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Chemical composition and nutrient loading by precipitation in the Trachypogon savannas of the Orinoco llanos, Venezuela

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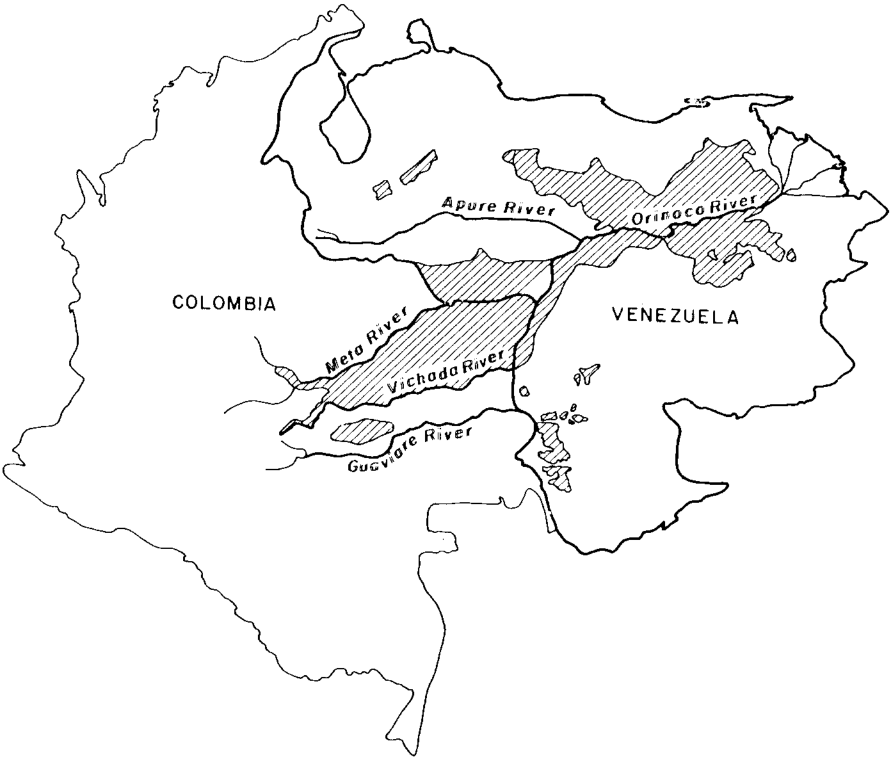
Abstract. Samples of bulk precipitation were collected in the Trachypogon savanna, Calabozo, Venezuela, during three consecutive years. In the first year, rain samples were taken daily; in the following years the samples were grouped on a monthly basis. In addition, samples of dry deposition were collected during the dry seasons. All samples were analyzed for the following water soluble cations and anions: PO_4-P, SO_4-S, NO_3-N, NH_4-N, Ca^{+2}, Mg^{+2}, K^+, Na^+ and H^+. The mean annual input rate of chemical constituents (Kg ha^{-1} $year^{-1}$) was: PO_4-P (0.42); SO_4-S (2.62); NO_3-N (0.21); NH_4-N (2.03); Ca^{+2} (3.50); Mg^{+2} (11.31); K^+ (3.60); Na^+ (5.93) and H^+ (0.03). The total mean input of particulate material to the savanna during the dry season was 2.06 Kg ha^{-1} $year^{-1}$, with a soluble fraction of 30%. Possible sources of nutrients input were analyzed.

Introduction

Trachypogon savannas are widely distributed in northern South America, covering circa 480 000 Km^2 of the Orinoco Llanos; the Oriental Llanos of Colombia; the hydrographic basins of the Rivers Orinoco, Casiquiare and Negro in the Amazon Federal Territory, Venezuela and the Valleys of the Amazon and Esequibo (San Jose et al. 1985) (Map 1).

Aboveground primary production of the Trachypogon savannas varies between 7.0 and 9.1 t ha^{-1} (San Jose & Garcia Miragaya 1982), and underground production between 1.2 and 2.9 t ha^{-1} (San Jose et al. 1982). This low productive capacity has been attributed to physical and chemical soil characteristics (San Jose & Garcia Miragaya 1982). These soils are excessively dry with a lithoplinthic horizon (Smith et al. 1977) close to the surface; low in: pH, cation exchange capacity, nitrogen and phosphorus.

Studies in tropical communities growing on oligotrophic soils indicate that atmospheric deposition could be an important source of nutrient input



Map 1. Distribution of the Trachypogon savannas at the Orinoco Llanos.

to the ecosystem (Will 1959; Coutinho 1979; Jordan et al. 1980; Kellman et al. 1982), even though most nutrients might be recycled from the same system (Wetselaar & Hutto 1963). According to our knowledge, there is no information available on the importance of rains as nutrient suppliers to the Trachypogon savannas, only estimates of the quantities of nutrients in the precipitation based on sporadic determinations (Escobar 1977).

The present investigation was conducted to determine the precipitation chemistry and to estimate the soluble constituents of bulk precipitation and dry deposition during three consecutive years in the Trachypogon savannas of the Orinoco Llanos. It was felt to be particularly important to quantify the total chemical input to this savanna, in view of the extreme oligotrophic character of the soils.

Materials and methods

This study was carried out in a permanent 1-ha plot, located in the Trachypogon savanna of the Biological Station of the Plains (8°56′N; 67°25′W).

The climate of the area is characterized by a 4–5 month dry season with potential mean annual evapotranspiration (2400 mm) exceeding annual mean precipitation (1228 mm), and a mean annual temperature of 26 °C. The studied plot is covered by a bush island savanna with a herbaceous layer, isolated trees and small patches of semi-deciduous forest. The dominant grasses are *Trachypogon plumosus* (Humb. & Bompl.) Nees and *Axonopus canescens* (Trin.) Pilger. Vegetation and soil of the Biological Station have been described in detail (Aristeguieta 1965; Blydenstein 1962; Monasterio & Sarmiento 1968; Smith et al. 1977).

Three polypropylene (Nalgene) containers with a 2 L capacity each, were placed (May 1st 1981) in an open field on poles 1.60 m above the surface of the herbaceous layer and spaced at 10 m intervals, delimiting the vertices of an equilateral triangle. A standard rainwater gauge was placed in the centre of the same. The system for sample collection has been described in detail by Montes et al. (1985), with the following characteristics: the containers remained open throughout the study period; the samples include a combination of wet precipitation and dry deposition, defined as bulk precipitation (Whitehead & Feth 1964).

After collecting each rain sample, the containers and funnels were washed with iso-propyl alcohol, followed by three portions, 200 ml each, of distilled water. This procedure assures the elimination of any microorganism that may develop on the container walls. Daily samples with visible organic matter contamination, bird excrement and/or frass of insects were discarded. Rain samples were collected daily during three consecutive years (1981–1984) (see Fig. 2 for pattern of precipitation). Daily samples were analyzed during the first year but during last two years half volumes of each daily precipitation were taken and composited in polypropylene containers. Thereafter monthly samples were analyzed. During the dry period dry deposition was collected on 10 aluminium trays (294 cm^2 surfaces and 10 cm depth) placed at random, at the same height as the rain collectors. These trays were used during three annual courses on January 19th, 1982; January 4th, 1983 and November 17th, 1983; and samples collected on February 18th and March 28th, 1982; February 15th, 1983 and February 20th and March 25th, 1984, respectively. Each tray was washed with 250 ml of distilled water, and this suspension was filtered through pre-weighed Whatman No. 11 filter paper. These pre-weighed filters were dried out at 80 °C and re-weighed to obtain the weight of the particulate material. There was no organic debris on the trays and an additional control treatment was carried out with aluminium containers not exposed to atmospheric conditions.

Samples of bulk precipitation and the filtrate of the particulate material of dry deposition were preserved in chloroform (10.5 ml per liter) and stored in darkness, in polypropylene containers (NALGENE) at 4 °C. Test standards stored under the same conditions for the same length of time were included in the experimental design. The chemical determinations were carried out in less than a month. Samples were colorimetrically analyzed for water-soluble macronutrients (PO_4–P, NO_3–N and NH_4–H), using a Bausch and Lomb., Spectronic 20 photocolorimeter. Phosphate determinations involved the formation of an antimony-phospho-molybdate complex, which was reduced to an intensely blue-coloured complex by ascorbic acid (Environmental Protection Agency 1979); nitrate was reduced to nitrite with hidrazine sulfate, and the nitrite was determined by diazotizing with sulfanilamide and N-1-naphtha ethylenediamine dihydrochloride to form a coloured azo-dye (Kamphake et al. 1967); ammonium was measured by the salycilate method (Environmental Protection Agency 1979); sulphate was obtained by the barium chloride precipitation method (Golterman 1969), using a Shimadzu, Double Bean Spectrophotometer UV-150-02. Calcium, magnesium and potassium were determined using the Varian Tectron 120-A/A atomic absorption spectrophotometer. Solutions of lanthanum (La_2O_3) were added to the samples to suppress phosphate interference for calcium and magnesium analysis. Samples were analyzed for sodium by flame photometry with Coleman (Perkin Elmer Co.) photometer.

For each rain event the mean bulk precipitation chemistry was calculated from values for three collectors with a correction for rainfall volume differences after applying the equation:

$$\mathrm{VWMC} = \frac{\Sigma[(c)(vol)]}{\Sigma(vol)}$$

where $c = \mu M l^{-1}$ of ion in the bulk precipitation and vol = sample volume of rainwater present.

To determine the total quantities of nutrients annually incorporated to the savanna ecosystem, the amount of nutrients in bulk precipitation collected during the wet season were added to the amount of nutrients in the dry fallout collected during the dry season. Thus, bulk precipitation correspond exclusively to composite samples of rainfall and dry fallout collected only during the wet season. The second term, dry deposition was collected in aluminium trays as dry fallout only during the dry season.

Results

From May 1st 1981 to April 30th 1982, the daily volume of 101 rains was measured. Twenty seven samples were not analyzed since their volume

(< 3 mm) was insufficient for carrying out the required chemical determinations. Another 36 rains presented problems of contamination and accidental spilling and the samples were discarded. As a result only 38 sampled rains were analyzed.

Nutrient concentration

Daily volume and the VWMC of soluble constituents (PO_4–P, SO_4–S, NO_3–N, NH_4–N, Ca^{+2}, Mg^{+2} and K^+) in the sample rains, are shown in Table 1. The effect of rain volume on the concentration of the soluble constituents was analyzed by correlating the mean weighted concentration of each constituent (PO_4–P, SO_4–S, NH_4–N, Ca^{+2}, Mg^{+2}, and K^+) with the precipitation volume. The results showed no Pearson's correlation (Conover 1980); except for the anion NO_3–N with a negative coefficient (rho $= -0.40$, $p < 0.05$), which indicates an effect of dilution.

Correlations among the VWMC for all anions were significant and they also were correlated with the cations Ca^{+2}, and K^+; NH_4–N was only correlated with SO_4–S and NO_3–N. The concentrations of Mg^{+2} were not statistically associated with the other ions.

The VWMC of soluble macronutrients (PO_4–P, SO_4–S, NO_3–N and NH_4–N) were significantly higher at the beginning of the wet season (May, 1981 and April, 1982) as compared with the end of the season (October, 1981) (Mann Whitney U Test in Conover 1980).

A particular case was PO_4–P which reached concentrations of 0.12 ppm on May 25th 1981 and 0.10 ppm on the 6th April (Table 1). Sporadic increases in the concentration of some constituents were observed during the wet season. On the other hand, seasonal patterns of the cations Ca^{+2}, Mg^{+2} and K^+ (Table 1) were less evident. However, there were significant differences among them, according to the Mann Whitney U test. The mean monthly concentrations for the annual courses; 1982–1983 and 1983–1984, show similar values and analogous trends to those described for the daily concentrations.

Daily rate of nutrient input

The daily rate of soluble nutrient input by bulk precipitation in the Trachypogon savannas, showed (Fig. 1) a high deposition value ($mg\,m^{-2}\,day^{-1}$) in mid wet season (July) of: PO_4–P (2); SO_4–S (29); NH_4–N (23); Ca^{+2} (25); Mg^{+2} (63) and K^+ (42). These high values were associated with the highest daily precipitation (85 mm) occurring in mid wet season (July).

Table 1. Precipitation and volume-weighted mean concentration of soluble constituents in the Trachypogon savannas at the Orinoco Llanos.

Date	Precipitation (mm)	PO_4–P Mean S.E. $(mg\,l^{-1})$	SO_4–S Mean S.E. $(mg\,l^{-1})$		NO_3–N Mean S.E. $(mg\,l^{-1})$	NH_4–N Mean S.E. $(mg\,l^{-1})$	Ca^{+2} Mean S.E. $(mg\,l^{-1})$	Mg^{+2} Mean S.E. $(mg\,l^{-1})$	K^{+} Mean S.E. $(mg\,l^{-1})$
May									
01	42.50	0.05 ± 0.02	0.20 ± 0.06		0.04 ± 0.02	0.16 ± 0.03	0.33 ± 0.13	0.49 ± 0.02	0.19 ± 0.06
09	7.40	0.03 ± 0.01	0.43 ± 0.02		0.04 ± 0.03	0.11 ± 0.06	0.24 ± 0.09	0.59 ± 0.06	0.21 ± 0.03
19	11.10	0.01 ± 0.00	1.33 ± 0.13		0.01 ± 0.02	0.30 ± 0.02	0.07 ± 0.03	0.50 ± 0.03	0.48 ± 0.02
25	13.40	0.12 ± 0.08	0.12 ± 0.03		0.03 ± 0.01	0.14 ± 0.05	0.03 ± 0.00	0.69 ± 0.06	0.28 ± 0.01
26	18.30	0.01 ± 0.00	0.47 ± 0.10		0.02 ± 0.00	1.28 ± 0.30	0.05 ± 0.03	0.45 ± 0.03	0.19 ± 0.02
27	18.50	0.04 ± 0.01	0.57 ± 0.17		0.02 ± 0.01	0.10 ± 0.00	0.13 ± 0.01	0.85 ± 0.04	0.23 ± 0.03
June									
02	26.20	0.03 ± 0.01	1.07 ± 0.09		0.00 ± 0.00	0.27 ± 0.15	0.37 ± 0.06	0.69 ± 0.05	0.21 ± 0.02
04	3.50	0.01 ± 0.00	0.87 ± 0.43		0.01 ± 0.01	0.10 ± 0.00	0.17 ± 0.08	1.11 ± 0.39	0.27 ± 0.09
09	4.10	0.01 ± 0.01	0.24 ± 0.10		0.03 ± 0.01	0.38 ± 0.15	0.13 ± 0.08	1.00 ± 0.09	0.45 ± 0.20
15	7.90	0.01 ± 0.01	0.80 ± 0.32		0.00 ± 0.00	0.34 ± 0.20	0.22 ± 0.06	1.54 ± 0.24	0.11 ± 0.06
18	38.70	0.02 ± 0.02	0.00 ± 0.00		0.00 ± 0.00	0.07 ± 0.00	0.03 ± 0.00	0.34 ± 0.10	0.16 ± 0.02
25	6.60	0.01 ± 0.00	0.00 ± 0.00		0.01 ± 0.01	0.08 ± 0.01	0.07 ± 0.02	0.84 ± 0.16	0.22 ± 0.04
28	12.70	0.02 ± 0.01	0.11 ± 0.10		0.02 ± 0.01	0.07 ± 0.02	0.14 ± 0.10	0.79 ± 0.30	0.22 ± 0.15
July									
06	85.90	0.02 ± 0.02	0.33 ± 0.10	0.00	0.00 ± 0.00	0.26 ± 0.13	0.29 ± 0.14	0.73 ± 0.37	0.49 ± 0.12
09	12.70	0.00 ± 0.00	0.03 ± 0.03	0.01	0.01 ± 0.01	0.14 ± 0.10	0.16 ± 0.04	0.65 ± 0.10	0.28 ± 0.02
15	17.10	0.00 ± 0.00	0.00 ± 0.00	0.01	0.01 ± 0.01	0.08 ± 0.04	0.25 ± 0.05	0.25 ± 0.10	0.22 ± 0.02
18	24.20	0.03 ± 0.01	0.00 ± 0.00	0.00	0.00 ± 0.00	0.10 ± 0.01	0.52 ± 0.03	0.52 ± 0.03	0.22 ± 0.04
27	30.00	0.03 ± 0.01	0.00 ± 0.00	0.02	0.02 ± 0.02	0.08 ± 0.02	0.29 ± 0.01	0.29 ± 0.01	0.20 ± 0.02
28	8.30	0.02 ± 0.01	0.10 ± 0.10	0.00	0.00 ± 0.00	0.09 ± 0.02	0.43 ± 0.00	0.43 ± 0.00	0.17 ± 0.03
29	5.30	0.02 ± 0.00	0.37 ± 0.15	0.02	0.02 ± 0.01	0.07 ± 0.01	0.61 ± 0.08	0.61 ± 0.08	0.16 ± 0.01
31	16.80	0.03 ± 0.01	1.60 ± 0.90	0.00	0.00 ± 0.00	0.07 ± 0.00	0.65 ± 0.20	0.65 ± 0.20	1.16 ± 0.18

August									
10	12.20	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.04 ± 0.02	0.08 ± 0.02	0.65 ± 0.02	0.29 ± 0.06
13	45.30	0.02 ± 0.01	0.00 ± 0.00	0.01	0.01 ± 0.01	0.09 ± 0.06	0.03 ± 0.01	0.27 ± 0.06	0.07 ± 0.06
18	92.60	0.01 ± 0.01	0.23 ± 0.20	0.00	0.00 ± 0.00	0.03 ± 0.01	0.12 ± 0.04	0.42 ± 0.02	0.14 ± 0.01
19	17.70	0.00 ± 0.01	0.00 ± 0.00	0.01	0.01 ± 0.01	0.03 ± 0.01	0.09 ± 0.06	0.34 ± 0.04	0.22 ± 0.03
31	24.90	0.02 ± 0.01	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00	0.09 ± 0.01	0.27 ± 0.10	0.20 ± 0.00
September									
01	33.70	0.03 ± 0.02	0.11 ± 0.01	0.00	0.00 ± 0.00	0.00 ± 0.00	0.10 ± 0.01	0.11 ± 0.03	0.23 ± 0.05
08	23.00	0.02 ± 0.01	0.08 ± 0.05	0.00	0.00 ± 0.00	0.00 ± 0.00	0.18 ± 0.01	0.34 ± 0.16	0.18 ± 0.02
16	60.60	0.01 ± 0.01	0.13 ± 0.07	0.00	0.00 ± 0.00	0.02 ± 0.01	0.10 ± 0.02	0.09 ± 0.02	0.18 ± 0.02
October									
11	6.00	0.01 ± 0.01	0.11 ± 0.04	0.03	0.03 ± 0.03	0.11 ± 0.03	0.12 ± 0.03	0.91 ± 0.40	0.22 ± 0.07
23	55.60	0.01 ± 0.01	0.13 ± 0.01	0.00	0.00 ± 0.00	0.13 ± 0.04	0.11 ± 0.02	0.52 ± 0.30	0.18 ± 0.04
24	23.70	0.01 ± 0.00	0.14 ± 0.01	0.00	0.00 ± 0.00	0.13 ± 0.03	0.19 ± 0.04	0.24 ± 0.07	0.15 ± 0.03
November									
03	9.80	0.03 ± 0.02	0.14 ± 0.04	0.04	0.04 ± 0.01	0.57 ± 0.10	0.28 ± 0.08	0.19 ± 0.07	0.29 ± 0.20
April									
06	15.70	0.11 ± 0.02	1.02 ± 0.12	0.02	0.02 ± 0.01	0.42 ± 0.10	0.38 ± 0.20	0.71 ± 0.07	0.50 ± 0.07
08	8.30	0.08 ± 0.04	1.39 ± 0.49	0.02	0.02 ± 0.02	0.62 ± 0.12	0.22 ± 0.06	0.50 ± 0.09	0.33 ± 0.06
20	8.00	0.03 ± 0.01	0.73 ± 0.43	0.02	0.02 ± 0.00	0.50 ± 0.30	0.24 ± 0.06	0.50 ± 0.03	0.55 ± 0.20
27	31.70	0.02 ± 0.01	1.12 ± 0.22	0.02	0.02 ± 0.01	0.47 ± 0.10	0.23 ± 0.03	0.55 ± 0.30	0.50 ± 0.20

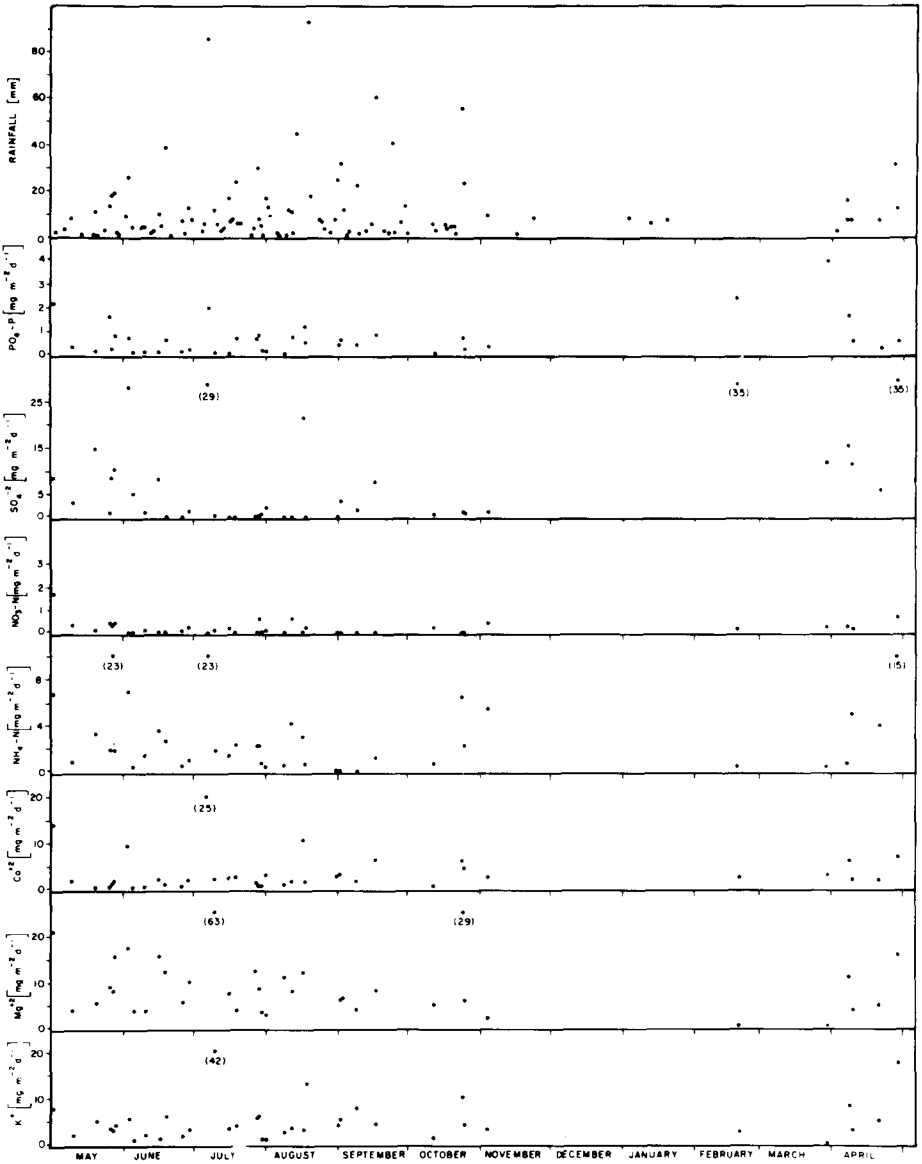


Fig. 1. Precipitation and daily input rate of constituents during one annual course (1981–1982) in the Trachypogon savannas at the Orinoco Llanos.

Wet season

The ionic input of non-analyzed rains (1981–1982) was estimated as follows: due to a statistically significant effect of dilution on the concentration of

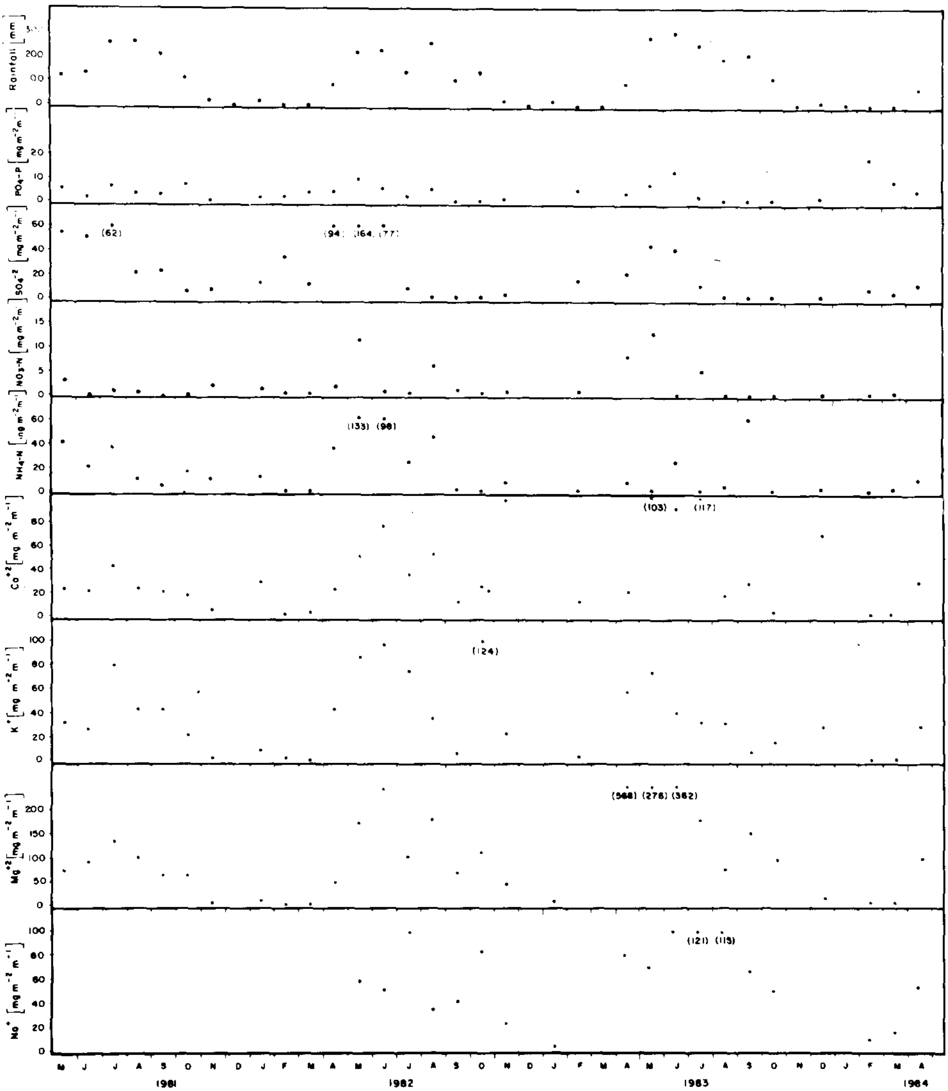


Fig. 2. Monthly input rate of soluble constituents during three consecutive annual courses (1981–1984) in the Trachypogon savannas at the Orinoco Llanos.

NO_3–N depended upon the monthly data, the unknown concentration of NO_3–N per rain event was estimated from the corresponding monthly regression of the NO_3–N concentration analyzed per event as a function of rainfall amount. For the other ionic concentrations (which were not correlated with rainfall volume), the mean concentration of each ion was estimated from the analyzed rain samples and this value was multiplied by the volume of non-analyzed precipitation. These last calculations were justified on the basis of temporal changes in concentration observed from statistical comparisons (Mann Whitney U test on Conover 1980) of the values between the beginning and the middle of the wet season.

The pattern of monthly input of the ions (PO_4–P, SO_4–S, NO_3–N, NH_4–N, Ca^{+2}, Mg^{+2}, and Na^{+2}) as components of the soluble fraction of bulk precipitation (Fig. 2) showed a marked increase at the beginning of the wet season. Thereafter this trend was followed by a decrease at the end of the wet season to values of zero. According to Noether's test (1956), the monthly input rate of ions measured during the studied periods did not show a cyclical trend with a probability ranging from 0.15 to 0.29. Ion input rates were zero in 1981, in November and from September to November for PO_4–P and NO_3–N, respectively; in 1982, from September to October for PO_4–P, SO_4–S, NO_3–N and NH_4–N and in 1983 from August to October for PO_4–P, SO_4–S and NO_3–N, with the ion NH_4–N showing the same trend only in October.

Dry season

Table 2 shows the amount of dry deposition (mg m^{-2} day^{-1}) collected during the three dry seasons and the input rate of ions of the soluble fraction

Table 2. Input rate of particulate matter and chemical composition of soluble constituents analyzed in the dry deposition during three consecutive years at the Trachypogon savanna of the Orinoco Llanos.

Date	Particulate material (mg m^{-2} day^{-1})	H^+	PO_4-P	SO_4-S (μg m^{-2} day^{-1})	NO_3-N	NH_4-N	Ca^{+2}	Mg^{+2}	K^+	Na^+
January 19th–February 18th, 1982	5.00	28.3	81.0	118.0	3.0	48.0	67.0	16.0	10.0	–
	(0.20)	(7.3)	(8.6)	(15.0)	(0.8)	(5.3)	(10.5)	(2.6)	(1.5)	
February 18th–March 28th,	7.37	5.6	12.0	11.0	5.0	32.0	67.0	12.0	3.0	–
March 28th, 1982	(1.50)	(1.3)	(0.8)	(4.3)	(0.7)	(10.0)	(5.3)	(1.6)	(1.0)	
January 4th–February 15th, 1983	7.86	1.1	124.0	362.0	22.0	17.0	276.0	224.0	67.0	194.0
	(2.10)	(0.3)	(5.8)	(20.5)	(6.3)	(8.3)	(15.3)	(12.6)	(13.2)	(6.5)
November 17th–	1.58	1.1	193.0	85.0	3.0	6.0	20.0	58.0	16.0	108.0
February 20th, 1984	(0.90)	(0.2)	(10.5)	(5.6)	(0.2)	(1.6)	(3.2)	(20.2)	(2.5)	(5.8)
February 20th–March 25th 1984	3.64	2.4	262.0	155.0	15.0	94.0	50.0	157.0	26.0	458.0
	(1.10)	(0.5)	(15.0)	(11.0)	(1.7)	(5.7)	(3.6)	(15.2)	(3.2)	(30.6)

Mean value of N = 10; ( ) = standard error.

of dry fall. It was observed that the input rate of ions of the soluble fraction of dry fall varied within and among the dry seasons. The NO_3-N and K^+ depositions were lower as compared to other ions.

Discussion

Soluble constituents determined in the bulk precipitation and in dry deposition of the Trachypogon savannas during three consecutive years (May 1st 1981 to April 30th 1984) were within the range of values reported in the literature for the tropics (Meyer & Pampfer 1959; Visser 1961; Thornton 1965; Steinhardt & Fassbender 1979; Jordan et al. 1980; Kellman et al. 1982). An exception was SO_4-S with values much lower than observations in other tropical sites.

Results reported here reflect the effect of dry deposition on the chemical composition of precipitation. Thus, the lack of correlation between ion concentration and precipitation volume might be attributed to seasonal differences in local meteorology, which affects the generation and dispersal of atmospheric aerosols (Brassell & Gilmour 1980).

Nutrients input of soluble constituents in bulk precipitation during the wet season as compared to dry season as expressed by a ratio, range from 2.3 to 7.8 for the three annual courses. These findings indicate that the distribution of rains seems to determine essential differences in nutrient inputs to the system. An exception was the phosphorus ratio with a range of 0.4 to 1.3 times. These results seem to be characteristic of areas with seasonal climate. Lewis (1981) found similar results for the Valencia Lake (Venezuela), a tropical watershed characterized by intensive industrial and agricultural activities. This result could reflect the relatively high concentration of phosphorus in the ashes produced after burning.

Unusual differences in dry deposition chemistry between years (dry season) seem also to be related with differences in the length of the dry season. Thus, lower Mg^{+2} and Ca^{+2} input rates occurred in 1982, a year with shorter dry season. Furthermore, the chemical composition and the input rate of dry deposition apparently also depended on the occurrence of sporadic rains during the dry season, and on the quality and quantity of the combustible material present in the Trachypogon savanna (San Jose & Montes 1987).

Possible sources of the soluble constituents might be related to local acitivities, induced by man, such as the traditional burning of the herbaceous vegetation during the dry season (November to April) to obtain palatable and nutritional food-stuffs for cattle. During the combustion of plant matter, nitrogen and sulfur oxides are released into the atmosphere in either gaseous or particulate forms. These gaseous oxides could be washed out and incorporated to the ecosystem after the rains begin (Bromfield 1974; Raison 1970; Lewis 1981; Lewis & Weibezahn 1981). Vegetation burning as a source of particulates may be evidenced from the analysis of the soluble fraction of particulate material collected during the dry season, which contained relatively higher concentrations of PO_4–P, SO_4–S, Ca^{+2}, Mg^{+2}, K^+ and Na^+ and low concentration of the nitrogen compounds. This ratio might reflect the chemical composition of the ashes from burned savannas (San Jose & Montes 1987). Similar results have been reported by Lewis (1981) who presumed that the absence of NH_4–N and NO_3–N ions in ash samples, is due to vaporization.

Soil dust also could be an important pool of particulates for the wet and dry deposition. The Mg:Ca ratio ranging from 2.77 to 4.22 in the bulk precipitation and from 0.22 to 3.07 in the dry deposition could be due to intra-system cycling of constituents coming from local and regional soils. Analysis of alluvial soils deposited by the main local rivers (Orituco and Guarico) indicate Mg:Ca ratios ranging from 1.50 to 2.11 (San Jose & Montes 1987). The source of these rivers occurs in the Coastal Range (less than 200 Km north) where deposits of ultrabasic rocks, consisting essentially of ferromagnesian minerals, are present (Ministerio Minas Hidrocarburos 1970).

Other possible sources of soluble consitituents in the bulk precipitation include local recycling by biological processes (Henzell & Ross 1973; Alexander 1977; Stutte et al. 1979), soil organic matter, microbial cell debris and pollen (Dalal 1978; Visser 1961), marine source (Eriksson 1952a, b) and atmospheric pollution (Prospero 1979) which should also be investigated in the Trachypogon savannas. On those lines, the ratio approaches could be used (Schlesinger & Hasen 1980; Schlesinger et al. 1982) for separating the deposition of new nutrients from the local recycling of nutrients in ashfall and soil dust. The mean Ca:Na ratio (0.69) for the monthly deposition of these ions in bulk precipitation suggested an enrichment of Ca ion in bulk precipitation. This ratio was relatively higher as compared to the ratio calculated (0.04) for sea water (Masson 1966). The K:Na (1.30 and 0.46 for 1982 and 1983 data) and Mg:Na ratios (2.70 and 3.01 for 1982 and 1983 data) in bulk precipitation were also higher than those ratios for the seawater (0.04 and 0.13, respectively) (Masson 1966) suggesting an enrichment of K and Mg. In relation to the analysis of dry deposition, the ratios (Ca:Na, K:Na, and Mg:Na) decrease as concentration of Na increased. These results indicated that marine aerosol could be an important source during the dry season when prevalence of the easterly trade winds. Similar findings have been previously reported by Sanhueza et al. (1986).

Table 3. Annual input of chemistry precipitation of the Trachypogon savanna at the Orinoco Llanos. Other tropical localities are included for comparison.

Locality	PO_4–P	SO_4^{-2}	NO_3–N		NH_4N (Kg ha^{-1} year^{-1})	Ca^{+2}	Mg^{+2}	K^+	Na^+	H^+	Source
Yoroberi-Kunda, Gambia	0.27	–[a]	–	(14.43)[b]	–	1.70	–	2.84	5.91	–	Thornton 1965
Kade, Ghana	0.41	–	–		–	12.65	11.30	17.47	–	–	Nye 1961
Adiopodoum, Ivory Coast	1.60	–	–		–	24.00	4.30	5.80	–	–	Bernhard-Reversat 1975
Siguatepeque, Honduras	0.50–0.10[c]	–	0.11–0.40		–	2.46–18.34	0.58–18.53	1.52–3.22	–	–	Kellman et al. 1982
St. Joseph Manzanilla Trinidad	–	32.30		(16.40)		34.70	7.5	19.30	40.90	–	Dalal 1979
Emas, Brazil	0.94	35.80	–		–	5.60	0.90	2.57	3.48	–	Coutinho 1979
La Carbonera, Venezuela	1.10	11.80		(9.90)		5.60	5.23	2.60	3.26	0.81	Steinhardt & Fassbender 1979
San Carols de Río Negro Venezuela	24.79	44.33	–		21.20	27.00	3.37	23.41	–	–	Jordan et al. 1980
Valencia Lake Watershed Venezuela	0.30	16.30	1.28		2.43	8.60	5.47	4.28	16.6	3.25	Lewis 1981
Mantecal, Venezuela	0.75	–	–		–	2.78	1.31	3.76	6.90	–	López-Hernández et al. 1983
Calabozo, Venezuela	0.43	3.85	0.07		1.97	2.13	5.94	3.07	–	0.02	This study (1981–82)
	0.31	2.87	0.29		3.07	3.76	15.23	5.09	4.67	0.03	This study (1982–83)
	0.52	1.16	0.26		1.05	4.61	12.75	2.68	7.22	0.04	This study (1983–84)

[a] = non-measured; [b] = total nitrogen; [c] = range.

The present study indicates that nutrient input from bulk precipitation and dry deposition (Table 3) seems to supply some of the nutrients necessary for annual growth of the herbaceous vegetation in the Trachypogon savanna. Thus, comparing the calculated input of N, P and K with the respective amounts present in the total vegetation biomass, including the above ground biomass and the functional belowground phytomass (San Jose & Montes 1987) suggests that atmospheric deposition supplied only 19.5, 17.4 and 30.7%, respectively of the total amount of nutrients required for a burned Trachypogon savanna to reach a maximum biomass of 482.33 $g\,m^{-2}$ during the growth season (San Jose & Montes 1987). An exception to this trend was Mg input, which was 3.0 fold higher than necessary for the vegetation. If we suppose that nutrients lost from the system after burning are partially recycled through precipitation and sedimentation of particles, then an additional source of nutrients could be the bare soil, which is easily eroded by wind. The role of the wind erosion as a recycling mechanism might be evidenced from the high proportion of annual input supplied as dry deposition.

Nutrient input from the sources analyzed to the Trachypogon savannas, of extreme oligotrohpic soils, seems to be an important pool for the function of the savanna ecosystem and further studies could be profitable for understanding the nutrient cycle in these savannas. Thus, it could be necessary to establish the strength of these sources in relation to insoluble constituents, which make up a high proportion of the particulate matter (Lewis 1981).

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References

Alexander M (1977) Introduction of Soil Microbiology. 2nd edition. Wiley and Sons, New York

Aristeguieta L (1965) Flórula de la Estación Biológica de los Llanos. Boletin de la Sociedad Venezolana de Ciencias Naturales 26: 228–307

Bernhard-Reversat F (1975) Nutrients in throughfall and their quantitative importance in rain forest mineral cycles. In: Golley F & Medina E (Eds) Tropical Ecological Systems, Ecological Studies II (pp 153–159) Springer-Verlag, New York

Blydenstein J (1962) La sabana de Trachypogon del Alto Llano. Boletin de la Sociedad Venezolana de Ciencias Naturales 23: 139–206

Brasell H & Gilmour D (1980) The cation composition of precipitation at four sites in far north Queensland. Australian Journal of Ecology 5: 397–405
Bromfield AR (1974) The deposition of sulfur in the rainwater in Northern Nigeria. Tellus B 26: 408–411
Conover WJ (1980) Practical non Parametric Statistics. 2nd edition. Wiley and Sons, New York
Coutinho LM (1979) Aspectos ecologicos do fogo no cerrado. III. A precipitacao atmosferica de nutrients minerals. Revista Brasilera de Botanica 2: 97–101
Dadal RC (1979) Composition of Trinidad rainfall. Water Resources Research 15: 1217–1223
Environmental Protection Agency (1979) Methods for chemical analysis of water and wastes. E.P.A. Pub. 600: 4–79–020
Eriksson E (1952a) Composition of atmospheric precipitation. I. Nitrogen compounds. Tellus B 4: 215–230
Eriksson E (1952b) Composition of atmospheric precipitation. II. Sulfur, chloride, iodine compounds. Tellus B 4: 280–303
Escobar A (1977) Estudio de las sabanas inundables de *Paspalum fasciculatum*. Thesis Magister Scientiarum. Instituto Venezolano de Investigaciones Ciéntificas. Caracas. Venezuela
Golterman HL (1969) Method for chemical analysis of fresh water. Int. Biological Programme Handbook No. 8. Blackwells, Oxford, England
Henzell EF & Ross PJ (1973) The nitrogen cycles of pastures ecosystems. In: Butler G & Bailey R (Eds) Chemistry and Biochemistry of Herbage. Vol. 2. (pp 227–246) Academic Press, New York
Jordan C, Golley F & Hall J (1980) Nutrient scavenging of rainfall by the canopy of an Amazonian rain forest. Biotropica 12: 61–66
Kamphake LJ, Hannak SA & Cohen JM (1967) Automated analyses for nitrate by hydrazine reduction. Water Resources Research 1: 206–211
Kellman M, Hudson J & Sanmugadas K (1982) Temporal variability in atmospheric nutrient influx to a tropical ecosystem. Biotropica 14: 1–9
Lewis WN Jr (1981) Precipitation chemistry and nutrient loading by precipitation in a tropical watershed. Water Resources Research 17: 169–181
Lewis WN Jr & Weibezahn F (1981) Acid rain and major seasonal variation of hydrogen ion loading in a tropical watershed. Acta Científica Venezolana 32: 236–238
Lopez-Hernandez D, Sosa M, Yanez L & García L (1983) Annual budgets of some elements in a flooded savanna (Modulo Experimental, Mantecal, Venezuela). Environmental Biogeochemistry. Ecol. Bull. (Stockholm) 35: 541–545
Masson B (1966) Principles of Geochemistry. 3rd edition. Wiley and Sons, New York
Meyer J & Pampfer E (1959) Nitrogen content of rain water collected in the humid Central Congo Basin. Nature 29: 714–718
Ministerio Minas Hidrocarburos (1970) Léxico Estratigráfico de Venezuela. 2nd edición Editorial Sucre. Caracas
Monasterio M & Sarmiento G (1968) Análisis ecológico y fisiológico de la sabana en la Estación Biológica de los Llanos. Boletín de la Sociedad Venezolana de Ciencias Naturales 27: 43–114, 477–524
Montes R, San Jose JJ, García-Miragaya J & Parra N (1985) pH of bulk precipitation during 3 consecutive annual courses in the Trachypogon savannas of the Orinoco Llanos, Venezuela. Tellus B 37: 304–307
Noether GE (1956) Two sequential tests against trends. Journal of American Statistical Association 51: 440–450
Nye PH (1961) Organic matter and nutrient cycles under moist tropical forest. Plant and Soil 13: 333–346

Prospero JN (1979) Mineral and sea salt aerosol concentration in various ocean regions. Journal of Geophysical Research 84: 725–731

Raison RJ (1979) Modification of the soil environment by vegetation fires, with particular references to nitrogen transformations. A review. Plant and Soil 51: 73–108

Sanhueza E, Serrano J & Bifano C (1986) Preliminary determination of trace elements during vegetation burning season in the Venezuelan savannah atmosphere. In: Lester JN, Perry R & Steritt RM (Eds) Chemicals in the Environment (pp 348–353) Proceeding International Conf. Lisbon Portugal

San Jose JJ, Berrade F & Ramirez J (1982) Seasonal changes of growth, mortality and disappearance of belowground root biomass in the Trachypogon savanna grass. Acta Oecologica 17: 347–358

San Jose JJ & Garcia-Miragaya J (1982) Factores operacionales en la producción de materia nica de las sabanas de Trachypogon. Boletín de la Sociedad Venezolana de Ciencias Naturales 139: 347–374

San Jose JJ & Montes R (1987) Comparación entre las comunidades vegetales de los llanos del Orinoco. Informe Final del Proyecto S1DF.DC.FORT-1EBLL. CONICIT, Caracas, Venezuela. 749 pp

San Jose JJ, Montes R, Garcia-Miragaya J & Orihuela B (1985) Bio-production of Trachypogon savannas in a latitudinal cross-section of the Orinoco Llanos, Venezuela. Acta Oecologica 6: 25–43

Schlesinger WH & Hasey M (1980) The nutrient content of precipitation, dry fallout, and intercepted aerosols in the chaparral of southern California. American Midland Naturalist 103: 114–122

Schlesinger WH, Gray JT & Gilliam FS (1982) Atmospheric deposition processes and their importance as sources of nutrients in a chaparral ecosystem of southern California. Water Resources Research 18: 623–629

Smith G, Brito P & Luque O (1977) The litoplinthic horizon, a diagnostic horizon for soil taxonomy. Journal of Soil Science Society of America 41: 1212–1214

Steinhardt U & Fassbender HW (1979) Características y composición química de las lluvias de los Andes Occidentales de Venezuela. Turrialba 29: 175–182

Stutte CA, Weiland RT & Blem AR (1979) Gaseous nitrogen loss from soybean foliage. Journal of Agronomy 71: 95–97

Thornton I (1965) Nutrient content of rainwater in the Gambia. Nature 20: 1025

Visser S (1961) Chemical composition of rainwater in Kampala, Uganda, and its relation to metereological and topographical conditions. Journal of Geophysical Research 66: 3759–3765

Whitehead HG & Feth JH (1964) Chemical composition of rain, dry fallout and bulk precipitation at Menlo Park, California, 1957–1959. Journal Geophysical Research 69: 3319–3333

Wetselaar R & Hutton JT (1963) The ionic composition of rainwater at Kathering N.T., and part in the cycling of plant nutrients. Australian Journal of Agriculture Research 14: 319–329

Will GM (1959) Nutrient return in litter and rainfall under some exotic conifer stands in New Zealand. New Zealand Journal of Agriculture Research 2: 719–734