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Boundary line method to update critical soil phosphorus and potassium levels in banana plantations in Santa Catarina

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Abstract - The rational use of correctives and fertilizers in banana orchards depends on reliable standards for interpreting soil fertility. The study aimed to establish critical levels (CL) for phosphorus (P) and potassium (K) in the soil of banana plantations in Santa Catarina, using the Boundary Line (BL) method. A database with information of soil chemical analysis and fruit yield obtained from orchards in producing regions was used. Scatter plots were obtained relating P and K concentration in the soil extracted by the Mehlich-1 method with the relative productivity of fruits and then the pairs of data in the upper border were selected and used to establish a mathematical model. The model was derived and obtained the concentrations of P and K in the soil that provided the maximum physical productivity (100 %) and maximum economic productivity (90% of the maximum production), corresponding to the CL in the soil. It is proposed that the update of critical levels of P and K for banana cultivation in Santa Catarina to be 85 and 229 mg/dm^3, respectively. The banana grower will be able to suppress the P and K doses in a punctual and temporary way in areas of built fertility with the proper monitoring of productivity, soil and leaf analysis.

Index terms: *Musa* spp.; fertility classes; fertilization

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Método da linha de fronteira na atualização dos níveis críticos de fósforo e de potássio no solo em bananais catarinenses

Resumo – O uso racional de corretivos e de fertilizantes em pomares de bananeira depende de padrões confiáveis de interpretação da fertilidade do solo. O trabalho objetivou estabelecer níveis críticos (NC) para fósforo (P) e potássio (K) no solo, em bananais de Santa Catarina, usando o método de Linha de Fronteira (LF). Foi utilizado um banco de dados com informações de análises químicas do solo e da produtividade de frutos, coletados em pomares de regiões produtoras. Gráficos de dispersão foram obtidos relacionando os teores de P e K no solo extraídos pelo método Mehlich-1, com a produtividade relativa de frutos, e, em seguida, os pares de dados da fronteira superior foram selecionados e usados para estabelecer modelos matemáticos. Os modelos foram derivados, e obtidos os teores de P e K no solo, que proporcionaram a máxima produtividade física (100 %) e a máxima produtividade econômica (90 % da produção máxima), correspondente ao NC no solo. É proposto que a atualização dos níveis críticos de P e K no solo, para a bananicultura em Santa Catarina, seja de 85 e 229 mg/dm^3, respectivamente. O bananicultor poderá suprimir as doses de P e K de forma pontual e temporária, em áreas de fertilidade construída com o devido monitoramento da produtividade, das análises de solo e de folha.

Termos para Indexação: *Musa* spp.; classes de fertilidade; fertilização.

Introduction

Banana (*Musa* spp.) is one of the most produced and consumed fruits in the world. In Brazil, the fourth largest producer of the world, banana is cultivated mainly by small producers and occupies an area of 453 thousand hectares with a production of 6.8 million tons and average productivity of around 15 t ha^{-1} in 2021 (FAOSTAT, 2023).

Banana is cultivated in the entire national territory and the North region of Santa Catarina stands out as one of the main fruit production poles in Brazil (COLTRO; KARASKI, 2019). However, Santa Catarina is a large producer, one of the main limitations in banana production in the state, is related to soil fertility and the nutritional imbalance of plants, caused by both deficiency and excessive application of fertilizers (GUIMARÃES; DEUS, 2021).

The fertilization recommendations for banana plants are made almost exclusively based on soil chemical analysis and recommendation tables (DEUS et al., 2018). These recommendations are generalized and, in many cases, do not take into account the specific edaphoclimatic conditions of each orchard nor the distinct requirements among cultivars, and can underestimate / overestimate the fertilizers doses to be applied.

When comparing the nutritional needs of Cavendish banana cultivated in the state of São Paulo with the fertilization recommendation proposed in the recommendation tables, Teixeira et al. (2008) concluded that the recommendation underestimates the need for potassium (K) in the implementation of the culture and recommends annual nitrogen (N) doses much higher than the export of this nutrient by the bunches.

When diagnosing soil fertility and the nutritional status of banana plantations in Santa Catarina, Guimarães and Deus (2021) found that 85 and 64 % of the sampled commercial orchards presented phosphorus (P) and potassium (K) levels in the soil, respectively, classified as “very high” according to liming and fertilization manual of the state of Santa Catarina (CQFS-RS/SC, 2016).

The high P and K levels in the soil indicate excess of these nutrients, which can cause nutritional imbalance in banana plant and compromise the production of fruits, besides generating unnecessary expenditures with fertilizers. Although it is not clear, whether the critical levels (CL) of these nutrients, established for banana cultivated in Santa Catarina (SC) conditions are out of date. However, it is known that the critical levels presented in the state recommendation tables for banana culture, encompass all fruit species, besides grain cultures, vegetables and pastures (CQFS-RS/SC, 2016). It is notorious that CL should be specific by culture or culture group, considering the different nutritional demands among the species.

The establishment of critical nutrient levels in the soil can be done using commercial planting monitoring data, through the Boundary Line method (BL) proposed by Webb (1972). BL defines the best performance in the population and allows “isolate” the effect of a certain production factor on commercial crop productivity, in which the other production factors were not maintained constant (WALWORTH et al., 1986; SCHNUG et al., 1996; SHATAR; McBRATNEY, 2004).

The BL method consists in relating productivity with the nutrient content in the soil, adjusting a model and later, obtaining the value of this attribute that maximizes productivity. The points below BL refer to observations where other growth factors, limit the culture response to nutrient (SMITH; HARDIE, 2022). This method has been used successfully in the establishment of soil fertility interpretation patterns for several cultures (EVANYLO; SUMNER, 1987; DEUS et al., 2018; SOUSA et al., 2018; LIMA NETO et al., 2020). Therefore, the study aimed to establish P and K critical levels (CL) in the soil in banana commercial orchards, by the Boundary Line method (BL).

Materials and Methods

The study was developed from a database with results of soil chemical analysis, leaf analysis and fruit productivity, collected from September 2018 to April of 2019, in 53 commercial orchards of caturra banana (Cavendish subgroup), located in the Itajaí Valley and Santa Catarina North Coast region (GUIMARÃES; DEUS, 2021). The areas soils present clay levels ranging from 20 to 40 % type 3 interpretation class and the CEC from 7.6 to 15 $cmol_c/dm^3$ average interpretation class (CQFS-RS/SC, 2016) with predominance of Argisolos (Ultisols) and Cambisols (Inceptisols) (EMBRAPA, 2004).

Fifteen simple soil samples were collected randomly and distributed in the entire area of each orchard, in the 0-20 cm layer, to compose a composite sample. Subsequently, these samples were properly identified, shadow dry, ground and chemically analyzed for the determination of P and K levels, extracted by the Mehlich-1 method, according to the methodology described in Tedesco et al. (1995).

The leaf sampling followed the recommendation proposed by Martin-Prével (1984) adopting the International Reference Sampling Method (MEIR). Samples of approximately 10 cm were collected from the central part of each side of the third leaf limbo (f3) from the apex in the flowering stage (beginning of bunch emission) and the samples extremities were disposed. Each composite sample consisted of the collection of 15 plants per area/orchard. The plant tissue samples (leaf) were dried in greenhouse with air circulation at 60 ºC until constant weight and then sent to the vegetable tissue analysis laboratory. P and K levels were determined according to the methodology described by Malavolta et al. (1997).

Productivity in the 53 commercial orchards was obtained from the quantification and weighing of fruits produced by area. Subsequently, the orchard with the highest absolute productivity equal to 100 % was identified and for the other orchards, the relative productivities were calculated proportionally.

Critical P and K levels in the soil were established by the Boundary Line method (WEBB, 1972). The relative fruit productivity (y), obtained in each orchard was related by means of dispersion charts [y = *f*(x)], with the respective soil P or K levels. In the relationship point cloud, we selected the data pairs (xy) corresponding to the upper border (border population) that provides an optimal relationship between relative productivity and P or K levels (EVANYLO; SUMNER, 1987).

The selected points in the upper border were used to obtain second-degree polynomial equations, which enable the optimal point calculation for each production factor. From the BL equation were estimated the P and K levels in the soil that provide the maximum physical production (100 %) and the production of maximum economic efficiency (90 % of the maximum production), these being the P and K levels corresponding to the CL in the soil (90 %).

After obtaining the CL by the BL approach, the foliar P and K levels with their respective levels in the soil were related in the 53 evaluated orchards. For this, the method called Quadrant Diagram of the Plant-Soil Relationship was used (QDpsR) according to Deus et al. (2018) and Sousa et al. (2018). In the present study the CL in the soil was used for the x axis and the value higher than the appropriate range in the leaf for P (2.2 g/kg) and K (54.0 g/kg) in banana plants from the subgroup in Santa Catarina (GUIMARÃES et al., 2020) for delimitation in the y axis of the quadrants.

Results and Discussion

The high variability of P and K levels in commercial orchard soils, as well as banana productivity, indicate the heterogeneity of the banana plantations, cultivated in SC (Table 1). As presented by Guimarães and Deus (2021), the high levels of these nutrients in the soil can be attributed to the absence of adequate nutritional management, which besides favoring the nutritional imbalance of the banana plant, also generate unnecessary costs with fertilizers. Even in orchards with relative production below 70 % (< 54.3 t/ha) the average P and K levels in the soil are higher than the CL considered suitable for fruit trees in Santa Catarina (CQFS-RS/SC, 2016). On the other hand, both P and K levels in the soil of these orchards, presented positive correlation with bunch weight (GUIMARÃES;

Table 1. Descriptive analysis of P and K levels in the soil and the productivity of 53 commercial orchards of caturra banana according to the relative production and CL.

Variable	P	K	Productivity
	mg/dm³	mg/dm³	t/ha/year [1]
Orchards with relative production < 70 % (n = 42)			
Minimum	6.7	44.0	20.7
Average	78.4	211.3	42.2
Maximum	201.0	448.0	54.3
D.P	45.1	78.2	7.8
Orchards with relative production ≥ 70 % (n = 11)			
Minimum	47.3	180.0	55.9
Average	159.7	283.3	63.9
Maximum	271.8	456.0	78.8
D.P	80.1	90.6	7.1
CL (CQFS-RS/SC, 2016)[2]	18.0	90.0	-
CL estimated by the BL method	85.0	229.0	-

P and K extracted by the Mehlich-1 method; [1] Considering an average of 1,400 plants/ha and each family has produced 1 banana bunch per year; [2] Critical level of P and K for the fruit group, for soil with clay levels between 20 and 40 % and CEC between 7.6 and 15.0 $cmol_c/dm^3$ (CQFS-RS/SC, 2016).

DEUS, 2021). This suggests that the CL of these nutrients in banana plantations are higher than the current values adopted in the soil analysis interpretations and fertilizer recommendation.

The dispersion of the points that relate the P or K levels in the soil due to the relative fruit production, as well as the selected point set (xy) which are in the upper region of the data cloud, corresponding to the upper BL of the relationship, are presented in Figure 1. The mathematical models adjusted between the relative fruit productivity and the phosphorus and potassium levels in the soil, allowed to establish the P and K critical levels (CL) of 85 and 229 mg/dm^3, respectively (Table 1; Figure 1). These results suggest that the P and K critical levels (CL) presented in the liming and fertilization manual for the states of Rio Grande do Sul and Santa Catarina (CQFS-RS/SC, 2016), are underestimated for the banana culture.

Critical P and K levels in the soil estimated by the BL are 4.7 and 2.5 times higher respectively, to those presented in the manual (Table 1). This indicates that, besides the need for CL updates for the decision-making in the nutritional management, it is also important to consider how the nutrient doses recommendations should be in areas where the soil levels are much higher than CL values, like what happened for P and K in banana plantations in Santa Catarina. These high nutrient levels in the soil above the CL can even lead to situations where the temporary suppression of phosphorus and potassium doses is recommended.

There are many doubts of how to make this decision (suppression of doses), technically, so as not to impact on productivity and production quality, besides maintaining the nutrient balance in the soil and plant. Studies with fruit species, focusing on the suppression of doses in soils with high nutrient levels are still quite scarce and more common information for grain production systems. Lacerda et al. (2015) verified that the P levels available in the soil remained unchanged after three successive grains' crop (soybean/corn/soybean) without decrease in soybean productivity. According to these authors, in the treatments where there was increase of productivity according to fertilization, the acquisition and application costs of fertilizers were not sufficient to justify this practice, not presenting economic viability for built fertility soils.

This fact shows the differences that should be considered when performing the nutritional management of soils with built fertility, from those who need to have this fertility built. Although the term 'built fertility' is more commonly used for agricultural grain production systems, the same can be used for other cultures, including fruit trees as is the case of banana plantation. Resende et al. (2016) addressed questions about the need for revision of nutrients CL in the soil, indicated by classical literature for intensive and high productivity systems. These authors pointed out that the latest studies have presented an increase trend in CL values for P and K in built fertility soils.

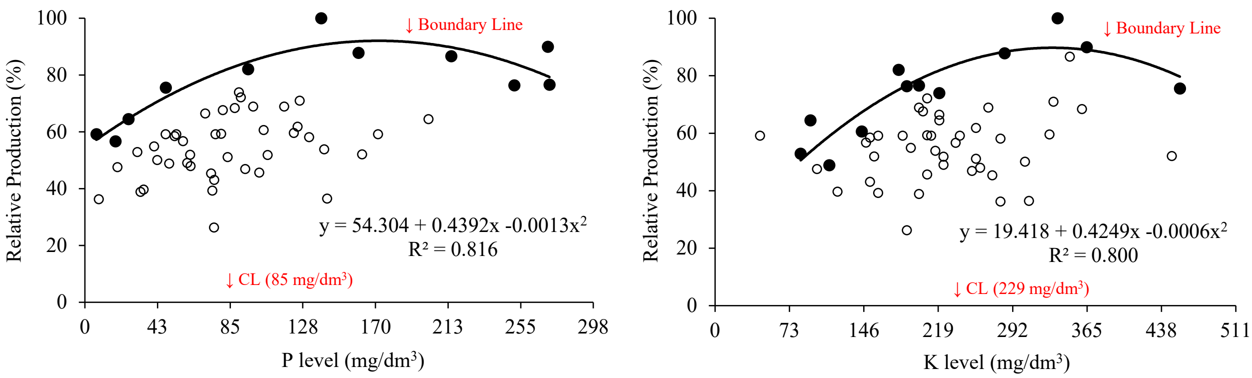

Figure 1. Boundary line established from the point cloud of the relative productivity ratio of banana fruits according to the P or K level in the soil.

Critical levels (CL) refer to the nutrient level available in the soil (it can also be used for the leaf) necessary to obtain the production of maximum economic efficiency, if other nutrients and production factors are not limiting. Therefore, the specific CL updates for each species/cultivar, considering the current production systems, is essential basis for assisting in nutritional management, ensuring higher productions, higher efficiency in the use of fertilizers and lower environmental impacts. It is also necessary to consider some principles that guide and are commonly called General Fertilization Laws, which bring together the Minimum Law (LIEBIG, 1843), the Decrease increments Law (MITSCHERLICH, 1909) and the Maximum Law (VOISIN, 1973). These laws, together, guide the nutritional management and the recommendations of the correction, maintenance, or replacement fertilizations, used by liming and fertilization manuals (CQFS-RS/SC, 2016).

In addition to the CL for P and K (Figure 2), the levels of these nutrients in the soil are also included, equivalent to maximum physical efficiency productivity (100 %) and the equivalent of 90 % of the maximum productivity after the maximum physical efficiency point. In this context, it is noticed that for soil levels above the CL, productivity will reach a plateau with little variation or response in this productivity from the CL, however, with increasing increments in the nutrient content in the soil. For example, considering the P and K doses necessary to achieve the CL in the soil and the equivalent of 90 % after the maximum physical efficiency point, the difference is 770 kg/ha of P_2O_5 and 602 kg/ha of K_2O (Figure 2).

For a productivity of 45 t/ha Teixeira et al. (2008) verified accumulation and export of 46 and 20 kg/ha for P_2O_5 and accumulation and export 757 and 244 kg/ha for K_2O, respectively, in banana plants of the Cavendish subgroup. For this same level of productivity, Deus et al. (2020a) verified accumulation and export of 101 and 37 kg/ha for P_2O_5 and accumulation and export 1.035 and 234 kg/ha for K_2O in banana plants of the Prata subgroup. Therefore, in areas with soil levels of 253 and 480 mg/dm^3 of P and K, respectively, which correspond to an increase of the doses applied to the soil of 770 kg/ha of P_2O_5 and 602 kg/ha of K_2O, compared to those necessary to achieve the critical level (90 %), far exceed the nutritional needs for P accumulation and exportation, while for K the export needs for production fertilizations are well met. While for the accumulated in the whole plant, the dose above the CL meets 79.5 % of the K need for the implementation of Cavendish banana (TEIXEIRA et al., 2008) and 58.2 % for Prata banana (DEUS et al., 2020a).

On the other hand, the current P and K CL informed in the liming and fertilization man-

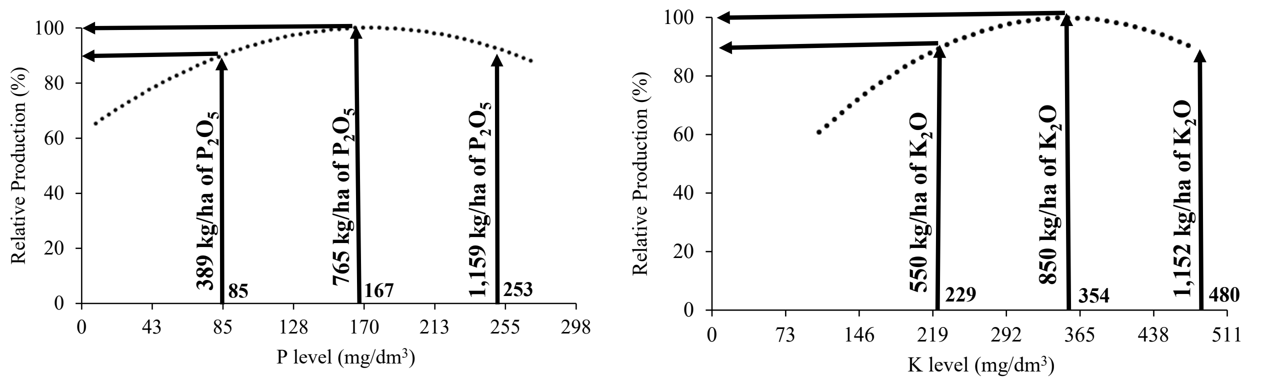

Figure 2. P and K levels in the soil and relative productivity (RP) of 53 commercial orchards of catura banana and values equivalent to doses in the soil of P_2O_5 and K_2O according to the P and K levels in the soil. Conversion factor (mg/dm^3 × 2 = kg/ha), (P × 2.29 = P_2O_5) and (K × 1.20 = K_2O).

ual of Rio Grande do Sul and Santa Catarina (Table 1), of 18 and 90 mg/dm³, which are equivalent to the soil doses of 36 kg/ha of P_2O_5 and 180 kg/ha of K_2O, respectively, do not even meet the quantities exported of these nutrients by banana plants of the Cavendish and Prata subgroups, for a production of 45 t/ha (TEIXEIRA et al., 2008; DEUS et al., 2020a).

It should be noted that, even in areas with nutrient levels in the soil far above the CL, like what was verified for P and K in commercial orchards in Santa Catarina (GUIMARÃES; DEUS, 2021), banana growers continue using fertilizer doses above the need of the orchard or when even it is not necessary to fertilize, for fear of productivity losses. This can generate doubts, including by the technicians, about which nutrient content in the soil is possible to suppress the doses safely so as not to have production and quality losses.

The suppression of fertilizer doses is not a simple decision to be taken by the technicians, besides it is not recommended when based only on soil chemical analysis, because, even when this analysis indicates nutrient levels in the soil available, these will not necessarily be absorbed, translocated and redistributed within the plant, being influenced by factors intrinsic to the plants related to the absorption and use of nutrients (MOREIRA; FAGERIA, 2009a; MOREIRA; FAGERIA, 2009b). For this safe decision-making is indispensable besides the soil analysis make use of the leaf analysis, this tool still quite neglected in the nutritional management of banana plantations (DEUS et al., 2018), because the same together with soil analysis and history of fertilizations and productivities, will make it possible to safely recommend doses with or without suppression.

Taking as the results obtained in this study, we recommend that the P and K doses, which would eventually be employed by the banana grower routine, can be suppressed when some basic premises are met: the collection and sampling of soil and leaf were performed correctly, respecting the literature recommendations; the soil analysis results, indicate P and K levels above the availability class “High”, that is, above 167 and 354 mg/dm³, respectively; the levels in the leaf are above the appropriate range being considered in the present study values above 2.2 and 54.0 g/kg for P and K, respectively, according to Guimarães et al. (2020), these values can be obtained by univariate, bivariate (DRIS) or multivariate (CND) methods in the interpretation. Logically this suppression is punctual and temporary, and it is monitored by the soil and leaf analyses subsequently.

In addition to the need to use soil and leaf analyses, it is important the correct recording and monitoring *in situ* of the productivities obtained with the construction of the orchard productive history, because, only in this way, it will be possible to verify if there is an increase, reduction or stabilization in productivity according to the adopted management (DEUS et al., 2020b).

As in the bulletins the fertilizer doses are recommended based on the soil nutrient levels and the production estimate, the CL update should be constant as new materials are launched in the market and when there are changes in the management system. Due to the slow and operational costs for conducting experimental networks for correlation and calibration studies in the determination of CL, the BL approach is presented as a potential tool for adjustments and updates of these values in a faster and lower cost way, besides better portray the edaphoclimatic and management conditions adopted for each region (EVANYLO; SUMNER,1987; DEUS et al., 2018; SOUSA et al., 2018; LIMA NETO et al., 2020).

After the individual evaluation of the soil analysis and leaf analysis, it is also necessary to integrate these results for decision-making using the QDpsR method. The plots that are in quadrants I and III are those in which there is indeed a direct cause and effect relationship among the y variables in function of x (Figure 3). Differently, in the II and IV plots the absence of response is due to other non-nutritional factors and if nutritional for other nutrients of the function y = f(x), as reported by Deus et al. (2018), Sousa et al. (2018) and Lima Neto et al. (2020). Therefore, in this context, the plots present in quadrants I and III are those that should focus on identifying whether or not there will be response to fertilization.

In quadrant I where the soil levels are above the CL and the levels in the leaf are above the appropriate range, it is likely that there will be no response to fertilization on the productivity of banana fruits. For the evaluated plots, 39.6 % for P and 37.7 % for K fit in this quadrant (Table 2). Therefore, if the plots present levels in the soil above the maximum physical efficiency point, that is, above 167 and 354 mg/dm^3 for P and K, respectively, the banana grower will be able to suppress safely the doses for these nutrients at that moment, without the occurrence of productivity losses, monitoring with the soil and leaf analyses subsequently.

These results also suggest that only 11.3 % for P and 9.4 % for K of the evaluated orchards, which are represented in quadrant III, present response potential to phosphate and potassium fertilization. On the other hand, in approximately 50 % of these orchards (represented in quadrants II and IV), banana productivity is limited by factors other than nutritional or, if nutritional, caused by nutrients other than phosphorus and potassium. In this case, a more detailed diagnosis will be necessary to identify the limitations of these orchards.

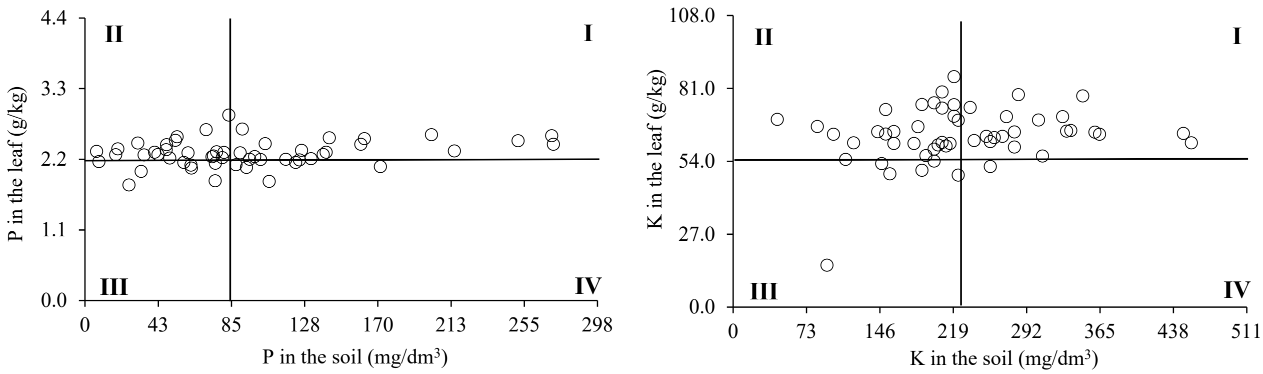

Figure 3. P and K levels in the banana diagnostic leaf according to the P and K levels in the soil obtained by the quadrant diagram of the plant-soil relationship (QDpsR).

Table 2. Distribution of the plots and criteria established by the Quadrant Diagram of the Plant-Soil Relationship method (QDpsR) for classification.

Nutrient	Criteria	Quadrant	% Plots
P	∀ **x** ≥ 85.0 mg/dm^3 and ∀ **y** ≥ 2.2 g/kg	I	39.6
	∀ **x** < 85.0 mg/dm^3 and ∀ **y** ≥ 2.2 g/kg	II	41.5
	∀ **x** < 85.0 mg/dm^3 and ∀ **y** < 2.2 g/kg	III	11.3
	∀ **x** ≥ 85.0 mg/dm^3 and ∀ **y** < 2.2 g/kg	IV	7.5
K	∀ **x** ≥ 229.0 mg/dm^3 and ∀ **y** ≥ 54.0 g/kg	I	37.7
	∀ **x** < 229.0 mg/dm^3 and ∀ **y** ≥ 54.0 g/kg	II	50.9
	∀ **x** < 229.0 mg/dm^3 and ∀ **y** < 54.0 g/kg	III	9.4
	∀ **x** ≥ 229.0 mg/dm^3 and ∀ **y** < 54.0 g/kg	IV	1.9

x – corresponds to the values of P and K levels in the soil chemistry analysis; y – corresponds to the values of P and K levels in the leaf chemical analysis.

Conclusion

The current P and K levels extracted by the Mehlich-1 method corresponding to the CL in the soil for banana plant cultivated in Santa Catarina are underestimated and require updates. It is proposed that the new values of critical levels for banana plantation in Santa Catarina are 85 and 229 mg/ dm^3 for P and K, respectively. Banana grower can suppress P and K doses in built fertility areas, considering a joint evaluation of the soil analysis, leaf analysis, historical record of productivity, doses and fertilizers used.

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References

COLTRO, L.; KARASKI, T.U. Environmental indicators of banana production in Brazil: *Cavendish* and *Prata* varieties. **Journal of Cleaner Production**, Amsterdam, v.207, p.363-78, 2019.

CQFS-RS/SC - Comissão de Química e Fertilidade do Solo. **Manual de calagem e adubação para os Estados de Rio Grande do Sul e de Santa Catarina**. Florianópolis: Sociedade Brasileira de Ciência do Solo – Núcleo Regional Sul, 2016. 376p.

DEUS, J.A.L.; NEVES, J.C.L.; LIMA NETO, A.J.; NATALE, W.; ALVAREZ V., V.H.; ALBUQUERQUE, F.M.R. Partitioning of macronutrients and nutritional efficiency in fertigated Prata banana. **Revista Brasileira de Fruticultura**, Jaboticabal, v.42, n.4, p.e-611, 2020a.

DEUS, J.A.L.; NEVES, J.C.L.; SOARES, I.; ALVAREZ, V.; V.H.; LIMA NETO, A.J.; ALBUQUERQUE, F.M.R.; SANTOS, L.L.; NATALE, W. Multivariate selection andclassification of mathematical models to estimate dry matter partitioning in the fertigated Prata banana in the Northeast Brazil. **Field Crops Research**, Amsterdam, v.255, p.107897, 2020b.

DEUS, J.A.L.; NEVES, J.C.L.; SOARES, I.; ALVAREZ V., V.H.; ALBUQUERQUE, F.M.R.; SANTOS, L.L.; NATALE, W. Modeling in the adjustment of fertilization recommendation through leaf analysis in fertigated 'Prata' banana. **Revista Brasileira de Ciência do Solo**, Viçosa, MG, v.42, p.e0170372, 2018.

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária. **Solos do Estado de Santa Catarina**. Rio de Janeiro: Centro Nacional de Pesquisa de Solos, 2004. 745p. (Boletim técnico, 46).

EVANYLO, G.K.; SUMNER, M.E. Utilization of the boundary line approach in the development of soil nutrient norms for soybean production. **Communications in Soil Science and Plant Analysis,** New York, v.18, p.1379-1401, 1987.

FAOSTAT - Food and Agriculture Organization Corporate Statistical Database. Crops Crops and livestock products 2019. Rome: Food and Agriculture Organization of the United Nations, 2023. Disponível em: *http://www.fao.org/faostat/en/#data/QC*. Acesso em: 31 jan. 2023.

GUIMARÃES, G.G.F.; DEUS, J.A.L. Diagnosis of soil fertility and banana crop nutrition in the state of Santa Catarina. **Revista Brasileira de Fruticultura**, Jaboticabal, v.43, n.4, p.e-124, 2021.

GUIMARÃES, G.G.F.; DEUS, J.A.L.; ROZANE, D.E. Calagem, adubações e valores de referência de nutrientes na cultura da banana. *In*: BRUNETTO, G. (org.). **Atualização sobre calagem e adubação em frutíferas**. Porto Alegre: Núcleo Regional Sul da Sociedade Brasileira de Ciência do Solo, 2020. p.65-77.

LACERDA, J.J.J.; RESENDE, A.V.; FURTINI NETO, A.E.; HICKMANN, C.; CONCEIÇÃO, O.P. Adubação, produtividade e rentabilidade da rotação entre soja e milho em solo com fertilidade construída. **Pesquisa Agropecuária Brasileira**, Brasília, DF, v.50, n.9, p.769-78, 2015.

LIEBIG, J.von. **Die chemie in ihrer Anwendung auf Agricultur und Physiologie**. 3rd ed. Braunschweig: F.Vieweg und Sohn, 1843.

LIMA NETO, A.J.; NEVES J.C.L.; MARTINEZ, H.E.P.; SOUSA J.S.; FERNANDES, L.V. Establishment of critical nutrient levels in soil and plant for eucalyptus. **Revista Brasileira de Ciência do Solo**, Viçosa, MG, v.44, p.e0190150, 2020.

MALAVOLTA, E.; VITTI, G.C.; OLIVEIRA, S.A. **Avaliação do estado nutricional das plantas**: princípios e aplicações. 2nd ed. Piracicaba: POTAFOS, 1997. 319 p.

MARTIN-PRÉVEL, P. Bananier. *In*: MARTIN-PRÉVEL, P.; GAGNARD, J.; GAUTIER, P. (ed.). **L'analyse végétale dans le contrôle de l'alimentation des plantes tempérées et tropicales**. Paris: Tec & Doc, 1984. p.715-51.

MITSCHERLICH, E.A. Das gesetz des minimums und das gesetz des abnehmenden bodenertrages. **Landwirtschaftliche Jahrbücher**, Berlin, v.38, n.1, p.537-52, 1909.

MOREIRA, A.; FAGERIA, N.K. Repartição e remobilização de nutrientes na bananeira. **Revista Brasileira de Fruticultura**, Jaboticabal, v.31, n.2, p.574-81, 2009a.

MOREIRA, A.; FAGERIA, N.K. Yield, uptake, and retranslocation of nutrients in banana plants cultivated in upland soil of Central Amazonian. **Journal of Plant Nutrition**, New York, v.32, n.3, 443-57, 2009b.

RESENDE, A.V.; FONTOURA, S.M.V., BORGHI, E., SANTOS, F.C., KAPPES, C., MOREIRA, S.G., OLIVEIRA JUNIOR, A., BORIN, A.L.D.C. Solos de fertilidade construída: características, funcionamento e manejo. **Informações Agronômicas**, Piracicaba, n.156, p.1-19, 2016.

SCHNUG, E.; HEYM, J.; ACHWAN, F. Establishing critical values for soil and plant analysis by means of the boundary line development system (bolides). **Communications in Soil Science and Plant Analysis**, New York, v.27, n.13-14, p.2739-48, 1996.

SHATAR, T.M.; McBRATNEY, A.B. Boundary-line analysis of field-scale yield response to soil properties. **Journal of Agricultural Science**, Cambridge, v.142, n.5, p.553-60, 2004.

SMITH, J.F.N.; HARDIE, A.G. Determination of foliar nutrient sufficiency ranges in cultivated rooibos tea using the boundary-line approach. **South African Journal of Plant and Soil**, Pretoria, v.39, n.3, p.226-33, 2022.

SOUSA, J.S.; NEVES, J.C.L.; MARTINEZ, H.E.P.; ALVAREZ V., V.H. Relationship between coffee leaf analysis and soil chemical analysis. **Revista Brasileira de Ciência do Solo**, Viçosa, MG, v.42, p.e0170109, 2018.

TEDESCO, M.J.; GIANELLO, C.; BISSANI, C.A.; BOHNEN, H.; VOLKWEISS, S.J. **Análise de solo, plantas e outros materiais**. 2.ed. Porto Alegre: Departamento de Solos da Universidade Federal do Rio Grande do Sul, 1995. 174p. (Boletim técnico de solos, 5).

TEIXEIRA, L.A.J.; RAIJ, B.V.; BETTIOL NETO, J.E. Estimativa das necessidades nutricionais de bananeiras do subgrupo Cavendish cultivadas no Estado de São Paulo. **Revista Brasileira de Fruticultura**, Jaboticabal, v.30, n.2, p.540-45, 2008.

VOISIN, A. **Adubos**: novas leis científicas de sua aplicação. São Paulo: Mestre Jou, 1973. 130 p.

WALWORTH, J.L.; LETZSCH, W.S.; SUMNER, M.E. Use of Boundary Lines in establishing diagnostic norms. **Soil Science Society of America Journal**, Madison, v.50, n.1, p.123-8, 1986.

WEBB, R. Use of the boundary line in the analysis of biological data. **Journal of Horticultural Science**, Ashford, v.47, n.3, p.309-19, 1972.