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STATISTICAL MODEL FOR ESTIMATING N-P-K DEPOSITION FROM PRECIPITATION IN AGROECOSYSTEMS OF THE BRAZILIAN SEMI-ARID REGION

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Resumo

Modelo estatístico para estimativa da deposição de N-P-K da precipitação em agroecossistema do semiárido brasileiro. O objetivo do estudo foi ajustar um modelo estatístico linear para estimar a entrada de N, P, e K, por meio da precipitação pluviométrica, em agroecossistemas da região Agreste da Paraíba. Os dados para a parametrização do modelo foram obtidos em experimento de campo conduzido no município de Esperança, Paraíba, no período de janeiro a dezembro. Utilizou-se a estatística descritiva, inferencial e probabilística para o desenvolvimento metodológico deste estudo. As equações obtidas pelo modelo linear podem ser usadas para a estimativa da deposição de nutrientes através da precipitação pluviométrica em condições climáticas similares às da região em estudo. Deve-se ressaltar a necessidade de estudos comparativos com outros sistemas produtivos praticados na região, para validação dos dados e do modelo.
Palavras-chave: ciclagem, nitrogênio, fósforo, potássio, agreste.

Abstract

The objective of the study was to adjust a linear statistical model to estimate the input of N, P, and K, through rainfall, in agroecosystems in the Agreste region of Paraíba. The data for the parameterization of the model were obtained in a field experiment conducted in the municipality of Esperança, Paraíba, from January to December. Descriptive, inferential and probabilistic statistics were used for the methodological development of this study. The equations obtained by the linear model can be used to estimate nutrient deposition through rainfall in climatic conditions similar to those of the region under study. The need for comparative studies with other production systems practiced in the region must be highlighted, to validate the data and the model.
Keywords: cycling, nitrogen, phosphorus, potassium, agreste

INTRODUCTION

In the Brazilian Semi-Arid Region (SAB), family farming predominates over other agrarian systems implemented in the countryside. These systems are characterized by the low use of external agricultural inputs. Under these conditions, nutrient deposition through rainfall is an important process in the biogeochemical cycling of nutrients (TIECHER *et al.*, 2013). Nutrient input via rainfall can occur through various processes, such as: (1) direct incidence on the soil without interaction with tree canopies, known as total precipitation, (2) through canopy wash-off and deposition on the soil, or throughfall, and (3) by stemflow and soil infiltration (GIGLIO; KOBIYAMA, 2013).

According to Perez-Marin *et al.* (2008), in the first process, nutrient input into the system results directly from the total precipitation composition in terms of elements necessary for plant nutrition. In this situation, the absorption of these nutrients by plants can occur either after water infiltration into the soil or, to a lesser extent, through foliar absorption of nutrients contained in the portion of precipitation intercepted by vegetation. In the second and third processes (throughfall or stemflow), rainwater, as it passes through the canopy, carries particulate material deposited on the surface of leaves, trunks, and vegetative tissues during dry periods, leading to changes in the chemical composition of the rainwater as it penetrates the soil (SCHROTH *et al.*, 2001; NUNES *et al.*, 1986; BIALKOWSKI; BUTTLE, 2015; LIU *et al.*, 2015).

For some mineral nutrients, the inputs to the soil occurring through these wash-off processes can exceed the amount normally returned to the soil via litter decomposition (RODRIGUES *et al.*, 2015; DICK; SCHUMACHER; ARAÚJO, 2020). Thus, the use of plant species that contribute to the deposition of organic material is important, as it improves the physical-chemical quality of the soil in terms of the nutritional content accumulated in vegetative tissues and their release, thereby maintaining soil fertility and biota (REIS *et al.*, 2012;

SILVA *et al.*, 2014). Experimental studies conducted by Perez-Marin *et al.* (2008) in an agroforestry system in the Agreste region of Paraíba demonstrated the input of essential nutrients through different deposition processes. They observed that of the total rainfall, 67% was throughfall, 0.74% was stemflow, and 32% was intercepted by the tree canopies. The nitrogen (N) and phosphorus (P) levels were similar in the throughfall and stemflow water samples, but these were approximately 300% higher when compared to the rainwater deposited directly on the soil.

The potassium (K) content in the stemflow water was approximately 100% and 600% higher than in the throughfall water and rainwater, respectively. The average inputs of N, P, and K to the soil were 5; 1; and 24 kg ha-1 in rainwater; 9; 2; and 62 kg ha^{-1} in throughfall water; and 0.12; 0.02; and 1 kg ha^{-1} in stemflow water, respectively. These results demonstrate the importance of understanding the dynamics of these processes for the sustainability of agricultural systems with low use of external inputs.

Thus, this study aims to understand the dynamics of essential nutrient (N, P, and K) deposition through rainfall in low-input agricultural systems. In this context, mathematical models capable of simulating essential element deposition can be an extremely useful tool for understanding and optimizing resources and nutrient flows.

Therefore, this study is based on the hypothesis that rainfall influences the deposition of essential nutrients. To this end, the objective was to adjust a linear regression mathematical model to estimate the flux of essential nutrients (N, P, and K) via rainfall and to understand the deposition through rainfall.

MATERIALS AND METHODS

Location and Characterization of the Research Area

The field study was conducted at the São Miguel Agroecological Center (CASM), the headquarters of the Non-Governmental Organization (NGO) Assessoria e Serviços a Projetos de Agricultura Alternativa (AS-PTA), located in the municipality of Esperança, in the Agreste region of Paraíba (7º19'S and 33º51'W), over a 12-month period (January to December). The region is characterized by a rainy season, from March to July, and a dry season, from September to December, with an annual rainfall of 750 mm, an average annual temperature of 22.5 °C, and relative humidity ranging from 80% to 85% (FRANCISCO *et al.*, 2018). The soil in the experimental area is classified as a Regolithic Neosol (EMBRAPA, 2013).

Data collection

Daily rainfall data (mm day^{-1}) were collected using four Ville de Paris rain gauges, each with a diameter of 20 cm and a catchment area of 314 cm^2, installed at a height of 1.50 m above ground in an open area. The readings from the rain gauges were taken after each rainfall event, within a maximum of 2 hours after the end of each event.

For each rainfall event, 50 ml subsamples were collected for subsequent determination of nitrogen (N), phosphorus (P), and potassium (K) levels. The samples and subsamples were stored in polyethylene containers, which were thoroughly washed with 6 mol L^{-1} HCl, followed by tap water and deionized water, as recommended by Likens *et al.* (1967). Before storing the subsamples, the containers were rinsed with water from the collected samples. The samples and subsamples collected in the field were frozen and stored until laboratory analysis, in accordance with the procedures outlined by Likens *et al.* (1967).

The concentrations of N, P, and K were routinely determined in the laboratory. Potassium levels were analyzed using flame photometry, phosphorus by colorimetry, and nitrogen by colorimetry using a Technicon Auto-Analyzer. The analyses were conducted at the Soil and Plant Fertility Laboratory of the Department of Nuclear Energy at the Federal University of Pernambuco.

Data processing and analysis

Descriptive statistics were employed throughout the processing and analysis of the collected data. This methodology included measures of central tendency, specifically the arithmetic mean, as well as measures of dispersion, including variance and standard deviation. Additionally, graphical statistics were utilized. The correlation analysis involved examining the relationship between precipitation and the quantities of nitrogen, phosphorus, and potassium, as expressed by the following formula:

$$\text{Correl} = \frac{\text{Cov}(x,y)}{\text{SxSy}} \quad (1)$$

Where, Cov (x,y) represents the covariance between precipitation (x) and nutrient levels (y), and Sx and Sy are the standard deviations of x and y, respectively.

A linear regression model was employed, given by:

$$y_i = \alpha + \beta x_i + U_i \quad (2)$$

Where Y_i is the nutrient variable, X is precipitation, α and β are the intercept and slope coefficients, respectively, and U_i is the random error component.

The Student's t-distribution was applied to assess the significance of the adjusted equations, with the hypotheses stated as follows: H*o* (null hypothesis) is the statistical hypothesis to be assessed, and H_1 is different from zero. Specifically:

If H_0: β = 0, the equation is not significant, meaning the phenomenon can be attributed to chance. However, if H1: β ≠ 0, the regression is significant and can therefore be used in modeling the dynamics of the phenomenon.

Rejection of H_0 implies acceptance of H_1. The alternative hypothesis represents the assumption we wish to prove, with H_0 being formulated expressly to be rejected.

A significance level of 5% was used to evaluate the theoretical "t_b" (tabulated) and the calculated "t_c" values, according to the following expression:

$$t_c = \frac{b}{\frac{S}{\sqrt{\text{Sxx}}}} \quad (3)$$

Where t is the critical value of the distribution, b is the slope of the regression, and Sxy and Sxx are the standard deviations of the data.

The values of tb (tabulated critical value) and tc (calculated critical value) were analyzed according to the Student's t-distribution.

If *m* is an unbiased estimator of an unknown population parameter *M*, with variance σ² (*m*), we can construct a confidence interval for *M* with a confidence level of (1-α) %" (Fonseca, 2006). Thus, we have the following expression:

$$P = \left(b - t\frac{\alpha}{2}\frac{S}{\sqrt{\text{Sxx}}} \leq \beta \leq b + t\frac{\alpha}{2}\frac{S}{\sqrt{\text{Sxx}}}\right) = 1 - \alpha \quad (4)$$

Where t, with n-2 degrees of freedom, is the critical value of the distribution, *b* is the slope coefficient of the regression, and Sxy and Sxx are the standard deviations of the data.

RESULTS

The *in situ* collected rainfall data were classified according to the magnitude of the precipitation and its daily totals. The daily rainfall intensity ranged from 0.6 mm to 67.4 mm, indicating the occurrence of precipitation from low intensity to heavy torrential rains (Figure 1).

The daily accumulated rainfall values ranged from 0.6 mm to 67.4 mm, indicating the occurrence of precipitation from low intensity to torrential (Figure 1).

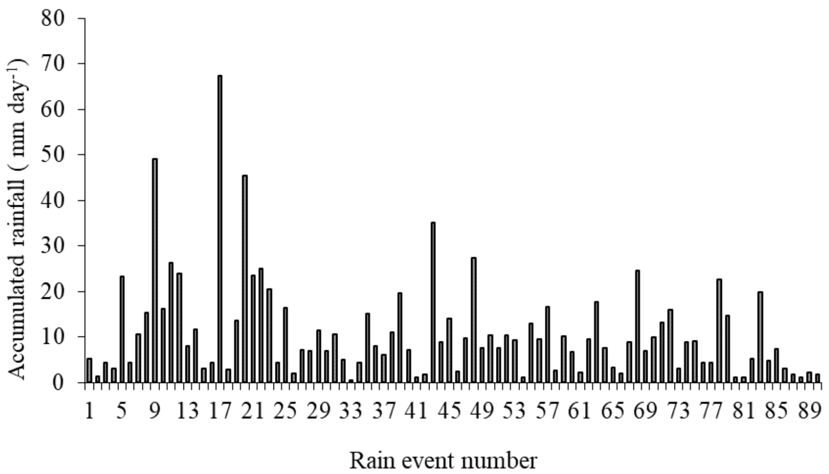

Figure 1. Accumulated rainfall (mm day^{-1}), from January to September 2004, Esperança – PB.
Figura 1. Precipitação pluviométrica acumulada (mm day^{-1}), no período de janeiro a setembro de 2004, Esperança – PB.

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Descriptive statistics showed that both precipitation and nutrient levels exhibited strong temporal variability (Table 1).

Table 1. Descriptive statistic of accumulated rainfall (mm day^{-1}), nitrogen (N), phosphorus (P) and potassium (K).
Tabela 1. Estatística descritiva da precipitação pluviométrica acumulada (mm dia^{-1}), nitrogênio (N), fósforo (P) e potássio (K).

Descriptive Statistics	Precipitation	N	P	K
	----------mm day^{-1}---------	--------------------------g ha^{-1}---------------------		
Mean	11,00	60,41	14,06	268,44
Standard deviation	10,97	64,51	18,30	276,80
Coefficient of variance	99,38	106,79	130,14	103,11
Minimum	0,60	3,42	0,97	14,62
Maximum	67,40	404,40	114,58	1728,17

The analysis of accumulated rainfall revealed an average of 11.00 mm per day, with strong temporal variability, as indicated by a standard deviation of 10.97 mm and a coefficient of variation of 99.38%. The coefficient of variation exceeding 100% for all nutrients (N, P, K) indicates significant variability in the samples, suggesting a complex behavior of these nutrients over time.

For the nutrients, the average nitrogen (N) was 60.41 g ha^{-1}, with a standard deviation of 64.51 g ha^{-1} and a coefficient of variation of 106.79%. Phosphorus (P) had an average of 14.06 g ha^{-1}, with a standard deviation of 18.30 g ha^{-1} and a coefficient of variation of 130.14%. Potassium (K) had an average of 268.44 g ha^{-1}, with a standard deviation of 276.80 g ha^{-1} and a coefficient of variation of 103.11%.

The minimum and maximum values indicate the range of the data. For example, the minimum precipitation was 0.60 mm per day, while the maximum was 67.40 mm per day. For the nutrients, the minimum and maximum values also vary significantly, demonstrating the diversity in the samples.

These results suggest that the climatic conditions and nutrient levels in the sample are highly variable, which may have important implications for understanding and managing the agroecosystem under study.

Regarding the correlation between precipitation and the levels of N, P, and K, a strong correlation was observed in all samples analyzed for the macronutrient levels, with N at 0.987, P at 0.876, and K at 0.995. The correlation results encouraged further research to find regression equations that could estimate the amounts of N, P, and K based solely on precipitation (Pp), as shown in Figures 2A, 2B, and 2C.

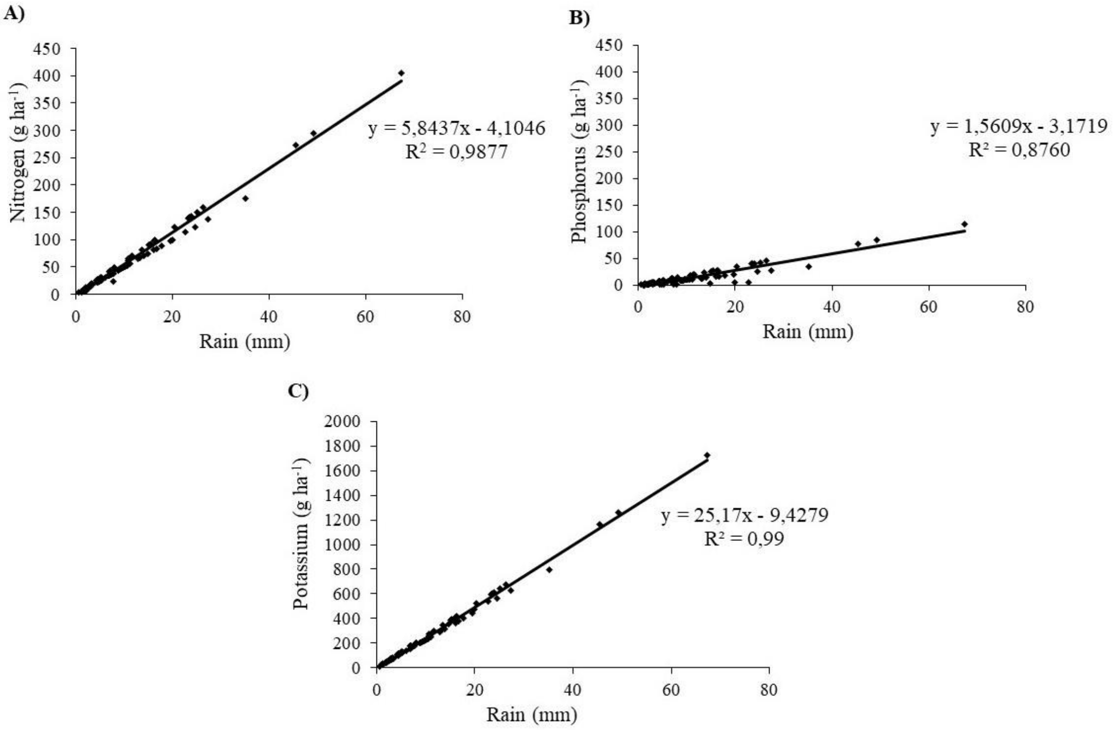

Figure 2. Adjusted regression for three nutrients, as a function of accumulated rainfall, A) Nitrogen; B) Phosphorus; and C) Potassium.

Figura 2. Regressão ajustada para três nutrientes, em função da precipitação pluviométrica acumulada, A) Nitrogênio; B) Fósforo e C) Potássio.

Thus, the scatter plots showed that the behavior is linear, and the regression models provided excellent results, with a satisfactory coefficient of determination (R^2) for N, P, and K, respectively (Figures 3A, 3B, and 3C).

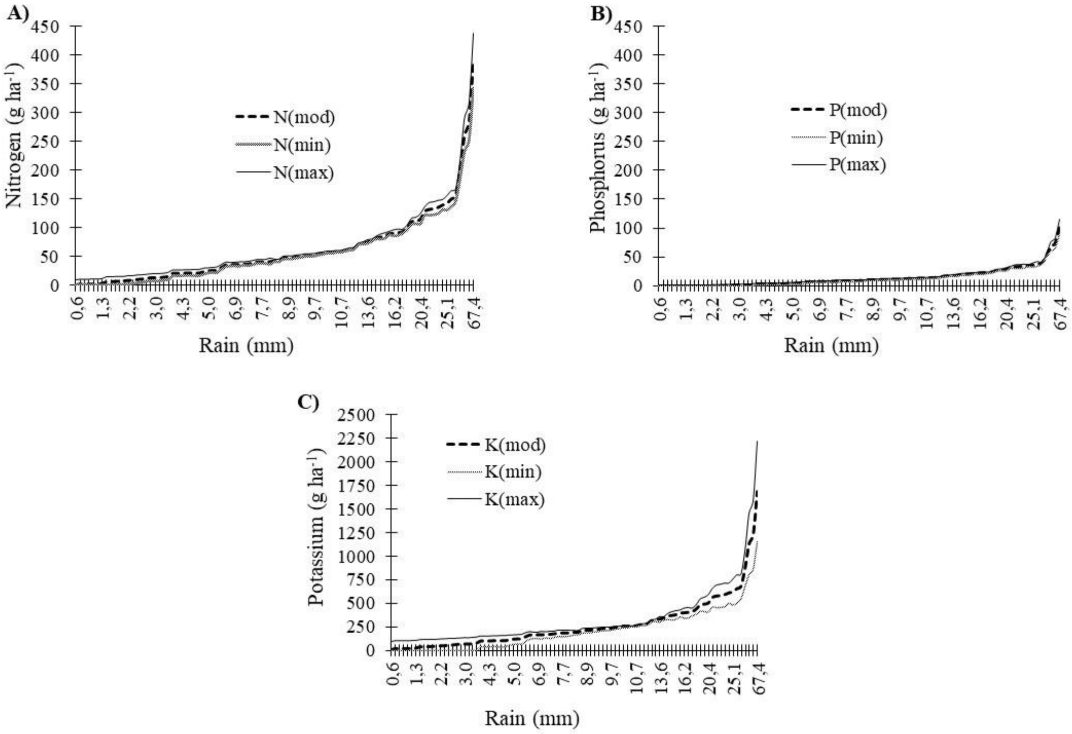

Figure 3. A) Modeling of Nitrogen; B) Phosphorus; and C) Potassium; as a function of precipitation, with confidence interval, respectively.

Figura 3. A) Modelagem do Nitrogênio; B) Fósforo; e C) Potássio, em função da precipitação, com intervalo de confiança, respectivamente.

By fixing the confidence level and calculating the t variable with 89 degrees of freedom (df), the Critical Region and Acceptance Region for H_0 were determined. A value of tb = 1.99314 was found using the Student's t-table. The calculated t (tc) for the nutrients was evaluated using Equation 3: N = ±84.52375; P = ±25.06956; and K = ±137.9393. Since the absolute values of tc for all nutrients (N, P, and K) were greater than the theoretical tb (1.99314), H_0 was rejected, concluding with a 5% risk that a significant linear regression exists. Based on these results, a higher confidence level was required, leading to an evaluation of the confidence intervals for the estimates of N, P, and K. The analysis showed minimal variability around the value calculated by the regression model, with mean percentage errors of 15.25% (N), 8.02% (P), and 8.55% (K).

DISCUSSION

The temporal and spatial variability of rainfall in the Northeast of Brazil (NEB) is caused by various atmospheric systems due to the high daily energy availability (OLIVEIRA JÚNIOR *et al.*, 2021), which directly influences the concentrations of macronutrients (N, P, and K) entering the soil through precipitation.

The primary atmospheric system responsible for rainfall in the Northeast of Brazil (NEB), particularly from January to April, is the Intertropical Convergence Zone (ITCZ). This system is characterized by a band of convective clouds extending across the equatorial region. According to Oliveira Júnior *et al.*, 2021, several multiscale meteorological systems interfere with its variability and intensity in the NEB region. In addition to the ITCZ, the region also experiences the South Atlantic Convergence Zone (SACZ), Frontal Systems (FS), Tropical Cyclonic Vortices (TCV), Disturbances in Trade Winds (DTW), sea breezes, Trade Wind Inversion Layer (TWIL), Eastern Wave Disturbances (EWD), and Instability Lines (IL) (LYRA *et al.*, 2014; SILVA *et al.*, 2018; SOUZA *et al.*, 2020; RODRIGUES *et al.*, 2020; COSTA *et al.*, 2020).

Regarding applicability, the equations obtained from the linear model (Figures 2A, 2B, and 2C) can be used to estimate nutrient input via precipitation under conditions resembling those of the experimental area (Figures 3A, 3B, and 3C).

In this study, it was estimated that the rainfall contributed annually approximately 5.0, 1.0, and 24.0 kg ha^{-1} of N, P, and K, respectively. Data obtained from other regions show values resembling those observed in this study. For example, Schroth *et al.* (2001) reported annual depositions of N, P, and K via precipitation (Pp) of 5.0, 0.07, and 2.6 kg ha^{-1}, respectively, while Nunes *et al.* (1986) reported annual values for P and K of approximately 11.1 and 19.4 kg ha^{-1}, respectively. The differences between the studied systems, vegetation, rainfall, methodologies, and sampling intensity explain the variations in nutrient inputs via precipitation.

Cruz *et al.* (2018) obtained an adjusted regression coefficient similar to those obtained in the present study when evaluating nutrient input in relation to precipitation. The results highlight the importance of modeling nutrient flows via precipitation as a strategy for sustainable soil and water use in semi-arid regions, where the use of external resources such as mineral fertilizers is low due to the financial constraints of most farmers (PEREZ-MARIN *et al.*, 2008). These mechanisms, through modeling, could be optimized, leading to reduced soil, nutrient, and water losses from erosion, leaching, and subsurface runoff (SARI *et al.*, 2016).

It is important to note that the developed model applies to the environmental conditions where the study was conducted and to areas with similar climatic conditions. However, there is a need for complementary studies across the diverse agroecological situations found in the Brazilian semi-arid region (SAB) to generate comparative data that would allow for the validation of models and their extrapolation to larger areas. The SAB extends over more than 900,000 km², encompassing a rich diversity of ecological, social, and cultural situations that form a mosaic of agroecological scenarios (ALBUQUERQUE; MELO, 2018). The SAB covers at least a sizable portion of 17 of the 20 landscape units into which the Northeast was divided and 105 of the 172 geoenvironmental units identified in the region (LIMA, 2014).

CONCLUSIONS

- Daily accumulated precipitation data in the municipality of Esperança – PB revealed the presence of several synoptic systems involved in the precipitation process, which, along with its variability, influences the nutrient content derived from rainfall.
- The simple linear model proved effective in estimating the nutrient flow (N, P, and K) through precipitation for the Agreste Paraibano region. It has the potential to optimize the fertilization processes for family farming in the Brazilian semi-arid region, as proposed in the hypothesis and objectives.
- The adjusted model can serve as a basis for the quantitative analysis of nutrients and monitoring the dynamics of phenomena in agroecosystems of the Brazilian semi-arid region. However, new tests are needed in other agroecosystems and under different environmental conditions, including new methodological approaches.

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