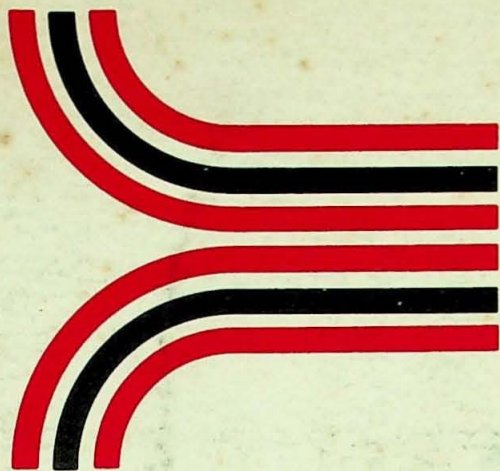
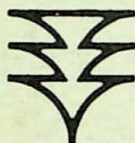


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THE BEHAVIOR OF VINASSE CONSTITUENTS IN THE UNSATURATED AND SATURATED ZONES
IN THE BOTUCATU AQUIFER RECHARGE AREA

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ABSTRACT

Vinasse has been widely replacing chemical fertilizers in sugar cane plantations as a source of nutrients, mainly potassium. Despite its value as a fertilizer, which has already been shown, there are very few publications about the mobility of its constituents as well as their effect on groundwater quality.

In a sugar cane plantation located on the Botucatu aquifer recharge area, a research project has been developed to determine the dynamic of the constituents of vinasse through the unsaturated and saturated zones, aiming at defining the agronomic rate of vinasse irrigation in order to preserve the groundwater quality.

Geological and hydrogeological surveys were carried out utilizing data from geophysical methods (electromagnetism and electroresistivity), boring and piezometers.

The area was divided into three plots where vinasse was applied at rates of 150 and 300 m³/hectare.

A monitoring net was installed after the hydrogeological characterization of the site, consisting of monitoring wells, multilevel piezometers, tensiometers, suction and pan lysimeters, which allow the evaluation of the water flow and solute transportation through the unsaturated and saturated zones.

This paper shows the preliminary results of the monitoring and the methodology used.

INTRODUCTION

Vinasse has been widely used as a source of nutrients in the sugarcane plantation, being mainly irrigated by means of tank trucks, infiltration furrows and sprinkling systems.

Several authors have highlighted the beneficial effects of vinasse on the productivity of the sugar cane (Almeida, 1962), on some chemical properties of the soil - such as the cation exchange capacity and the availability of nutrients (Valsechi and Gomes, 1954; Nunes et alii, 1981) - and on the populations of microorganisms in the soil (Casarini, 1989).

Notwithstanding, research on the mobility of the vinasse in soils (Camargo et alii, 1987; Cunha et alii, 1987) and moreover, its effect on groundwater quality (Hassuda, 1987) is still scarce.

Sugar cane plantations are mainly located in the Northwestern area of the State of São Paulo where recharge areas of important aquifers - such as the Bauru and the Botucatu - are located. The latter one is considered to be the main groundwater supplier in the State. Some of the most important cities in this region are entirely or partially supplied by this water-bearing formation.

Thus being, due to the lack of information related to the alteration of the quality of groundwater caused by the vinasse, it is important to evaluate the effects of the several disposal systems used, such as channels, sprinkling, and infiltration furrows and lagoons.

This paper aims at assessing the effects of the irrigation using vinasse on groundwater in the recharge area of the Botucatu Aquifer, describing the methodology employed in the study of the behavior of the vinasse constituents in the unsaturated and saturated zones as well as some preliminary results.

SELECTION OF THE AREA STUDIED

The area studied was chosen due to the fact that it is located on the Botucatu Aquifer, because it is a strategic region for the protection of this important water-bearing formation in the State of São Paulo. Such system, in its outcropping area (recharge area) and in the region where it is confined by basaltic formations (90 per cent of the aquifer), comprises 60% of the State territory and thanks to its high potential, it is the main groundwater reservoir in São Paulo (Rocha, 1986).

Other criteria used for the selection of the area studied were: shallow water table (facilitating boring operations and enabling quicker results), homogeneous medium (permitting an easier interpretation of results), the existence of a local discharge area (allowing the identification of the groundwater flow pattern) and controlled or absent sources of pollution uphill.

The area selected is located in the municipality of Serrana, State of São Paulo (21o07' South, 47o34' West; Figure 1).

The climate in the region, according to the Koppen classification, can be said to pertain to Group A of mesothermic climates, with well defined characteristics during winter (dry) and summer (wet) (DAEE, 1974). Rainfall in the area studied was 1,688 millimeters in 1989, following the same distribution pattern in the region as a whole.

The area studied is 1,280 square meters, with flat relief, located within Usina da Pedra sugarcane plantations.

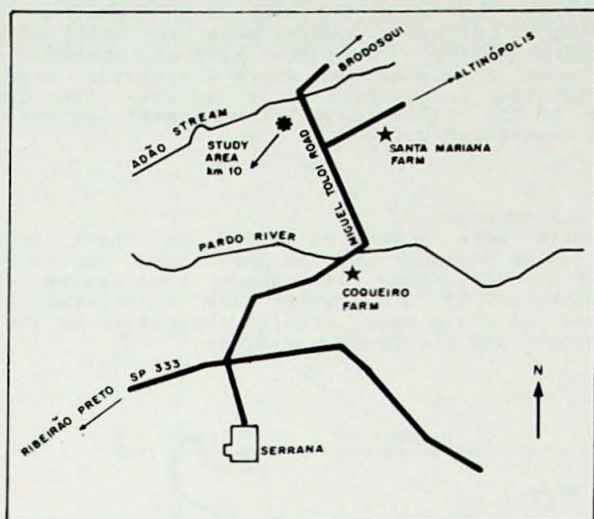


Fig. 1. Localization of the area studied.

GEOLOGICAL AND HYDROGEOLOGICAL CHARACTERIZATION

Local geological and hydrogeological characterization is aimed at identifying and characterizing both physically and chemically the unsaturated and saturated zones in the area studied, identifying the potential pollutants runways within such zones and orienting the location of monitoring equipment (USEPA, 1986).

Thus, auger boring and trenches were used in order to allow the collection of undeformed samples. Deformed samples underwent granulation analysis and the results obtained showed an homogeneous medium (0 to 450 cm) with an average of 89.91% sand (being 30.65% coarse sand and 56.26% fine sand), 2.85% silt and 10.24% clay.

Undeformed analysis helped determine the apparent density, the total porosity and the water retention curve.

The soils, as well as the sediments, can be classified as Red-Yellow Latosol with predominant quartz constitution.

Geophysical Characterization

Two electric soundings were carried out and three geoelectrical layers were defined. The first one (1,200 ohm/m resistivity and 2.5 m thickness) was interpreted as being an unsaturated zone of the Botucatu Formation. The second one (4,700 ohm/m resistivity and 28 m thickness) is the saturated zone of the same Formation. The third layer (600 ohm/m and undefined thickness) is thought to be part of Pirambóia Formation, due to its clay content.

Electromagnetic transections carried out with Geonics' EM-31 and EM-34 showed low conductivity (0.4 to 3.5 ohm/m, decreasing with depth) up to 15 m depth, which confirms the electro-resistivity sounding interpretations. Through these methods, intrusive bodies were not observed within the area studied, which characterizes - with the help of physical data - a poorly stratified homogeneous porous medium where dispersion processes probably occur mainly during the transportation of solutes. The low conductivity measures obtained by the electromagnetic equipment indicate, for the area, measures close to background values.

Groundwater Flow

Six monitoring wells were bored in order to check groundwater level variations which, from November 1988 to April 1990, varied between 1.70 and 2.60 meters. Potentiometric maps were drawn from these data aiming at evaluating the direction of groundwater flow in several different dates. Figure 2 shows one of these maps, with an indication of the flow direction (assuming an isotropic and homogeneous medium).

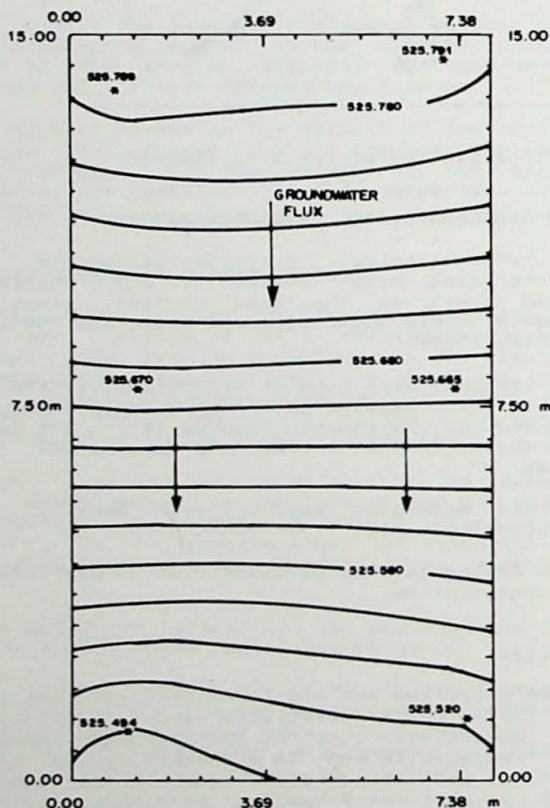
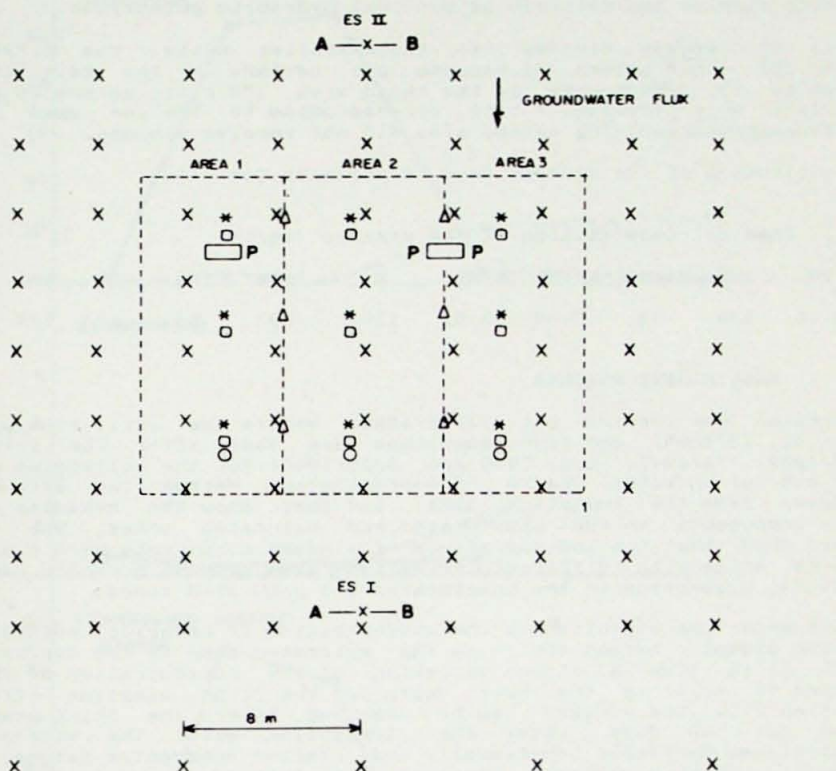


Fig. 2. Potentiometric map.

EXPERIMENTAL DELINEATION

The groundwater flow direction in the area studied defined the location of the monitoring equipment for the unsaturated and saturated zones, as shown in Figure 3. For monitoring of the unsaturated zone, nine stations with six



LEGEND






- | | | | |
|---|---|---|-----------------------|
|  | AREA OF APPLICATION |  | 6 TENSIMETERS |
| A-x-B | ELECTRICAL SOUNDING |  | MONITORING WELL |
| X | ELECTRICAL CONDUCTIVITY NETWORK (EM) | * | 5 LYSIMETERS |
|  | P TRENCH FOR SOIL SAMPLING AND PAN-LYSIMETERS |  | MULTILEVEL PIEZOMETER |

Fig. 3. Scheme of the area studied.

tensiometers for the determination of soil humidity and five suction lysimeters for collecting soil solution samples. The tensiometers were positioned at 20, 60, 100, 140, 180 and 220 centimeters of depth, and the lysimeters, at 40, 80, 120, 160 and 200 centimeters. In order to sample the solutes transported by macropores and channels, six pan lysimeters were placed - three at 50 centimeters and three at 150 centimeters of depth.

Three multilevel piezometers were positioned at at 2.90 and 4.50 meters for collecting samples and determining punctual hydraulic potentials.

The area studied was divided into three smaller units. The first area received 150 cubic meters of vinasse per hectare - the rate commonly disposed by the tank trucks. In the third area, 300 cubic meters of vinasse per hectare were disposed - rate corresponding to the one used in the sprinkling irrigation. The second area did not receive vinasse.

The constitution of the vinasse used is shown on Table 1.

Table 1: Chemical constitution of the vinasse (mg/l)

TOC	TKN	N-NH4	N-NH3	N-NH2	K	Ca	Mg	Cl	SO4	pH
21.950.00	135	12	0.08	0.01	1200	107	83	673	814	7.7

PRELIMINARY RESULTS

One sampling was carried out (11/22/1989) before the irrigation with the vinasse (11/23/1989) and four samplings were made after the irrigation (12/13/1989, 1/1/1990, 1/31/1990 and 3/15/1990) for the collection of soil solute and groundwater. Charts of concentration versus time versus depth were drawn from the analytical data, and they show the behavior of the vinasse components in the unsaturated and saturated zones. The results obtained show that the concentrations of vinasse components were similar in the three areas with different irrigation rates. It was probably caused by the lateral dispersion in the unsaturated and saturated zones.

Figure 4 shows the variation of the concentration of chloride, potassium and dissolved organic carbon (DOC) in the saturated zone in two depths (2.9 m and 4.5 m) in time. A strong variation of the concentration of chloride (reaching 55 mg/l) in the lower depth in the first sampling after the irrigation with the vinasse can be observed. After the third sampling, carried out 40 days after the irrigation with the vinasse, the concentrations decreased continually and reached apparently natural values (0.5 mg/l), which highlights the great mobility of this anion. Due to the predominant horizontal flow and the small descending vertical component, alterations in the concentration of chloride in the higher depth (4.5 m) were only found in the fourth sampling, 70 days after the irrigation.

Potassium concentrations were maintained close to natural values (0.3 to 1.4 mg/l), while DOC's behavior was similar to that of the chloride, reaching concentrations of 80 mg/l and 50 mg/l in the lower and the higher depths, respectively. Such alteration in the concentration of carbon in groundwaters is probably associated to leaching of soluble organic compounds of the vinasse, which has a high concentration of organic material (Table 1), mostly colloidal.

Figure 5 shows the behavior of the nitrogen forms in the vinasse within the saturated zones. Significant variations of the NKT were observed from the third sampling on, showing a delayed transportation of the nitrogen forms encompassed in this analysis compared to chloride. Alterations in the concentration of NKT were not observed for the higher depth studied up to the last sampling.

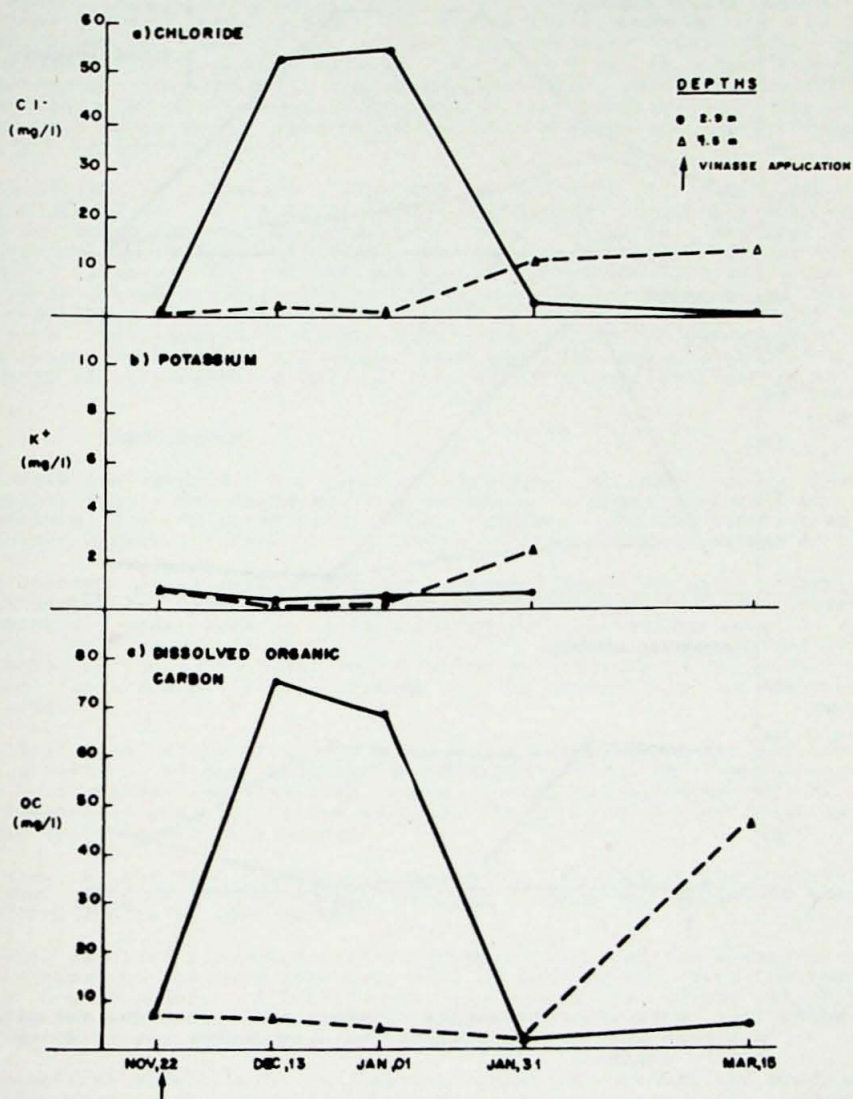


Fig. 4. Chloride (a), potassium (b) and dissolved organic carbon (c) concentrations in groundwater at 2.90 m and 4.50 m depths.

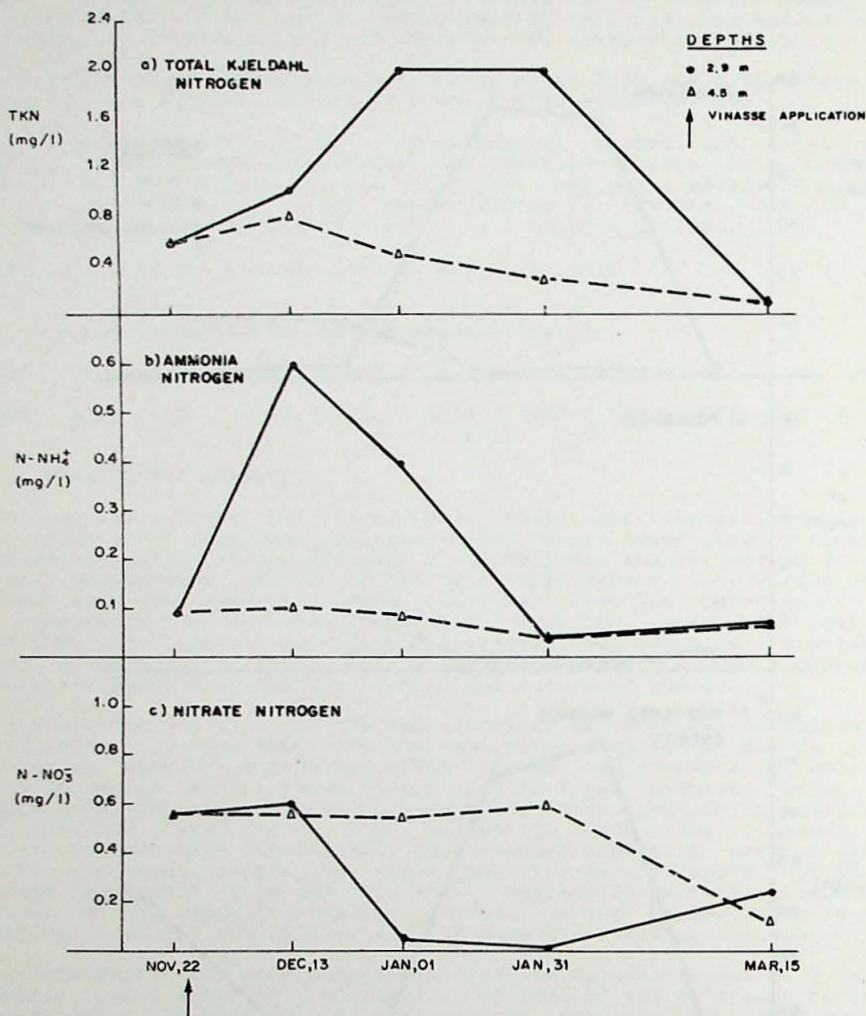


Fig. 5. Total kjeldahl nitrogen (a), ammonium nitrogen (b) and nitrate nitrogen (c) concentrations in groundwater at 2.90 m and 4.50 m depths.

In view of the quick transportation process of the NKT and $N-NH_4$ in the unsaturated zone, a significant nitrification process probably did not occur, because the concentrations of nitrate in the groundwater did not vary and the concentration of nitrate in the vinasse was very small.

Figure 6 shows the variation in the concentration of chloride and potassium in depth in the unsaturated zone in different sampling routines. After the irrigation with the vinasse, the concentrations of chloride in all depths (12/13/1989, 20 days after irrigation) increase and, after this date, decrease again, reaching natural values in time. This fact shows the quick leaching of this anion in the unsaturated zone, which enabled the growth of the levels of concentration observed in the saturated zone. The unsaturated zone must have acted as a source of this element for the groundwater for a certain period of time.

With regard to potassium, a strong increase of its concentration in the depth of 80 cm in the first sampling after the irrigation with the vinasse can be noted, and it progressively goes backwards, reaching background values in the subsequent samplings. However, the leaching of such element was not observed for higher depths, and this reduction in concentration at 80 cm is probably associated to the removal by the sugar cane. This fact was also observed by Cunha et alii (1986) in a similar soil, though originated of more argillaceous material. Such retention of the potassium at 80 cm and the later removal by the sugar cane explains the non-alteration of the quality of groundwater with regard to this element, as observed in Figure 4.

CONCLUSIONS

Although preliminary, the results obtained in this study allow us to conclude that, for agronomic irrigations with vinasse in soil and permeable sediments, the chloride, the organic carbon, and the ammonium and organic nitrogen appear as elements that impose a risk to the groundwater quality.

The chances of alteration of the concentration levels of potassium in the groundwater is remote, in view of the retention of this element by the unsaturated zone, even in soils with low cation exchange capacity (CEC) such as the one studied. In such situation, the potassium remains available to be absorbed by the sugar cane, reducing the probability of the unsaturated zone to act as a source of this element for the groundwater, as observed for the chloride.

The following steps of this study must, in view of the preliminary results, pay attention to the possible transformation of some elements occurring in the unsaturated and saturated zones, such as nitrogen which, although predominantly organic in the vinasse, can, through a nitrification process, reach toxic levels as a nitrate.

In view of the high concentration of other elements in the vinasse, such as sulphur, calcium, sodium and others, it is important to include these in the monitoring to be carried out.

A more detailed following of the transportation of the elements comprising the vinasse in the saturated zone must be carried out, with the installation of a higher number of multilevels and decreasing of the interval between samplings, enabling thus a better characterization of the mechanisms of horizontal and vertical transportation of these elements.

Mathematical models will be used in order to predict the progress of the vinasse components in the unsaturated and saturated zones, enabling the simulation of the different irrigated rates used in this study, aiming at evaluating the risks of pollution of groundwater.

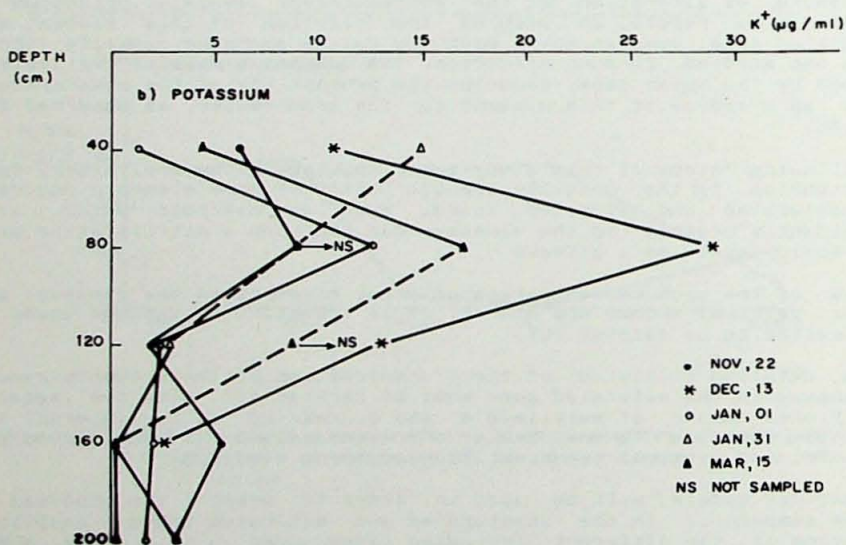
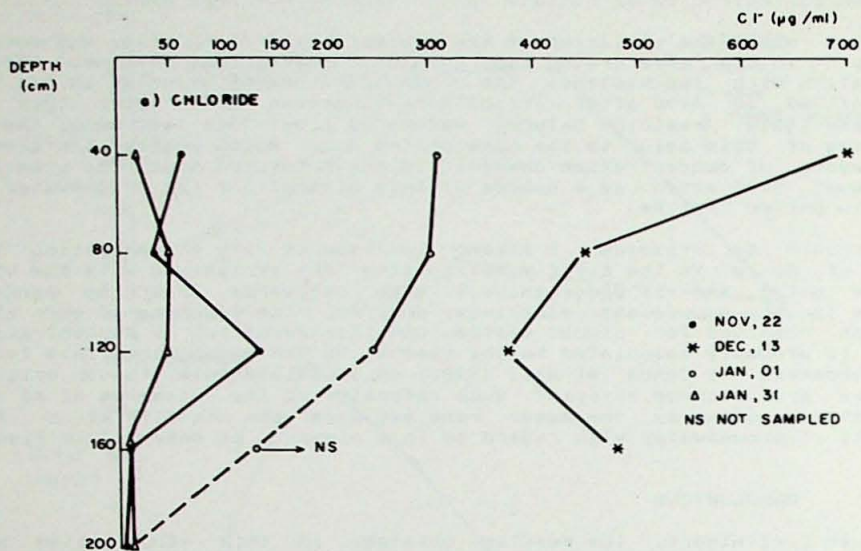


Fig. 6. Chloride (a) and potassium (b) concentrations in the soil solution.

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