DOI: <http://dx.doi.org/10.1590/1807-1929/agriambi.v19n10p926-930>

Critical levels for soil attributes in irrigated banana plantations in semiarid region

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Key words:

soil fertility
modelling
Musa spp.

ABSTRACT

This study aimed to estimate the critical levels for soil chemical attributes through the criterion of reduced continuous probability distribution (NCRIZ) in areas under irrigated banana cultivation and evaluate soil fertility of low-yield areas in the Apodi Plateau. A dataset composed of analysis of 60 producing areas and their respective yields was used. It was concluded that the method can be used to obtain critical levels for soil chemical attributes and the critical levels obtained for the irrigated areas under banana cultivation corresponded to 7.2 for pH, 0.91 g kg⁻¹ for N, 0.31, 6.34, 2.63, 1.42 and 25.76 mg kg⁻¹ for Cu, Fe, Mn, Zn and P, respectively, and 6.43, 1.14, 0.24 and 0.36 cmol_c kg⁻¹ for Ca, Mg, Na and K, respectively. In the low-yield areas, the highest deficiencies were of P and Fe, and there was an excess of Mg.

Palavras-chave:

fertilidade do solo
modelagem
Musa spp.

Nível crítico para atributos do solo em áreas de bananeira irrigada em região semiárida

RESUMO

Propôs-se, neste trabalho, estimar os níveis críticos para atributos químicos do solo pelo critério da distribuição contínua de probabilidade reduzida (NCRIZ) em bananeira irrigada e avaliar a fertilidade do solo em áreas de baixa produtividade da cultura na Chapada do Apodi; utilizou-se, para isto, banco de dados constituído por análises de 60 áreas produtoras, suas respectivas produtividades. Os níveis críticos obtidos para as áreas cultivadas com a bananeira irrigada foram de 7,2 para pH, 0,91 g kg⁻¹ para N, 0,31, 6,34, 2,63, 1,42 e 25,76 mg kg⁻¹ para Cu, Fe, Mn, Zn e P, respectivamente e de 6,43, 1,14, 0,24 e 0,36 cmol_c kg⁻¹ para Ca, Mg, Na e K, respectivamente. Nas áreas com baixa produtividade as maiores deficiências foram de P e Fe e excesso de Mg.

INTRODUCTION

Brazil stands out as one of the countries with the largest productions of banana, with total of more than 6.97 million tons in an area of 486,991 thousand hectares in 2011 (FAO, 2011), and a current increasing number of irrigated areas. The main banana production centers in Brazil are: Bahia; the Ribeira Valley, in the southern coast of São Paulo; north of Minas Gerais; the northern coast and the Itajaí Valley, in Santa Catarina; the Açu Valley, in Rio Grande do Norte; and the Apodi plateau, in Ceará. In the case of Ceará, part of the production is concentrated in the irrigated district of Jaguaribe-Apodi, located in the Apodi Plateau, which stands out for the agricultural potential of its soils, originated from limestone, with good natural fertility and flat relief, favorable to mechanization. Cambisols are the predominant types of soil in this region and show high variability with respect to the properties affecting plant production (Costa et al., 2011).

The critical level for soil nutrients is obtained through calibration experiments at the field, by applying doses of the nutrient and obtaining crop yield. Once the dose with the highest economic efficiency is estimated, the critical level of the nutrient in the soil is obtained by associating the relation to the amounts recovered by the extractor as a function of the applied doses. Therefore, not only the extractor is taken into account in the calibration, but also the obtained yield and, based on the critical levels, it is possible to define a fertilizer dose to be applied according to the soil analysis. The soil analysis provides a measure of the phytoavailability, whether of the factor intensity (immediately available) or the factor quantity (available amount), and can be used as a guide for crop fertilization. Although the analytical determination of soil chemical attributes is relatively easy, it is difficult to relate analytical data to phytoavailability and to plant growth/development (Kopittke & Menzies, 2007).

For the determination of the critical level in the leaves without the need for field experiments, Maia et al. (2001) proposed a method based on the reduced continuous probability distribution (NCRIZ). Good results were observed for coffee plants by the same authors and the method was also evaluated in other crops, such as grape (Tonin et al., 2009), orange (Camacho et al., 2012) and sugarcane (Santos et al., 2013). Although the NCRIZ method was originally developed for leaf analysis, Souza et al. (2014) used it to estimate the critical level of some soil chemical attributes in family farming areas cultivated with maize and cowpea, in the 'Sertão' of Inhamuns-Crateús. According to the results, it is possible to obtain critical levels for soil attributes, without the need for installation and conduction of field experiments.

Therefore, determining the critical levels for soil chemical attributes will allow a more detailed interpretation of soil nutritional analysis and can sort the factors by the limitation of agricultural yield for many areas. Thus, it makes it possible to correct the problems, avoids the excessive use of fertilizer and decreases production costs and environmental impacts in the producing region. In this context, this study aimed to estimate the critical levels for soil attributes through the criterion of reduced continuous probability distribution (NCRIZ) in areas

under banana cultivation and evaluate the fertility of low-yield areas in the Apodi Plateau.

MATERIAL AND METHODS

The study was carried out in the region of the Apodi Plateau, located in eastern Ceará, Brazil, approximately 200 km distant from the city of Fortaleza, with geographic coordinates of 50° 04' S and 37° 59' W, and altitudes ranging from 100 to 130 m. According to Köppen's classification, the climate of the region is BSw'h' (hot and semiarid, with rainy season that can occur in the autumn) with temperatures above 20 °C in the coldest month and mean annual rainfall around 800 mm. The relief in the region is flat, with absent stoniness and high permeability (Brasil, 1973). The soils of the Apodi Plateau are classified as Haplic Cambisols (EMBRAPA, 1999) and have, as the parent material, residues of the decomposition of calcareous rock and the calciferous sandstone from the Jandaíra Formation. The contents of P and Zn are low and the depth ranges from 80 to 100 m, without stones and flat relief (Brasil, 1973).

For the calculation of the critical levels of soil chemical attributes, the data of Vasconcelos (2002) were used. This author evaluated 60 production areas cultivated with banana (cv. Pacovan), which were irrigated with water from wells and from the Jaguaribe River, using sprinkler or dripping systems. Soil samples were collected in the layer of 0.0-0.2 m using a Dutch auger and the values of pH and the contents of Ca, Mg, K, Na, P, N, Fe, Zn, Mn and Cu were determined in the laboratory according to the methodology developed by EMBRAPA (1997).

The 60 evaluated areas were classified according to their yields, considering the value of 27 Mg ha⁻¹ as a reference, which resulted in 22 high-yield areas and 38 low-yield areas.

The critical levels in the soil were determined through the methodology of reduced continuous probability distribution (NCRIZ), according to Maia et al. (2001), where Y is yield, ni is the soil attribute for which the critical level is determined and Q is defined as the ratio between Y and ni ($Q = Y/n_i$). The basic assumption to obtain the critical level through NCRIZ is that the data of Y and Q follow normal distribution. The normality of Y and Q was tested using the chi-square method. In case of non-normality, the data were transformed using the square root or the natural logarithm. The critical levels were obtained considering only the high-yield areas and calculated by Eq. 1, where m_1 and s_1 are the arithmetic mean and standard deviation of Y, and m_2 and s_2 the mean and standard deviation of Q, respectively.

$$NCRIZ_i = \frac{1.281552s_1 + m_1}{1.281552s_2 + m_2} \quad (1)$$

The soil fertility of the low-yield areas was evaluated through the I_i index, according to Eq. 2, in which negative and positive values indicate contents lower and higher than NCRIZ_i, respectively. A_i is the result of the soil analysis for each nutrient and NCRIZ_i the estimated critical level of the soil attribute i.

$$I_i = \frac{A_i}{NCRIZ_i} - 1 \quad (2)$$

RESULTS AND DISCUSSION

The critical levels calculated for the soil chemical attributes in the irrigated areas cultivated with banana are shown in Table 1. The values were considered very low for Fe, low for Mn and Cu, medium for Zn, good for P and Mg and very good for K and Ca, and high acidity for pH, according to Alvarez V. et al. (1999). It should be pointed out that the soils in the region originated from calcareous rocks, naturally showing medium or weak acidity, Fe and Mn concretions and low P contents.

Souza et al. (2014), using the same method to calculate critical levels of some soil attributes in family farming areas under maize cultivation in the Sertão of Inhamuns-Crateús, obtained NCRIZ of 6.6 for pH, 8.6 mg dm⁻³ for P and 2.8, 33.3 and 11.12 mmol_c dm⁻³ for K, Ca and Mg, respectively. For beans, these values were 6.5 for pH, 8.2 mg dm⁻³ for P and 2.7, 22.4 and 9.9 mmol_c dm⁻³ for K, Ca and Mg, respectively. For Zn in calcareous soils affected by salts and using DTPA extractor, Khoshgoftarmansh et al. (2012) obtained critical levels of 1.35

and 1.23 mg kg⁻¹ through the methods of Cate-Nelson and Mitscherlich, respectively.

According to the I_i index, P was the main limiting factor (Table 2), with contents ranging from 1 to 19 mg kg⁻¹ and mean of 5.08 mg kg⁻¹ for the 24 least productive areas, and from 23 to 585 mg kg⁻¹ and mean of 167 mg kg⁻¹ for the high-yield areas. This indicates that, because of the natural low fertility of the soils from the Apodi Plateau, especially for the nutrient P, banana plants have responded to P fertilizations, even though part of P is bound with Ca, due to the parent material, which has P-Ca little available to banana plants (Novais & Smyth, 1999). In addition, there was a residual effect caused by years of fertilization, resulting in high P contents, much higher than the critical level calculated for these soils. Increase in P contents in the soil of irrigated areas under banana cultivation was also observed by Nunes et al. (2008) in Minas Gerais.

In the same 24 areas with the lowest yields, there was also an excess in the contents of Mg in 11 areas (45.83%), Mn in 6 (25%), K in 2 (8.33%), Ca in 1 (4.17%) and Na in 4 (16.6%).

Table 1. Critical level for soil attributes through the reduced continuous probability distribution (NCRIZ)

pH	Ca	Mg	Na	K	Cu	Fe	Mn	Zn	P	N
	cmol _c kg ⁻¹				mg kg ⁻¹					
7.12	6.43	1.14	0.24	0.36	0.31	6.34	2.63	1.42	25.76	0.91

Table 2. I_i index of the analysed characteristics in area of irrigated banana in the Apodi Plateau

Area	Yield*	pH	Ca	Mg	Na	K	Cu	Fe	Mn	Zn	P	N
1	20.15	0.05	-0.07	1.37	0.45	-0.36	0.30	-0.05	0.71	0.27	-0.88	0.19
2	20.24	0.00	1.64	0.75	0.90	2.49	0.63	0.58	0.60	-0.01	-0.88	0.19
3	20.34	0.04	-0.02	1.19	0.53	-0.17	-0.02	-0.05	0.45	0.20	-0.92	0.02
4	20.45	-0.04	0.76	2.50	1.73	1.16	0.30	-0.05	0.60	-0.16	-0.92	0.65
5	20.45	0.03	-0.10	1.28	0.16	0.25	-0.02	-0.05	1.70	-0.01	-0.77	0.19
6	20.77	0.04	-0.04	0.93	0.24	-0.36	0.63	-0.05	1.40	0.41	-0.96	-0.13
7	21.13	0.01	0.45	1.37	1.36	0.63	0.63	-0.05	0.41	0.13	-0.81	0.23
8	21.30	-0.04	0.45	1.10	1.40	1.16	0.30	0.26	0.98	0.20	-0.88	0.47
9	21.34	-0.04	1.18	1.63	1.69	1.99	-0.02	-0.05	0.83	0.34	-0.88	0.32
10	21.36	0.03	-0.04	1.80	0.41	-0.17	-0.02	0.10	-0.16	-0.16	-0.61	0.46
11	21.43	-0.07	0.62	1.89	1.85	1.27	0.63	-0.05	1.89	0.20	-0.88	0.04
12	21.45	0.05	0.10	1.19	0.69	0.14	-0.02	-0.21	0.29	0.27	-0.84	0.37
13	21.45	-0.02	-0.33	1.19	-0.13	-0.31	-0.02	0.10	2.04	0.41	-0.61	0.08
14	21.48	0.07	0.43	2.42	0.74	0.25	-0.02	-0.05	0.71	-0.16	-0.84	0.36
15	21.77	-0.03	0.54	1.28	2.10	0.47	0.63	0.42	0.37	-0.01	-0.88	0.34
16	21.79	0.08	3.98	1.10	3.63	2.24	-0.02	0.42	2.16	0.76	-0.88	0.88
17	21.86	0.00	-0.35	1.19	-0.21	-0.14	0.30	0.10	0.98	0.27	-0.69	0.21
18	21.89	0.03	0.37	1.45	0.69	0.14	0.30	-0.05	2.04	-0.09	-0.88	0.35
19	22.10	0.03	0.48	0.93	1.03	0.47	0.63	-0.05	0.03	0.27	-0.88	0.23
20	22.34	-0.03	1.24	0.40	1.98	1.44	0.63	0.42	0.67	0.76	-0.88	0.76
21	22.35	0.00	0.40	1.54	1.23	0.47	0.95	-0.05	0.41	0.34	-0.84	0.36
22	23.32	0.04	1.71	2.42	1.60	1.71	-0.02	0.42	-0.16	1.04	-0.84	0.57
23	25.30	-0.06	0.00	1.10	0.57	0.47	0.30	-0.05	1.44	-0.01	-0.50	0.07
24	25.40	-0.02	0.37	2.33	0.24	1.13	-0.02	-0.05	0.48	1.46	-0.26	0.45
25	25.72	0.11	3.73	1.19	2.56	5.01	0.30	-0.05	0.33	1.39	6.69	1.39
26	25.93	0.03	1.80	2.33	3.09	2.91	1.28	-0.21	0.64	-0.16	19.34	0.72
27	26.06	0.14	1.33	1.10	1.23	1.38	0.95	-0.21	1.13	-0.09	-0.26	0.34
28	26.13	0.08	2.24	1.63	2.51	1.24	0.30	-0.21	-0.01	0.41	3.50	0.85
29	26.35	-0.03	1.96	1.37	0.57	1.63	-0.02	-0.05	1.85	0.48	24.54	2.12
30	26.38	0.01	2.02	2.94	5.08	4.48	0.95	-0.05	0.18	1.11	6.92	0.46
31	26.40	0.07	2.83	2.85	5.37	1.63	0.30	0.10	0.90	1.18	5.09	1.31
32	26.61	0.03	0.71	2.24	0.36	1.58	0.30	-0.21	0.26	1.25	-0.34	0.52
33	26.75	0.12	1.33	1.54	1.27	1.02	0.30	0.26	-0.05	0.20	2.88	0.94
34	26.83	0.12	2.03	1.98	2.43	3.02	-0.02	-0.05	0.86	0.83	5.09	1.10
35	26.85	0.10	2.84	2.77	4.08	3.10	0.95	-0.05	0.60	0.06	10.88	0.86
36	26.86	0.01	1.30	1.10	6.03	0.61	0.95	-0.21	1.05	0.41	0.13	0.68
37	26.89	0.00	0.12	0.14	0.45	1.33	-0.02	0.58	0.33	0.20	4.40	0.53
38	26.96	0.08	1.54	0.93	2.27	1.02	0.95	-0.21	0.56	-0.16	2.49	0.47

*Yield in Mg ha⁻¹

The excess of Mg is probably due to the quality of the irrigation water, especially when the ratio Ca/Mg in the water is lower than 1. However, the excess of Mg in relation to Ca in the irrigation water can contribute to higher absorption of other nutrients. Khanlari & Jalali (2011), evaluating the application of saline water, especially with low Ca/Mg ratio, on P availability, observed that higher Mg content in the irrigation water increased P availability in calcareous soils.

In the 14 areas with the lowest yields, Fe was the most limiting factor and 9 of them showed a negative index (64.29%). This deficiency can be associated with the high pH value, which ranged from 6.9 to 8.1 with mean value of 7.56 for these areas. The increase in soil pH leads to the decrease in the availability of soil nutrients, particularly micronutrients (Valdez-Aguilar & Reed, 2010), which can impair the adequate development and the yield of most crops.

For Na, although it is not considered as an important nutrient for the development of banana plants, the critical level is interpreted as tolerable and can be harmful, favoring the decrease in crop yield, as can be observed in the low-yield areas 8, 15, 19, 20, 31 and 36, where the excess of Na was critical.

The relation of the I_p as a function of the results of the attribute in the soil chemical analysis, is a line, with angular coefficient equal to the inverse of the NCRIz ($1/\text{NCRIz}_i$). Thus, the indices I_{pH} , I_P , I_{Ca} , I_{Mg} , I_K , I_{Zn} , I_{Mn} and I_{Fe} , as a function of the values of the soil analysis (Figure 1), showed higher sensitivity (higher angular coefficient) for K. The soil of the region is mostly calcareous; considering the antagonism between Ca and K and that Ca has not been applied in these soils, the correlation coefficient between these nutrients was equal to 0.8030 and 0.4126 for low- and high-yield areas, respectively.

This indicates the need for K application in order to increase banana yield in the low-yield areas. For practical purposes with this calibration and the evaluation of other areas, the value of the soil analysis must be entered in the linear equation in order to obtain the index for the attribute, with negative or positive values, below and above the NCRIz, respectively.

The method of the critical level through the reduced continuous probability distribution also allows calculating the critical level for the relationship between nutrients. In order to know the NCRIz of the Ca/K ratio, the $Q = \text{Yield}/(\text{Ca}/\text{K})$ or $\text{Yield}/(\text{K}/(\text{Ca}+\text{Mg}+\text{K}))$, the same procedure of the method must be followed. However, attention must be paid to the highest or the lowest ratio that will be the best one for agricultural yield. The ratios of Ca/K, Ca/Mg, K/Mg, K/(Ca+Mg+K) and Mg/(Ca+Mg+K) were evaluated and showed NCRIz values of 10.80, 3.43, 0.21, 0.03 and 0.09, respectively.

From the 38 low-yield areas, nearly 40% showed a more negative $I_{\text{K/Mg}}$ and approximately 53% showed a more positive $I_{\text{Mg}/(\text{Ca}+\text{Mg}+\text{K})}$, corroborating the data of Mg in the soil, which pointed to its excess in the low-yield areas. Morais et al. (2014), evaluating the quality in seven areas cultivated with banana in the region of Baixo Açu-RN, obtained K/Mg values from 0.31 to 0.69 with mean of 0.49. For Mg/(Ca+Mg+K), the values ranged from 0.13 to 0.22, with mean of 0.18, higher than those obtained in the present study, developed in the Apodi Plateau. According to Delvaux (1995), soils with K/Mg ratios from 0.30 to 0.45 are balanced, since ratios above 0.6 indicate the excess of K^+ , while ratios below 0.2 indicate K^+ deficiency in the soil. However, according to Aular & Natale (2013), there must be adequate contents of Mg in the soil for the application of K in banana plants, in order to avoid

Figure 1. Index of pH (A), P (B), Ca, Mg, K (C), Zn, Mn and Fe (D) as a function of the values of the soil analysis

the physiological disturbance that would cause symptoms of deficiency of this element. Kopittke & Menzies (2007) commented on the perfect proportion (ideal soil) between Ca, Mg and K in the exchangeable cations, which would be of 65, 10 and 5%, respectively, despite defending that the use of proportions in the interpretation of the soil analysis will result in the inefficient use of resources in agriculture.

CONCLUSIONS

1. The critical levels obtained for the areas cultivated with irrigated banana were of 7.2 for pH, 0.91 g kg⁻¹ for N, 0.31, 6.34, 2.63, 1.42 and 25.76 mg kg⁻¹ for Cu, Fe, Mn, Zn and P, respectively, and of 6.43, 1.14, 0.24 and 0.36 cmol_c kg⁻¹ for Ca, Mg, Na and K, respectively.

2. The highest deficiencies in the soil of the low-yield areas were of P and Fe, and there was an excess of Mg.

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