.2	9	7.6	10	8.8	8.9	8.8	0.8	8.6
(Shoot)	Straw	9.1	8.2	9.8	8.8	7.4	10.2	9	8.3	8.9	0.9	10.1
Total (P)		40.6	32.5	46.6	40.6	34.5	49.8	36.5	38.1	39.9	5.9	14.8
NOCa		2.9	11.4	-5.4	-10.3	11.8	-3.4	10.5	4.1	2.7	8.4	310.9
Leached (100 cm)		0	0	0	0	0	0	0	0	0	0	0

[a]NOC: Nitrogen in other compartments: soil (50-100 cm); part of rhizome; other losses. This line was used to close the balance according to: NOC = F_N – (S + P)
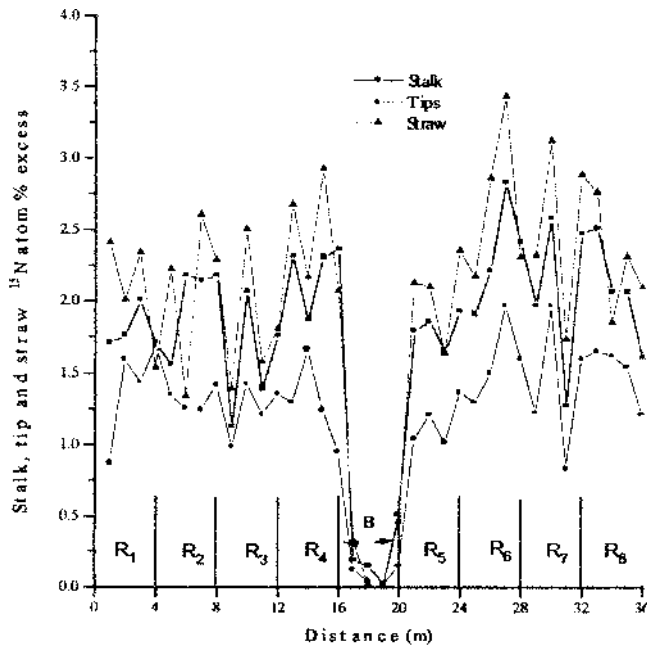
Figura 4 - Distribution of ^{15}N enrichment in stalk, tip (leaf 3$^+$) and straw at harvest (October 1998).

Figure 5 - Schematic average N balance at harvest (October 1998). Numbers without bracketts correspond to total N and numbers between brackets to N derived from fertilizer. *SOM*: *soil organic matter*
NOC: soil (50-100 cm) + part of rhizome + other losses

Figure 5 gives an average overview of the distribution of the nitrogen in the sampled compartments. The cane shoot presents 252.3 kg ha^{-1}, of which 39.9 are derived from the applied fertilizer, and 212.4 come from the soil, and possibly from non-symbiotic nitrogen fixation, as suggested by Urquiaga et al. (1992). The soil pool is large, corresponding to 7660.4 kg ha^{-1}, of which 20.4 were added through fertilization. This addition corresponds to 0.27%, which after one year (at harvest) presented a very low enrichment of 0.038 atom excess ^{15}N, making it more difficult to follow its fate for the next cropping season. As already said, the soil fractionation in five compartments indicates that most of the soil N derived from the fertilizer is in the fraction SOM$_4$ (11.3 kg ha^{-1}) that is the fraction obtained by wet seaving in the range 0 to 50 μm. Fraction SOM$_1$ (2.4 kg ha^{-1}), the floating fraction in the range 200 to 2000 μm, is not so expressive as it should be, since it includes fresh organic matter, mainly from roots and rhizome. It presented, however, the highest ^{15}N enrichment of all fractions: 0.443 atom excess.

The efficiency of the plant in using fertilizer N was extremely high, of the order of 60%. According to Trivelin et al. (1996) the efficiency seldomly overcomes 40%. Our high efficiency is due to the form of application, which was in solution, well distributed at the base of each row meter, when plants were sprouting and, therefore, with a significantly well developed root system. One day after label application the crop received a rain of 13.5 mm, which helped its homogenization, absorption, and was not sufficient to leach N to greater depths.

Nitrogen in other not measured compartments NOC, shown in TABLE 3, had a very low mean, not significantly different from zero, and presented, therefore,
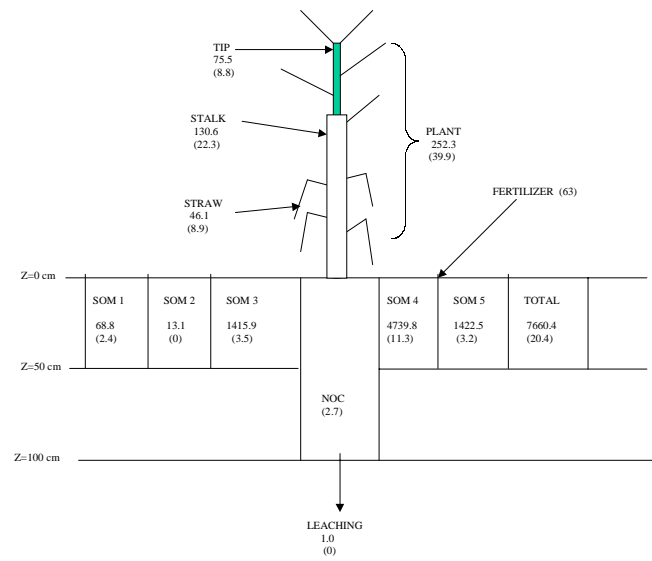
an extremely high CV, which has no scientific meaning. It is a result of the variabilities of the N data in all other measured compartments. Leaching was not measurable, which is also an exception since in many other situations it can reach values of the order of 15 kg ha^{-1} of total soil N, with little contribution from the fertilizer (3.0 kg ha^{-1}), as reported by Reichardt et al., (1982).

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