Leaching of nitrogen, potassium, calcium and magnesium in a sandy soil cultivated with sugarcane[1]

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Abstract – A lysimeter experiment was carried out with sugarcane aiming to evaluate the leaching of nitrogen derived from either urea (^{15}N) or the soil/sugarcane crop residues. The leaching of K^+, Ca^{2+}, and Mg^{2+} was also evaluated. The experiment was a factorial 2x4. The influencing factors were: firstly, the differential addition of two kinds of sugarcane remains to the soil, simulating conditions of cane-plantation renewal after the cane crop harvest, with and without previous straw removal by burning; secondly, four doses of N: 0, 30, 60, and 90 kg ha^{-1}. During the experimental period the total volume of water received by the sugarcane-soil system was 2,015 mm, with 1,255 mm as precipitation and 760 mm as irrigation. The loss of N by leaching from the fertilizer (^{15}N) was not detected. In the first three weeks the largest losses of N by leaching occurred, originating from the soil/sugarcane remains-N. The mean of leached N during the experimental period of 11 months was of 4.5 kg ha^{-1}. The mean losses of K^+, Ca^{2+}, and Mg^{2+} were of 13, 320 and 80 kg ha^{-1}, respectively.

Index terms: fertilizers, mineral nutrients, soil transport processes, lysimeters.

Lixiviação de nitrogênio, potássio, cálcio e magnésio em solo arenoso cultivado com cana-de-açúcar

Resumo – Realizou-se um experimento em lisímetro cultivado com cana-de-açúcar para avaliar a lixiviação do N, oriundo da uréia (^{15}N) ou do solo e de restos culturais, bem como do K^+, Ca^{2+}e Mg^{2+}. O experimento foi um fatorial 2x4. Os fatores foram: 1) adição diferenciada de dois tipos de restos culturais ao solo, simulando condições de reforma de canavial após a colheita da cana, com ou sem prévia despalha a fogo; 2) quatro doses de N: 0, 30, 60 e 90 kg ha^{-1}. Durante o período experimental o volume total de água recebido pela cultura foi de 2.015 mm, sendo 1.255 mm de precipitações e 760 mm de irrigações. Não foi verificada perda por lixiviação do N derivado do fertilizante (^{15}N). Nas três primeiras semanas ocorreram as maiores perdas de N por lixiviação que foram provenientes do solo ou dos restos culturais. O valor médio do N lixiviado durante o período experimental de 11 meses foi de 4,5 kg ha^{-1}. Os valores médios de perdas de K^+, Ca^{2+} e Mg^{2+} foram de 13, 320 e 80 kg ha^{-1}, respectivamente.

Termos para indexação: adubos, nutrientes minerais, processos de transporte no solo, lisímetro.

Introduction

The leaching of plant nutrients from agroecosystems is influenced by pedoclimatic and soil-plant system management factors. The following factors have been reported to affect the rate and the total mass of leached ions: soil texture and the cationic and anionic exchange capacity of the soil; the total amount and the rate of rainfall, which influences the soil hydric conditions and the volume of drained soil solution (Salcedo et al., 1988); the dose and the kind of the

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fertilizer (Camargo, 1989); the solubility of the salts and the affinity of their ions for the adsorption sites in the soil; the presence of accompanying ions; the chemical composition of the crop residues incorporated into the soil and microclimatic factors (soil temperature, moisture and aeration), which increase or decrease the mineralization of this new soil organic matter. The intensity with which the nutrients are removed from the soil solution, taken up by the plant roots or immobilized by microorganisms also influences percolation rates and leaching (Ng Kee Kwong & Deville, 1984; Orlando Filho et al., 1995).

Extraction of the soil solution by means of porous capsules is the method most used in field studies on nutrient leaching (Padovese, 1988; Camargo, 1989; Orlando Filho et al., 1995). However, the collection of percolated solution from laboratory soil columns (Maria et al., 1993; Bittencourt et al., 1996) and from cultivated lysimeters (Ng Kee Kwong & Deville, 1984; Coelho et al., 1991; Wong et al., 1992; Southwick et al., 1995) have also been used.

Ward et al. (1994) discussed some limitations of soil solution extraction with porous capsules, and Hansen & Harris (1975) considered that, in many cases, the number of samplings with porous capsules was insufficient. In lysimeters, the natural structure of the soil is modified if the soil material is disturbed during the collection and the reconstruction of the soil profile, which influences the drainage and the solutes percolation. On the other hand, this method avoids problems with sampling, because the volume of percolated solution and the nutrient content allow quantification of leaching losses with greater accuracy (Ng Kee Kwong & Deville, 1984).

The use of isotope techniques allows the quantification of the movement and the leaching of nutrients derived from the fertilizer, the soil or plant residues. Nitrogenous fertilizers enriched with the isotope ^{15}N have been frequently used in studies on nitrogen leaching (Takahashi, 1968; Ng Kee Kwong & Deville, 1984; Padovese, 1988; Salcedo et al., 1988; Camargo, 1989; Coelho et al., 1991).

The present work evaluated, in lysimeters, the leaching of ^{15}N, K^+, Ca^{2+}, and Mg^{2+} in a sandy soil cultivated with sugarcane.

Material and Methods

The experiment was carried out in lysimeters and the treatments, corresponding to a 2x4 factorial, were distributed into random blocks, with three replications. The factors were: 1) differential addition of two kinds of sugarcane residues to the soil, simulating conditions of cane-plantation renewal after cane crop harvest, with and without previous straw removal by burning; 2) four doses of N: 0, 30, 60, and 90 kg ha^{-1} of N. In the treatment that simulated cane-plantation renewal, without the removal of straw by burning before harvesting, deceased leaves (4.0 g kg^{-1} of N), tops and stalks (7.8 g kg^{-1} of N) and rhizomes (5.7 g kg^{-1} of N) as sugarcane residues, were incorporated into the soil at a dry matter weight equivalent to 7.0, 8.2 and 10 t ha^{-1}, respectively. Those amounts of sugarcane remains were defined based on the results of Camargo (1989) and Trivelin et al. (1995). In the second treatment, the plant residues were added to the soil in the amounts specified in the first treatment, with the exclusion of the deceased leaves in an attempt to simulate the condition of cane-plantation renewing with straw removal by burning before the previous crop harvesting. All the sugarcane residues were triturated grossly to simulate what occurs with the plant remains during field tillage.

The chemical and physical analyses of the soil used for construction of lysimeters were: pH in $CaCl_2$, 4.4; 19 g kg^{-1} of O.M.; 10 mg dm^{-3} of P; 44.1 mg dm^{-3} of S-SO_4^{2-}; 0.12 $mmol_c$ dm^{-3} of K^+; 1.7 $mmol_c$ dm^{-3} of Ca^{2+}; 0.3 $mmol_c$ dm^{-3} of Mg^{2+}; 0.4 $mmol_c$ dm^{-3} of Al^{3+}; 3.4 $mmol_c$ dm^{-3} of $H^+ + Al^{3+}$; 38% of V; 30 g kg^{-1} of very coarse sand; 90 g kg^{-1} of coarse sand; 270 g kg^{-1} of medium sand; 390 g kg^{-1} of fine sandy; 60 g kg^{-1} of very fine sandy; 840 g kg^{-1} of sand total; 60 g kg^{-1} of silt; 100 g kg^{-1} of clay; textural class: sandy.

Before the collection of the soil in the field, the remaining straw from the previous cane crop was removed from the soil surface and the rhizomes of the sugarcane ratoon removed from the underlying soil, in this way avoiding the mixture of the plant residues with the soil.

In the construction of the lysimeters, 220 L cylindrical plastic drums were used, 60 cm in diameter and 90 cm high. Each lysimeter had a drain at the bottom, consisting of a 10 cm layer of stone fragments (9 mm diameter), covered with a Bidim blanket. The solution that percolated through the soil was recovered by means of a PVC tube (5 mm diameter), below the drain.

The plant residues as well as CaO and MgO were added to the superficial layer of the lysimeter soils at a 2:1 relation, respectively, and at sufficient amounts to raise the soil basis saturation to 60%. Plant residues, CaO and MgO were well mixed with soil.

Ten days after pH correction and the addition of the plant remains to the soil, three plantlets of sugarcane, variety SP 80 1842, approximately 20 cm tall, were planted into each lysimeter. Before planting, the fertilizers were applied to a 15 cm deep hole in the center of the lysimeters. Urea containing 10.10 atom % of ^{15}N was applied in doses of 0, 30, 60, and 90 kg ha^{-1} of nitrogem. Potassium chloride and the triple superphosphate were applied in doses of 120 kg ha^{-1} of each of the respective oxides.

During the experimental period, January 8 to December 9, the total volume of water received by the culture was of 2,015 mm, being 1,255 mm by rainfall and 760 mm by irrigation.

Whenever the soil solution reached the drain, the collection was performed by determining its mass, while in a subsample the following contents of mineral N were also quantified: nitrate and ammonium (Keeney & Nelson, 1982), K^+, Ca^{2+}, Mg^{2+} (Zagatto et al., 1981).These values were used to calculate each nutrient mass contained in the drained solution, for each collection. The total mass nutrients drawn through by percolation over the experimental period was the sum of each nutrient mass, for each lysimeter.

In the first collections of the drained soil solution, calorimetric determination of urea with sensitivity of 20 mg kg^{-1} was performed, using the method of Bremner (1982). When the mass of mineral ($N\text{-}NO_3^-$ and $N\text{-} NH_4^+$), determined in a 100 mL aliquot was greater than 0.3 mg, the detection limit of the ATLAS MAT-CH4 mass spectrometer used for isotope analysis of N, the abundance of ^{15}N was determined in order to evaluate the leaching of the urea -^{15}N.

The total masses of the leached nutrients for each of the treatments were submitted to variance analysis and the averages compared by the Tukey test at 5% level of probability.

Results and Discussion

During the experimental period, 19 collections of the drained solution were carried out, 12 of them in the period from January to March and the others from September to December. For the entire experimental period, the mean value of the drained solution per lysimeter was 357 ± 22 mm (mean ± standard error of the mean).

During the first 90 days of the experiment (from January to March), the accumulated rainfall reached 542 mm, that is, 43% of the total rainfall registered from January to December 1996. Due to high frequency and low intensity of the rainfall over this period, the solution mass that percolated through soil and reached the drain represented only 37% of the total mass collected throughout the experimental period. On the other hand, the precipitation occurring from September to the beginning of December, although not very frequent, was intense and reached 615 mm which represents 49% of the total rainfall, so causing a non-proportional increase in the mass of the drained solution, that is, 63% of the total mass.

In the first 48 hours after fertilization, urea was not detected in the leached solution. During this period, the rains totaled 36 mm, resulting in 13 mm, a mean value, for the drained solution in the lysimeters. This drainage volume was due to the high moisture of the soil on the day of fertilization. Wang & Alva (1996) applied slow release urea, coated urea, onto 1.3 m columns containing a device to prevent the facilitated displacement of the percolated solution between the wall and the adjacent soil and verified the presence of amide-N (Bremner, 1982) in the percolated solution after five days.

Due to the naturally high ureolytic activity of the soil and plant remains (Oliveira, 1999), it can be assumed that the enzymatic hydrolysis of the urea occurred rapidly with the NH_4^+ produced being retained at the soil sorption sites or suffering nitrification, resulting in the absence of amide-N in the percolated solution.

During the experimental period, no-measurable losses of N from urea (^{15}N) were observed in those fertilizer-added treatments. It was also observed that the recovery of the ^{15}N was around 90% in the soil-plant system (Oliveira, 1999), from which approximately 35% were in soil, therefore evidencing the contribution of the microbiological sorption sites in soil to the absence of the fertilizer-^{15}N leaching.

In other studies, in which the fertilizer was labeled with ^{15}N, no (Takahashi, 1968; Padovese, 1988; Salcedo et al., 1988) or insignificant (Coelho et al., 1991) fertilizer-N loss by leaching was observed. However, higher losses by leaching have been documented. Camargo (1989) measured a 28.2% loss when using urea (^{15}N) as the N source; however when the aquammonia was used, the loss of the fertilizer-^{15}N was 7.5%.

The greatest leaching of mineral N (NO_3^-, NO_2^- and NH_4^+), coming out from the soil and/or from the plant remains, was observed in the first three weeks after planting. In this period, the pluvial precipitation was 137 mm and the mean value of the drained solution was 45 mm. In this solution, the mean N concentration was of 5.4 mg kg^{-1}, four times larger than the mean value obtained throughout the experimental period (1.3 mg kg^{-1} of N). That mean value of 1.3 mg kg^{-1} of N was lower than that observed by Ng Kee Kwong & Deville (1984), Salcedo et al. (1988), Camargo (1989) and Orlando Filho et al. (1995), but close to that obtained by Padovese (1988) and Southwick et al. (1995).

The N in the drained solution was mainly in the form of NO_3^-, because of the high solubility of the form and lower affinity of its ions for the adsorption sites in the soil, and similar to the results obtained by Ng Kee Kwong & Deville (1984), Padovese (1988) and Southwick et al. (1995).

No effect was observed on the doses of N or of the plant remains added to the soil, on the total leached N, by virtue of the microbiological immobilization, as discussed previously (Table 1).

Table 1. The leaching of N-(NO_3^- + NH_4^+), K, Ca, and Mg (kg ha^{-1}) from a sandy soil cultivated with sugarcane.

Dose of N (kg ha^{-1})	Treatment	Leaching of nutrients[(1)]			
		N-(NO_3^- + NH_4^+)	K	Ca	Mg
		Not burning			
0	T1	3.83a	16.9a	382a	91.4a
30	T2	4.97a	10.5b	282a	65.9a
60	T3	4.27a	10.3b	272a	74.7a
90	T4	4.60a	10.4b	304a	74.2a
Means		4.41a	12.0a	310a	76.6a
		Burning			
0	T5	6.08a	10.4b	357a	91.1a
30	T6	5.17a	10.1b	278a	74.2a
60	T7	4.33a	10.9b	384a	97.6a
90	T8	3.23a	10.7b	250a	70.6a
Means		4.70a	10.6a	317a	83.4a
General means		4.56	11.3	313	80
		F test			
Plant residues (R)		0.17^{ns}	6.20*	0.55^{ns}	1.63^{ns}
Dose of N (D)		1.13^{ns}	12.8*	2.88^{ns}	3.68^{ns}
R x D		1.99^{ns}	10.3*	1.45^{ns}	1.20^{ns}
CV (%)		28.71	14.80	25.30	16.50

(1)Means followed by the same letter do not differ significantly at the 5% level by the Tukey test. ^{ns}No-significant. *Significant at 5% level by the F test.

Extrapolating the medium value of the total leached N, during the experimental period, a value of 4.5 kg ha^{-1} of N is obtained, with 53% of this total occurring in the first three weeks, probably due to the limited development of the sugarcane root system, although the fine roots are reported to be very efficient in the absorption of water and nutrients (Ball-Coelho et al., 1992) (Figure 1). Preferential drainage between the internal surface of the lysimeter and the adjacent soil, not yet occupied by the roots of the plants, could also have contributed to that higher leaching rate, agreeing with the observations of Ng Kee Kwong & Deville (1984).

Nitrogen losses below one meter, verified by Padovese (1988), for fertilizer levels of 100 kg ha^{-1} of N, were approximately 0.5 kg ha^{-1}, being, therefore, smaller than that of the present work. However, losses close to 25 kg ha^{-1} of N were obtained by Salcedo et al. (1988) and Camargo (1989), but losses still higher (70 kg ha^{-1} of N) were observed by Ng Kee Kwong & Deville (1984) in soil with high organic matter content (81g kg^{-1}). In work carried out in the sugarcane-plantation region of the State of São Paulo, Orlando Filho et al. (1995), studying the application of vinasse (150, 300 and 600 m^3 ha^{-1}) and mineral fertilizer (60 kg ha^{-1} of N) in a Quartz-sandy soil, verified that there was no effect of the application of fertilizer-N or vinasse on N leaching.

N leaching obtained by Reichardt et al. (1982) was close to 6 kg ha^{-1} of N, when the rainfall oscillated around 1,500 mm per year and the fertilization rate was in the order of 90 kg ha^{-1} of nitrogem. Southwick et al. (1995) demonstrated that, for soils cultivated with sugarcane, the losses of mineral N by percolation below a depth one meter were also in the order of 6%.

For the total leaching of K, an interactive effect of dose and kind of sugarcane remains was observed only in the treatment with 0 kg ha^{-1} of N and with the addition of plant remains that simulated cane-plantation renewing in area without previous straw removal by burning (T1) (Table 1).

The largest amount of K incorporated into the soil, due to presence of deceased leaves (530 mg of K, more than in the other kind of plant remains), was associated with the fast liberation of K from the straw (Oliveira et al., 1999) and with limited root and aerial part development in the T1 (Oliveira, 1999), which was probably responsible for the increased leaching observed in these treatments (1.8 times more than the average of the other treatments).

The mean value of total for K in T1 was of 485 mg, while the average of the other treatments was 266 mg, with the standard error being 15 and 11 mg of K for each lysimeter, respectively. Extrapolating these values to 1 ha, the mean leaching values were approximately 17 and 9 kg of K, representing a mean loss of 8 and 4%, respectively, for the K added as fertilizer and cultural remains, plus the exchangeable K from the soil in the lysimeters, calculated using the initial values of the chemical analysis of the soil used for construction of lysimeters (Figure 2). Wong et al. (1992) studied lysimeters cultivated with maize and later rice, also, observing that the K losses were less

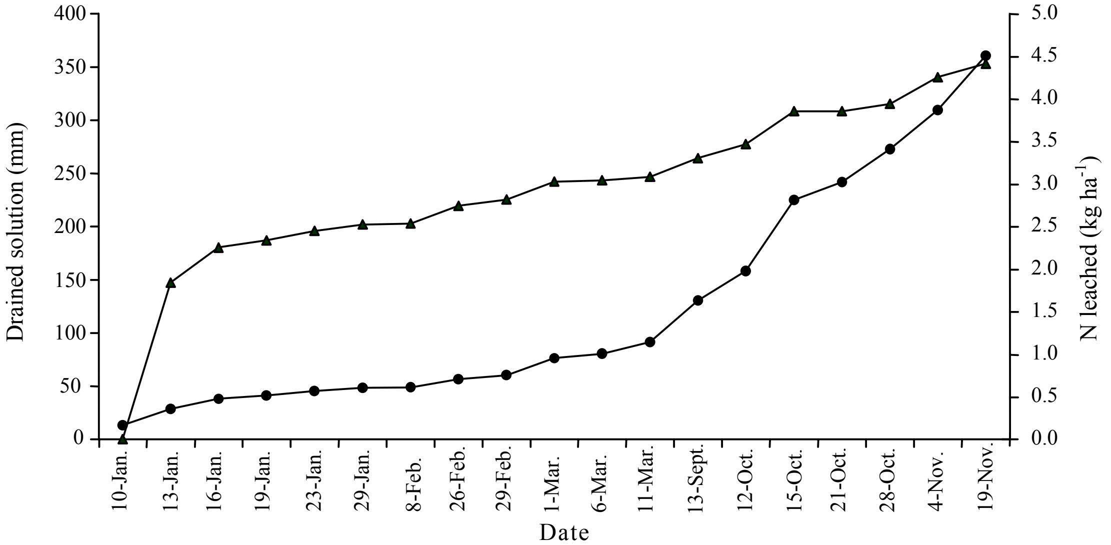

Figure 1. Drained solution (●) and amounts of N (NO_3^- + NH_4^+) (▲) leachead from sandy soil cultivated with sugarcane.

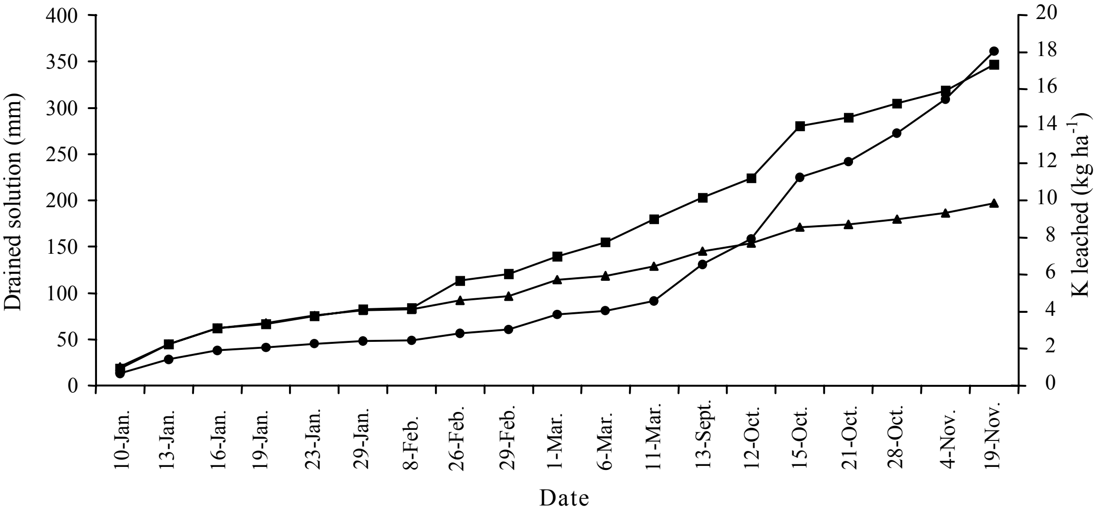

Figure 2. Drained solution (●) and amounts of K leached in the treatment 1 (■) and other treatment (▲) from sandy soil cultivated with sugarcane.

than 10% of the exchangeable K of the soil and added fertilizer.

In sugarcane crop fertilized with 100 kg ha^{-1} of K_2O and cultivated in Red-Yellow dystrophic Podsol in Northeast Brazil, Salcedo & Sampaio (1991) verified that the K loss for percolation below 100 cm was 9 kg ha^{-1}. For high doses of K (388 kg ha^{-1} as K_2O) applied as vinasse (200 m^3 ha^{-1}), Padovese (1988) did not observe percolation of this element at a depth of 100 cm. However, K losses, by leaching, varying of 64 to 136 kg ha^{-1} were verified by Ng Kee Kwong & Deville (1984) in lysimeters cultivated with sugarcane, which were fertilized annually with high doses of KCl, equivalent to 285 kg ha^{-1} year^{-1} of K_2O.

No treatment effect was observed for Mg and Ca leaching (Table 1). The mean mass values for Mg and Ca extrapolated for 1 ha were of 80 and 320 kg ha^{-1}, respectively (Figure 3). Wong et al. (1992), in studies using 1.35 m deep lysimeters cultivated with corn, reported high Ca losses (312 kg ha^{-1}) when finely milled, calcium hydroxide was applied at a dose of 1,025 kg ha^{-1}, to correct soil acidity.

The losses by percolation were related to the volume of the drained solution, more notably for Ca (Figure 3). On average, it was shown that the total loss of Ca and Mg, by percolation, at the end of the experimental period, corresponded to 64 and 39% of Ca and Mg applied as corrective of soil acidity. In this corrective, a mixture of CaO and MgO, the relationship Ca:Mg (w/w) was 2.38:1.00, although in the leached solution this relationship rose to 3.95:1.00, demonstrating higher percolation of Ca than of magnesium. Results of chemical analysis of soil samples collected before the addition of the corrective and at the end of the experimental period (Oliveira,1999) showed a decrease in the relationship between exchangeable Ca:Mg, demonstrating greater leaching of Ca in relation to magnesium.

The greater solubility of $Ca(OH)_2$ and $Mg(OH)_2$ resulting from hydrolysis of CaO and MgO probably is one of the causes for high Ca leaching. However, only the solubility factor does not entirely explain the differential losses between Ca and Mg, since the hydroxides resulting from hydrolysis of CaO and MgO, that is, $Ca(OH)_2$ and $Mg(OH)_2$, have been reported to have a relative solubility higher than 200:1 (Lide, 1998).

Another aspect to be considered is, when soil correction is carried out with $CaCO_3$ and/or $MgCO_3$, the losses of Ca and Mg are not significant (Maria et al., 1993; Bittencourt et al., 1996). Therefore, the high Ca and Mg leaching observed in the present study should not occur in commercial sugarcane plantations where $CaCO_3$ is normally used for the

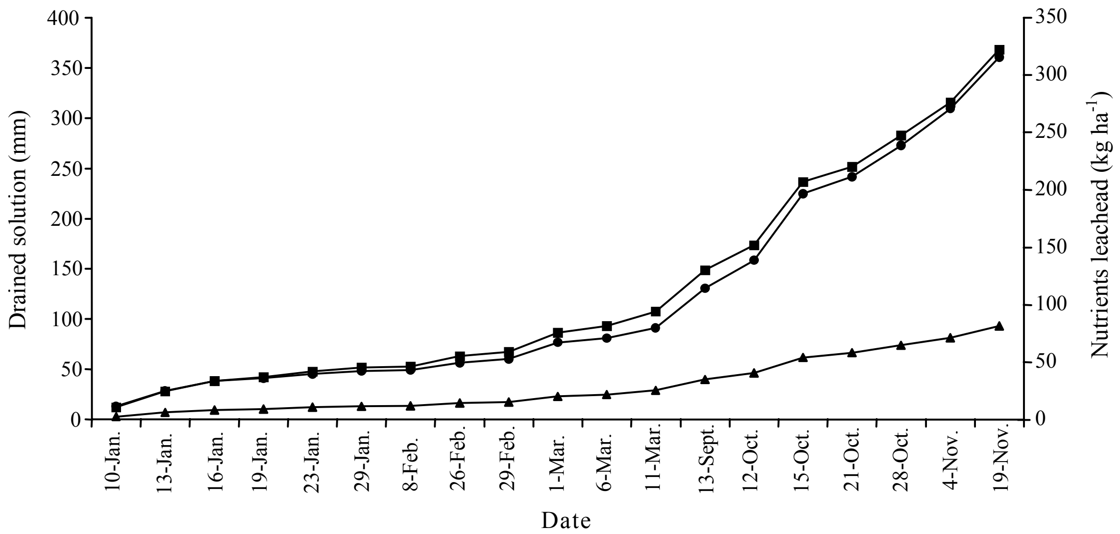

Figure 3. Drained solution (●) and amount of Ca (■) and Mg (▲) leached from sandy soil cultivated with sugarcane.

correction of soil acidity. Besides being much less soluble than Ca and Mg hydroxide, these salts do not possess the fineness of the p.a. grade chemical reagents.

Conclusions

1. There are no losses of N derived from fertilizer.
2. The loss of NO_3^- and NH_4^+ are of the magnitude of 5 kg ha^{-1}.
3. The mean losses for K^+, Ca^{2+}, and Mg^{2+} are of 13, 320, and 80 kg ha^{-1}, respectively.

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