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ORIGINAL ARTICLE

Reference values for vineyard nutrients in the Campanha Region estimated by the Mathematical Chance method

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Abstract - Viticulture in Rio Grande do Sul (RS), the southernmost state of Brazil, has been changing due to its expansion to new areas in the Campanha Region. Located in the south of the state, these areas have different edaphoclimatic conditions from those existing in the Serra Gaúcha, traditional production region. Thus, the estimation of reference values for leaf nutrient contents specific for the conditions of the Campanha is essential for the correct management of vineyards. Methods such as Mathematical Chance (MCh) enable the determination of sufficiency levels of leaf nutrients by evaluating commercial production areas. This work aimed to estimate reference values for nutrients in leaf tissue of grapevines in the region of Campanha by using the MCh method. Nutritional sufficiency ranges differed from those estimated by the official research for the state. However, they revealed high similarity with the results obtained by other studies carried out in the Campanha Region by using DRIS and CND approaches. Our results demonstrated that the MCh was able to estimate the infra- and supra-optimal limits, as well as the optimal levels for nutrients, indicating that there is potential for foliar diagnosis of vineyards in RS to be performed based on regionalized parameters.

Keywords: Leaf diagnosis. Viticulture. Plant nutrition.

Valores de referência para nutrientes em videira na Região da Campanha estimados pelo método da chance matemática

Resumo - A viticultura no Rio Grande do Sul (RS), estado mais ao sul do Brasil, vem se transformando devido à expansão para novas áreas na Região da Campanha. Localizadas no sul do estado, essas áreas apresentam condições edafoclimáticas diferentes das existentes na Serra Gaúcha, tradicional região produtora. Assim, a estimativa de valores de referência para teores foliares de nutrientes específicos para as condições da Campanha é fundamental para o correto manejo dos vinhedos. Métodos como a Chance Matemática (ChM) permitem determinar níveis de suficiência de nutrientes foliares por meio da avaliação de áreas de produção comercial. Este trabalho teve como objetivo estimar valores de referência para nutrientes no tecido foliar de videiras da região da Campanha pelo método da ChM. As faixas de suficiência nutricional diferiram daquelas estimadas pela pesquisa oficial para o estado. No entanto, mostraram grande semelhança com os resultados obtidos por outros estudos realizados na Região da Campanha que utilizaram as abordagens DRIS e CND. Nossos resultados demonstraram que a ChM foi capaz de estimar os limites infra e supra-ótimos, bem como os níveis ótimos de nutrientes, indicando que há potencial para o diagnóstico foliar de vinhedos no RS ser realizado com base em parâmetros regionalizados.

Palavras-chave: Diagnose foliar. Vitivinicultura. Nutrição vegetal.

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Introduction

The state of Rio Grande do Sul (RS) is the largest producer of wine grapes in Brazil, with annual harvests exceeding 600 million tons, from which more than 37 million liters of varietal wines are produced annually (MELO; MACHADO, 2020). Traditionally, Serra Gaúcha, in the northeast of the state, is the most important region for growing the *Vitis vinifera* grape. However, in the last ten years, the viticulture context in RS has undergone a wide range of changes due to the expansion of the culture to the Campanha Region, located in the south of the state (FLORES *et al.*, 2016; WÜRZ *et al.*, 2017). This expansion occurred because of the wide availability of cheaper lands and the more favorable edaphoclimatic conditions in Campanha, characterized by deeper and well-drained soils, larger thermal amplitude between day and night, higher daily insolation and reduced rainfall during the berry ripening period, in comparison to the Serra Gaúcha (MALUF *et al.*, 2014).

The introduction of viticulture in a region traditionally dedicated to beef cattle breeding and rice farming has challenged researchers to develop new and appropriated technologies for the local conditions. In this regard, soil fertility management and plant nutrition are major obstacles to achieving the balance between productivity and grape quality in the vineyard. The maintenance of soil nutrients availability, as well as their levels in an adequate range in plant tissue, depends on the correct assessment of soil fertility and on the processes related to plant nutrition, which are essential for the expression of the productive potential of the vine (BRUNETTO *et al.*, 2020).

Soil and plant tissue analyses are fundamental for diagnosing the nutritional status of plants. Nonetheless, in the case of perennial plants the responses to fertility management are not as fast as those of annual crops due to the large nutrient reserves existing in perennial plants (ROZANE *et al.*, 2020a). Therefore, to refine the evaluation of the nutritional status of vineyards it is necessary to use systems that integrate the different nutritional factors that together will define the productive capacity of the plants. From this perspective, the study of the relationships between soil parameters and the concentration of nutrients in the plant tissue helps to understand the synergistic and antagonistic processes related to plant nutrition (CIESIELSKA *et al.*, 2004).

The establishment of plant tissue nutrient sufficiency ranges allows the nutritional diagnosis of crops from leaf chemical analysis. In general, the establishment of sufficiency ranges is expensive and time-costly, since it depends on inter-institutional collaboration to carry out calibration network experiments with different fertilization levels. Alternatively, there are statistical methods capable of estimating the reference values for sufficiency ranges without the need for specific experiments. Such methods can be performed using data from commercial crops, taking advantage of the existing variability between samples. The Diagnosis and Recommendation Integrated System (DRIS) and the Compositional Nutrient Diagnosis (CND) (PARENT; DAFIR, 1992; SUMNER, 1977) are methodologies which, in addition to estimating the sufficiency ranges, are able to describe the nutritional status of agricultural crops. However, they involve complex statistical treatments for the elaboration of their norms. In turn, the Mathematical Chance (MCh) method (WADT, 1996) offers the possibility of estimating the nutrient sufficiency ranges by analyzing the distribution of the

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frequency of occurrence of high yields in a given range of foliar contents of a given nutrient; by having the advantage of demanding less sophisticated mathematical processing. This methodology allows the evaluation, on a local scale, within regions with particular soil and climatic characteristics, producing specific data for their conditions, which, in the case of wine-growing, can even contribute to processes of geographical indications.

In addition to the individual assessment of the levels of each nutrient in the plant tissue, it is also relevant to analyze their relationships with factors associated to grape quality and productivity. Thus, this study aims to estimate reference values for macro and micronutrients in the leaf tissue of vines, in the Campanha Region of RS, using the MCh method, and identify the level of association between nutritional parameters and the grape quality and productivity.

Material and Methods

Characterization of the study area

The study was implemented in mature vineyards belonging to a winery located in the city of Santana do Livramento/RS (30°48′ 31″ S; 55°22′ 33″ W). The climate is defined as humid subtropical (Cfa) (ALVARES *et al.*, 2013) and the soil is classified as Dystrophic Red Argisol (FLORES *et al.*, 2007; STRECK *et al.*, 2008). The average chemical characteristics of the studied soils are shown in Table 1. For the accomplishment of the study, 56 vineyards were evaluated, comprising six varieties of red wine grapes (Tannat, Cabernet Franc, Cabernet Sauvignon, Merlot and Pinotage) and four white (Chardonnay, Sauvignon Blanc, Semillon and Saint Emilion), which are cultivated in a trellis system, in plots of at least one hectare.

Table 1. Average chemical characteristics of studied vineyard in soils from the Campanha Region.

Clay	pH	SMP	P	K	OM	Al	Ca	Mg	H+Al	CEC
%			--- mg/dm³ ---		%	-----------------cmol$_c$/dm³-----------------				
9.0	5.6	6.8	32.7	81.2	1.3	0.1	2.2	0.9	1.91	6.1

%SAT CEC		S	Zn	Cu	B	Mn
Base	Al	------------------mg/dm³ ----------------				
61.0	4.4	7.0	5.6	26.5	0.5	14.4

SMP: SMP index; OM: organic matter; H+Al: potential acidity of the soil; CEC: cation exchange capacity; % Sat CEC bases: saturation of CEC by changeable bases (Ca^{2+} + Mg^{2+} + K^{+} + Na^{+}); % Sat CEC Al: saturation of the CEC by aluminum.

Collection and analysis of samples

Soil samples were collected in June 2006, and the productivity was evaluated was evaluated in the 2006-2007 harvest season. From each vineyard, 20 soil subsamples were collected at 0-20 cm depth, half of them from cultivation rows and the other half the inter-row spaces.

For plant tissue sampling, complete leaves were collected opposite to the first bunch of grapes (with flowering percentage between 50 and 80 %) from 30 plants per frame, totaling 90 leaves per vineyard (CQFS-RS/SC, 2016). Productivity of each vineyard was calculated by dividing the total grape weight by the vineyard area. Total soluble solids (TSS) were determined by refractometry using juice of berries from ten different bunches. Samples of soil and plant tissue were analyzed at the Soil Analysis Laboratory of the Federal University of Rio Grande do Sul, according to the standard methods recommended by the Official Network of Soil and Plant Tissue Analysis Laboratories of RS and SC (TEDESCO *et al*., 1995; CQFS -RS/SC, 2016).

Estimation of the nutrient sufficiency critical levels

The Mathematical Chance method (WADT *et al.*, 1996; WADT *et al.*, 1998a, b; KURIHARA, *et al.*, 2005) was used to determine the sufficiency ranges of N, P, K, Ca, Mg, S, B and Cu in vine leaf tissue, based on the analysis of plant tissue and the productivity data of each vineyard. To accomplish that, the foliar concentration was assembled with each nutrient from samples from high-yield vineyards, i.e., those with production above 12.0 Mg ha^{-1}. The number of possible classes (I) was calculated by the expression $I = n^{0.5}$, where n represents the number of vineyards evaluated in the study. From the determination of I and with the calculation of the amplitude (A) of the contents of each nutrient, the class interval (CI) for each nutrient was calculated by the formula CI =A/I.

In each content class, the Mathematical Chance was calculated as follows:

$$MCh = \{[(fH/nH).Prod].[(fH/n).Prod]\}^{0,5}$$

Where:

MCh: Mathematical chance (Mg ha^{-1})

fH: Frequency of high-yield vineyards in a given class;

nH: total number of high-yield vineyards;

Prod: Average production of high-yield vineyards in a given class;

n: total number of vineyards of the evaluated class.

The classes with the highest values for the Mathematical Chance were considered within the range of nutritional sufficiency for a given nutrient, with the lowest value being considered the critical level while the median value of the range was considered the optimal level of the nutrient. The value of 75 % of the highest MCh value for each nutrient was used as the criterion for separating the classes into sufficiency bands.

Association between nutritional factors and grape productivity and quality

The data on vineyard productivity, average sugar content of the grapes (Babo degrees) and nutrient contents in the plant tissue were subjected to a principal component analysis (PCA), using the software PAST version 1.32 (HAMMER *et al.*, 2004).

Results and Discussion

From the total number of vineyards analyzed, the number of possible classes was calculated as seven, for which the sufficiency ranges for each of the evaluated nutrients were determined. In the present study, the sufficiency ranges and the optimal nutrient levels estimated by the MCh method, shown in Figures 1 and 2, will be discussed in comparison with those estimated by CND (ROZANE *et al.*, 2020b) and DRIS (MELLO *et al.*, 2018), both methods used in the Campanha Region, and with the values of the official research for the states of RS and SC (CQFS-RS/SC, 2016). In Figure 2, in addition to the sufficiency ranges, the distribution of areas with high or low productivity and the optimal level of each nutrient estimated by the MCh method are presented.

Regarding N, the sufficiency range calculated by the MCh method, between 24.0 to 33 g kg^{-1}, is above that indicated by the official recommendation (CQFS-RS/SC, 2016) for the crop (16 to 24 g kg^{-1}) (Figure 1a). On the other hand, Melo *et al.* (2018), using DRIS, estimated the sufficiency range of 24 to 30 g kg^{-1} of N in plant tissue in vineyards in the Campanha Region. This data is highly similar to that obtained in the present study. Close similarity was also observed between the optimal levels of N determined by the MCh method (28.5 g kg^{-1}) (Figure 2a) and by CND (27 g kg^{-1}) (ROZANE *et al.*, 2020b), evidencing the effectiveness of using the MCh method to assess the nutritional condition of vineyards for specific soil and climate conditions.

When observing the distribution of high and low yield samples related to leaf N levels, it is possible to notice the occurrence of high yielding vineyards with contents above the sufficiency range (Figure 2a). This can represent a condition of luxury consumption of N, that is, a situation in which the N content increases in the plant tissue, but without increasing productivity (ACEVEDO *et al.*, 2020). The average soil organic matter content of the vineyards of this study is low (1.3 %), so that the high levels of N in the leaves must be the result of N input via fertilization. Due to the sandy texture of the soil, with less than 10 % of clay, N fertilization in the vineyards is split during the productive cycle of the crop, favoring the assimilation of the nutrient. Moreover, the nutritional dynamics of the vine in the local soil and climate conditions may also be producing a response different from that expected from the official recommendation, which was elaborated from calibration tests carried out in different soil classes and environmental conditions. This hypothesis emphasizes the need for establishing regional standards of nutritional sufficiency. In addition to these factors, it is also necessary to take into account the differences between the genetic materials used in the region, as well as the rootstock/crown ratio, which also interferes with the uptake of N by the vines (KULMANN *et al.*, 2020).

It was observed that 63 % of the evaluated vineyards are within the sufficiency range, according to the MCh method, while 29 % and 9 % are above and below the limits, respectively. This data indicate that, in general, N is not being a limiting factor for the productivity of the vineyards in Campanha. It also reinforce the need to adapt the management of nitrogen fertilization in the region, since about 1/3 of the samples present levels above the sufficiency range, indicating application of N above the necessary, which can generate economic and environmental damages.

As for the results related to the P (Figure 1b), it was observed that the sufficiency range from 2.9 to 4.4 g kg^{-1} intersects with the range of the official recommendation (1.2 to 4.0 g kg^{-1}) (CQFS-RS/SC (2016), and the optimal level determined by the MCh method (3.7 g kg^{-1}) is within this limits. Comparing the sufficiency range for P estimated by the MCh method with that obtained by the DRIS system (MELO *et al.*,

2018) for vineyards in the same region (2.9 to 3.9 g kg^{-1}), it is observed that there is high similarity between them, indicating the efficiency of the MCh method. Similarly, the optimal level of P in the vine leaf tissue obtained by the MCh method, 3.7 g kg^{-1}, is close to 3.3 g kg^{-1} estimated by CND (ROZANE *et al.*, 2020b), reinforcing that regional particularities related to soil and climate factors are crucial for the correct assessment of the nutritional status of plants.

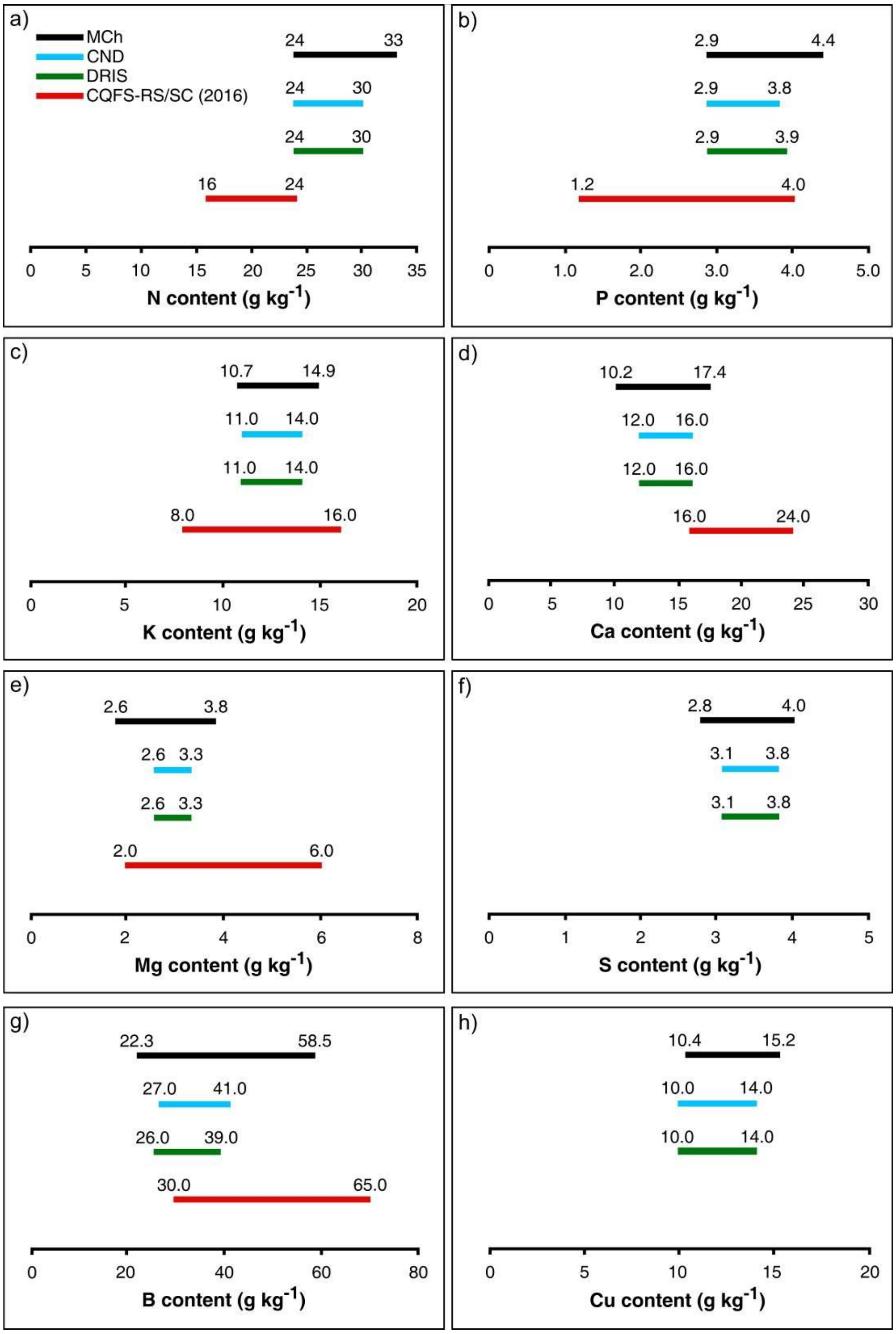

Figure 1. Leaf sufficiency ranges determined by the Mathematical Chance method (MCh), Compositional Nutrient Diagnosis (CND)[1] and Diagnosis and Recommendation Integrated System (DRIS)[2] for vineyards in the Campanha Region and official recommendation for the states of RS and SC[3] (CQFS-RS/SC) ([1]ROZANE *et al.*, 2020b; [2]MELLO *et al.*, 2018; [3]CQFS-RS/SC, 2016).

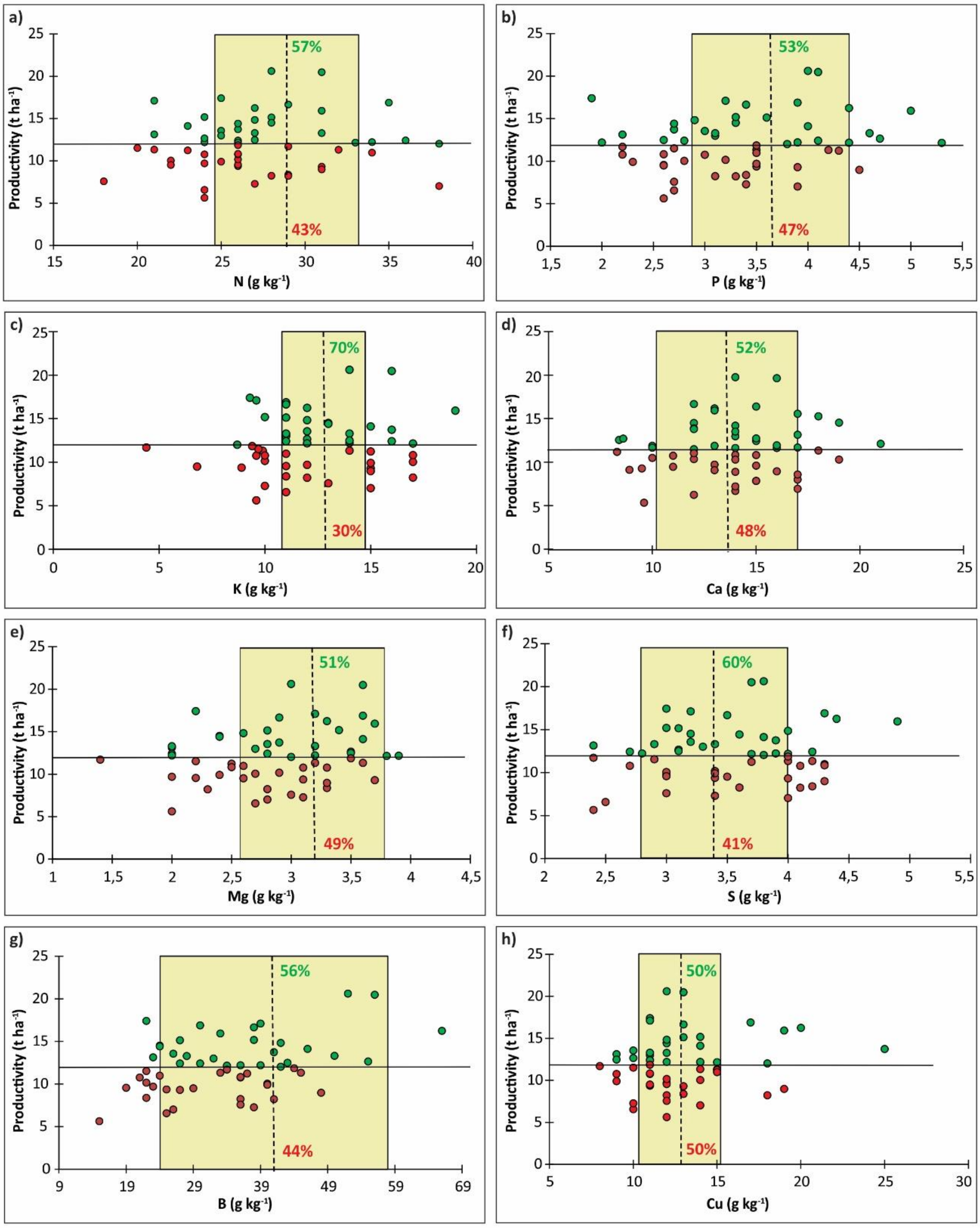

Figure 2. Relationship between grape yield and leaf nutrient contents. The green and red dots represent samples from vineyards with productivity above and below 12 t ha^{-1}, respectively, with their percentage within the sufficiency range. The yellow rectangle delimits the sufficiency range of each nutrient, calculated by the Mathematical Chance method (MCh). The dashed vertical line represents the optimal level of sufficiency.

Approximately 80 % of the evaluated vineyards are within the sufficiency range for foliar P levels, while 9 % had levels above and 11 % below the range. This result is consistent with the average available P levels in the soil (32.7 mg kg^{-1}), which is considered high according to CQFS-RS/SC (2016), indicating that, in general, P is not limiting the productivity of vineyards in the region.

The MCh method estimated the sufficiency range between 10.7 to 14.9 g kg^{-1} of K in the vine leaf tissue (Figure 1c). This range reflects the one established by the official recommendation for the states of RS and SC (8 to 16 g kg^{-1}). As in the case of P, the average exchangeable K content in the vineyard soils (81.2 mg dm^{-3}) is classified as high according to CQFS-RS/SC (2016), which may have contributed so that most tissue samples had more than 10 g kg^{-1} of K.

The narrow breadth of K sufficiency range is related to the concentration of high-yield samples within the range (Figure 1c). Because of the parent material, soils in the Campanha region are characterized by higher levels of exchangeable K, compared to soils in the Serra region (STRECK *et al.*, 2008, SOARES *et al.*, 2008), which may explain the differences between the K sufficiency ranges established in the present work and the official recommendation, which is adopted in a generalized way in the states of RS and SC. This assumption is supported by the results obtained by Melo *et al.* (2018) using the DRIS system to assess the nutritional status of vineyards in the Campanha Region. The authors delimited the K sufficiency range from 11.0 to 14.0 g kg^{-1}, which is practically equal to the range obtained in the present work. Furthermore, in relation to the optimal level of K in plant tissue, Rozane *et al.* (2020b), using the CND, determined the value of 12 g kg^{-1}, which is also very close to the value of 12.8 g kg^{-1} calculated in the present study by MCh.

Among the vineyards evaluated in this study, 48 % had foliar K contents within the sufficiency range, while 25 % and 27 % presented values above and below the range, respectively. These data suggest that there is a nutritional imbalance related to the levels of K in the leaf tissue, since the number of vineyards that present excess and deficiency of K surpasses those that are within the sufficiency range. Exchangeable K in the soil can be assimilated by plants through different absorption mechanisms and leaf levels of the nutrient, instead of being related to productivity, may be representing the occurrence of luxury consumption when they are above the sufficiency range (YE *et al.*, 2020).

The optimal level of foliar Ca was estimated by the MCh method in 13.8 g kg^{-1} (Figure 1d) and is similar to that determined by the CND system as 14 g kg^{-1} (ROZANE *et al.*, 2020b). Our sufficiency range of Ca (10.2 to 17.4 g kg^{-1}) is narrower than the official recommendation (16 to 24 g kg^{-1}). However, it shows great similarity with the range determined by DRIS (12 to 16 g kg^{-1}) (MELO *et al.*, 2018). The main reason for the narrow sufficiency range may be attributed to the exchangeable Ca contents in the soils of the present study. The average Ca^{2+} content was 2.2 $cmol_c$ dm^{-3} and 86 % of the soil samples had the nutrient content below the critical level (4.0 $cmol_c$ dm^{-3}) (CQFS-RS/ SC, 2016). Furthermore, exchangeable Ca contents in the sandy soils of the Campanha are lower than those of soils of basaltic origin in the Serra Region (STRECK *et al.*, 2008).

The difference between the official recommendation for the states of RS and SC and those obtained in the present work using MCh, along with those that used the DRIS and the CND, point to the occurrence of regional variability for the patterns of nutritional sufficiency, and, therefore, the need to develop regionalized standards. Considering the sufficiency range of foliar Ca obtained by the MCh method, 75 % of the samples

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presented adequate levels of the nutrient, while 11 and 16 % presented levels above and below the range, respectively. Therefore, according to the sufficiency range of Ca in the leaf tissue established in the present work, most vineyards present adequate levels of the nutrient. However, if we consider the range determined by the CQFS-RS/SC (2016), only 16 % of the samples would be within the appropriate range for foliar Ca content, indicating the inadequacy of the official recommendation for the specificity of the Campanha Region.

The sufficiency range for Mg was estimated, by the MCh method, between 2.6 to 3.8 g kg^{-1} (Figure 1e). Compared to the official recommendation for the crop (2 to 6 g kg^{-1}), the range estimated in the present study coincides only with the lower limit of that one. Once more, the range determined by Melo *et al.* (2018) for vineyards in the Campanha region, using the DRIS system (2.6 to 3.3 g kg^{-1}), is closer to the one obtained in the present study. The optimal level, based on the MCh method (median of the values of the sufficiency range for the nutrient) was 2.8 g kg^{-1} of Mg in the leaf tissue (Figure 2e), very close to the value of 2.9 g kg^{-1} estimated by Rozane *et al.* (2020b) using CND in vineyards in the same region.

The sufficiency range of leaf Mg, estimated by the MCh method, indicates that 71 % of the vineyards had adequate levels of the nutrient in the tissue, while 2 % and 27 % had levels above and below the limits of sufficiency. Therefore, there is an expressive number of Mg deficient vineyards, contrary to what is indicated by the official sufficiency range (CQFS-RS/SC, 2016), from 2.0 to 6.0 g kg^{-1}. In this case, we would have only 2 % of the vineyards showing deficiency for this nutrient, which indicates the overestimation of the sufficiency of the foliar contents of Mg in the vineyards of the region by the official research.

Concerning S (Figure 1f), the range of leaf sufficiency determined by the MCh method was from 2.8 to 4.0 g kg^{-1}. However, despite the importance of S in plant nutrition, which is directly related to the production of amino acids, proteins and coenzymes (VITTI *et al.*, 2006), there is still no official recommendation determining the limits of foliar sufficiency of this nutrient for the vine culture in the states of RS and SC. In this case, it becomes even more important to employ statistical methods that allow obtaining the sufficiency ranges by evaluating commercial vineyards.

Comparing the results of the present work with those of Melo *et al.* (2018), using the DRIS system for vineyards in the Campanha region (3.1 to 3.8 g kg^{-1}), it is to be noted a high degree of similarity between the two ranges. The optimal foliar S level estimated in the present work, 3.4 g kg^{-1}, exactly coincides with the value obtained by Rozane *et al.* (2020b) using the CND (Figure 2f). In view of the results discussed above, involving three different methods (MCh, Dris and CND), and the absence of official recommendation for the foliar sufficiency range of S, it is possible to adopt these reference values in a practical way to carry out the diagnosis based on the foliar contents of nutrients for vines in the Campanha region of RS.

The range of foliar S sufficiency estimated by the MCh method (Figure 2f) indicates that 71 % of the vineyards had adequate foliar S levels, while 18 and 11 % showed levels above and below the sufficiency range for the nutrient, respectively. The sparse occurrence of vineyards with nutritional S deficiency, according to the results of the present work, may be due to the systematic use of sulfur-based products for phytosanitary treatment.

The MCh method estimated the foliar sufficiency range of B from 22.3 to 58.81 mg kg^{-1} (Figure 1g),

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with an optimal level of 40.6 mg kg^{-1} (Figure 2g). These values do not differ much from the official recommendation for the crop, which defines the sufficiency range between 30 and 65 mg kg^{-1}, with an optimal level of 47.5 mg kg^{-1} (CQFS-RS/SC, 2016). On the other hand, differently from what was observed for other nutrients, the limits of B contents estimated by MCh differ from those obtained by Melo *et al.* (2018) for vineyards in the Campanha Region (26 to 39 mg kg^{-1}). Likewise, the optimal value for the B content in the vine tissue determined in the present work is above that obtained by the analysis of CND (34 mg kg^{-1}) performed by Rozane *et al.* (2020b). This difference can be explained by the dispersion of high productivity samples (Figure 2g), since only four high productivity samples are in the range between 49 and 58 mg kg^{-1} of B, but which generate a high MCh index because there was no low-productivity sample in this interval. Thus, the use of larger sampling number may be a way to improve the accuracy of the MCh method in predicting the range of nutritional sufficiency.

In turn, the range of foliar sufficiency of Cu was determined between 10.4 and 15.2 mg kg^{-1} (Figure 1h). Once again, this range was similar to that obtained using DRIS (10 to 14 mg kg^{-1}) (MELO *et al.*, 2018) and the optimal leaf level, calculated as 12.8 mg kg^{-1}, was very close to that estimated by CND as 12 mg kg^{-1} (ROZANE *et al.*, 2020b) (Figure 2h).

As for S, there is still no official reference for the levels Cu in grapevine tissue for the states of RS and SC. The determination of adequate levels of Cu is particularly important for the vine due to the phytosanitary treatments, which involve the frequent application of copper fungicides. The systematic usage of these products can lead to the accumulation of Cu in the soil, and its assimilation by the vine will be subject to the dynamics of the element in the soil, which may be more or less available depending on factors such as the organic matter content, which promotes the Cu complexation, and soil pH (ROSA *et al.*, 2020).

It was observed that 70 % of the sampled vineyards had adequate levels, while 13 % had excessive and 17 % had insufficient levels of Cu in leaf tissue (Figure 2h). These data do not indicate that deleterious levels of Cu, both in the soil and in the leaf tissue, are impacting the productivity of vineyards in the region. Soils with sandy texture and low levels of organic matter are prone to Cu losses by leaching, causing the levels of the metal to be stabilized (ABREU *et al.*, 2007). However, according to Miotto *et al.* (2017), the highest levels of available Cu in vineyard areas, in the sandy soils of Campanha, are concentrated in the 0-10 cm soil layer. The authors report applications of up to 6 kg ha^{-1} of Cu per harvest, resulting from phytosanitary treatments. The soils of the vineyards evaluated in the present work have an average available Cu content of 26.5 mg dm^{-3}, being that levels above 0.4 mg dm^{-3} are already considered high (CQFS-RS/SC, 2016). Miotto *et al.* (2014), in a study also carried out in vineyards in the Campanha Region, observed that high concentrations of available Cu in the soil did not alter the dynamics of N, P, K, Ca and Mg uptake by the vines, which may be related to root exploration in deeper soil layers, where micronutrient contents are lower.

The principal component analysis (PCA) explained 46.64 % of the total variance in the data, so that 19.67 % was explained by principal component 1 and 27.27 % by principal component 2 (Figure 3). It is possible to observe in the ordination plot that there is an association between productivity and leaf levels of Ca, Mg and B. On the other hand, there is an inverse relationship between productivity and K/Ca and K/Mg

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ratios in leaf tissue. It is known that high levels of exchangeable K in the soil can affect the foliar levels of Ca and Mg in the vine, and in severe cases, symptoms such as rachis desiccation and reduced vineyard productivity can be observed (HALL *et al.*, 2011). Furthermore, it was found that, among the vineyards evaluated in the present study, 16 % and 27 % had a nutritional deficiency of Ca and Mg, respectively. This condition may be associated with the fact that, in the evaluated soils, the average levels of these nutrients are below those considered adequate (Table 1). In turn, the levels of available K are interpreted as high, according to the official classification (CQFS-RS/ SC, 2016), which may be resulting in a nutritional imbalance in relation to Ca and, especially, to Mg in plant tissue.

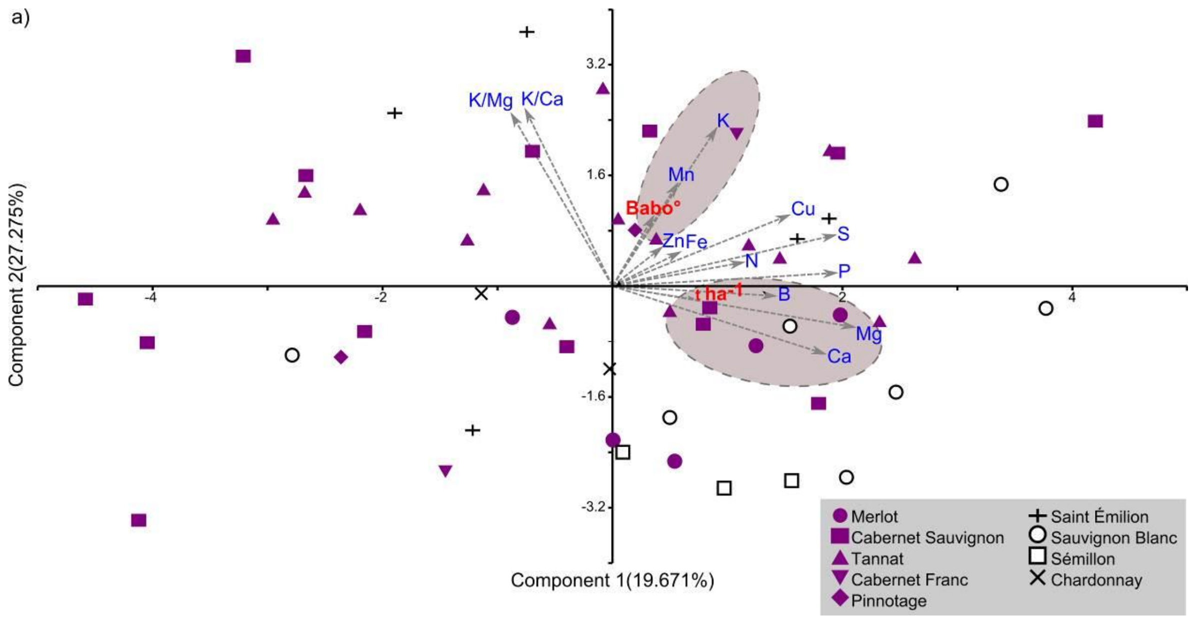

Figure 3. Principal component analysis of leaf nutrients in grapevine, vineyard productivity and average sugar content of the grapes (Babo degrees) in the Campanha Region, Rio Grande do Sul state, Brazil.

PCA also showed that the concentration of sugar in the must (Babo) is associated with the levels of K and Mn in plant tissue. It is estimated that the amount of Mn exported at harvest reach 1.5 kg ha^{-1} and that its deficiency affects several metabolic processes, including the synthesis of sugars (BATUKAEV *et al.*, 2015). Likewise, K is associated with the transport of sugars in the vascular tissues of the vine, which may explain the association between the nutrient and the sugar content in the must (ROGIERS *et al.*, 2017).

The Mathematical Chance method was suitable to estimate the sufficiency ranges and the optimal foliar level for macro and micronutrients for the vine crop in the Campanha region. In general, the Mathematical Chance method produced results similar to those obtained with the use of DRIS and CND in other works carried out in the same region. In addition, the three methods differ from the official recommendation, demonstrating that it is important to regionalize the estimation of reference values to perform the foliar diagnosis of the vine.

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Conflict of Interests

The authors declare that the research was conducted in the absence of any potential conflicts of interest.

Ethical Statements

The authors confirm that the ethical guidelines adopted by the journal were followed by this work, and all authors agree with the submission, content and transfer of the publication rights of the article to the journal. They also declare that the work has not been previously published nor is it being considered for publication in another journal.

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References

ABREU, C.A.; LOPES, A.S.; SANTOS, G.C.G. Micronutrientes. In: NOVAIS, R.F. et al. (Ed.) Fertilidade do solo. Viçosa: Sociedade Brasileira de Ciência do Solo, 2007, p. 645-736.

ACEVEDO, M.; ÁLVAREZ, C.; CARTES, E. et al. Production and establishment techniques for the restoration of Nothofagus alessandrii, an endangered keystone species in a Mediterranean forest. New Forests, v. 51, p. 159–174, 2020. https://doi.org/10.1007/s11056-019-09724-x.

ALVARES, C.A.; STAPE, J.L.; SENTELHAS, P.C.*et al*. Köppen's climate classification map for Brazil. **MeteorologischeZeitschrift**, v.22, n.6, p. 711-728, 2013. https://doi.org/10.1127/0941-2948/2013/0507.

BATUKAEV, A.A.; MAGOMADOV, A.S.; MALYH, G.P. *et al*. Influence of manganese fertilizer on efficiency of grapes on sandy soils of the Chechen Republic. **World Applied Sciences Journal**, v. 33, n. 2, p. 350-355,2015. https://doi.org/10.5829/idosi.wasj.2015.33.02.22288.

BRUNETTO, G.; RICACHENEVSKY, F.K.; STEFANELLO, L.O. *et al*. Diagnosis and management of nutrient constraints in grape. *In:* SRIVASTAVA, A.K.; HU, C. (Ed.). **Fruit Crops**. Amsterdam: Elsevier, 2020, p. 693-710. http://dx.doi.org/10.1016/B978-0-12-818732-6.00047-2.

CIESIELSKA, J.; MALUSÀ, E.; BOURLOT, G. Grape leaf diagnosis standards in comparison to pedological factors. **Acta Horticulturae**, v. 640, n. 1, p. 37-44, 2004. https://doi.org/10.17660/ActaHortic.2004.640.3.

CQFS-RS/SC. Comissão de Química e Fertilidade do Solo. **Manual de calagem e adubação para os Estados do Rio Grande do Sul e Santa Catarina**. 11. ed. Porto Alegre: Sociedade Brasileira de Ciência do Solo. 376 p. 2016.

FLORES, S.S.; FARIAS, C.; ANDRADE, G. *et al*. Competitive and innovation factors in wine tourism clusters: A comparative study between consolidated and emerging regions in Brazil and Uruguay. *In*: **BIO Web of Conferences**, 2016, Les Ulis, v. 7, n.1, p. 03024. https://doi.org/10.1051/bioconf/20160703024.

FLORES, C.A.; PÖTTER, R.O.; FASOLO, P.J. *et al*. **Levantamento Semidetalhado dos Solos: região da campanha - Folha Palomas**, RS. Porto Alegre: UFRGS, 2007. 96p.

HALL, G.E.; BONDADA, B.R.; KELLER, M. Loss of rachis cell viability is associated with ripening disorders in grapes. **Journal of Experimental Botany**, v. 62, n. 3, p. 1145–1153, 2011. https://doi.org/10.1093/jxb/erq355.

HAMMER, Ø.; HARPER, D.A.T.; RYAN, P.D. **PaST-Palaeontological Statistics**, version 1.32. Oslo, NO: University of Oslo. 2004.

KULMANN, M.S.D.S.; SETE, P.B.; PAULA, B.V.D.*et al*. Kinetic parameters govern of the uptake of nitrogen forms in ‘Paulsen’ and ‘Magnolia’ grapevine rootstocks. **Scientia Horticulturae**, v. 264, n. 1. p. 109174, 2020. https://doi.org/10.1016/j.scienta.2020.109174.

KURIHARA, C.H.; MAEDA, S.; ALVAREZ, V.H V. **Interpretação de Resultados de Análise Foliar**. Comunicado Técnico, 74. Colombo; Embrapa Florestas, 2005. 42 p. Available from: https://ainfo.cnptia.embrapa.br/digital/bitstream/item/38088/1/DOC200574.pdf. Accessed on: 27 Jun. 2022.

ISSN: 0104-907. ISSN ONLINE: 2595-7686.
Received on 28 Jun. 2022. Accepted on 07 Oct 2022.

MALUF, J.R.T *et al*. **Zoneamento agroclimático da videira europeia (*Vitis vinifera* L.) e videira americana (*Vitis labrusca* L.) no estado do RS**. Boletim Fepagro. Porto Alegre: Fepagro, 2014. 65 p.

MELO, L.M.R., MACHADO, C.A.E. Vitivinicultura brasileira: panorama 2019. Bento Gonçalves: Embrapa Uva e Vinho, 2020, 21 p. Available from: http://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/1124189. Accessed on: 27 Jun. 2022.

MELO, G.W.; ROZANE, D.E.; BRUNETTO, G. Identification of the critical levels, sufficiency ranges and potential response to nutrient fertilization in vineyards by the DRIS method. **Acta Horticulturae**, v. 1217, n. 1, p. 423-430, 2018. https://doi.org/10.17660/ActaHortic.2018.1217.55.

MIOTTO, A.; CERETTA, C.A.; BRUNETTO, G. *et al*. Copper uptake, accumulation and physiological changes in adult grapevines in response to excess copper in soil. **Plant and Soil**, v. 374, n. 1-2, p. 593–610, 2014. https://doi.org/10.1007/s11104-013-1886-7.

MIOTTO, A; CERETTA, C.A.; GIROTTO, E. *et al*. Copper accumulation and availability in sandy, acid, vineyard soils. **Communications in Soil Science and Plant Analysis**, v. 48, n. 10, p. 1167–1183, 2017. https://doi.org/10.1080/00103624.2017.1341908.

PARENT, L.E.; DAFIR, M.A. Theoretical concept of compositional nutrient diagnosis. **Journal of the American Society for Horticultural Science**, v. 117, n. 2, p. 239-242, 1992.https://doi.org/10.21273/JASHS.117.2.239.

ROGIERS, S.Y; COETZEE, Z.A.; WALKER, R.R.*et al*. Potassium in the grape (*Vitis vinifera* L.) berry: Transport and function. **Frontiers in Plant Science**, v. 8, n. 1629, p. 1-19, 2017. https://doi.org/10.3389/fpls.2017.01629.

ROSA, D.J.; AMBROSINI, V.G.; KOKKORIS, V. *et al*. Lime protection for young vines exposed to copper toxicity. **Water, Air, and Soil Pollution**, v. 231, n. 296, p. 1-10, 2020. https://doi.org/10.1007/s11270-020-04662-3.

ROZANE, D.E.; NATALE, W.; BRUNETTO, G. *et al*. Uso do CND para estimativa da composição nutricional em frutíferas. *In:* **Atualização sobre calagem e adubação em frutíferas**. Porto Alegre: SBCS Núcleo Regional Sul, 2020a. p. 45-63.

ROZANE, D.E.; PAULA, B.V.D.; MELO, G.W.B.D. *et al*. Compositional Nutrient Diagnosis (CND) applied to grapevines grown in subtropical climate region. **Horticulturae**, v. 6, n. 3, p. 56-68, 2020b. https://doi.org/10.3390/horticulturae6030056.

SOARES, A.P.; SOARES, P.C.; HOLZ, M. Correlações estratigráficas conflitantes no limite permo-triássico no sul da Bacia do Paraná: o contato entre duas sequências e implicações na configuração espacial do aquífero Guarani. **Pesquisas em Geociências**, v.35, n.2, p.115-133, 2008.

STRECK, E.V.; KÄMPF, N.; DALMOLIN, R.S.D. *et al*. **Solos do Rio Grande do Sul**. Porto Alegre: UFRGS, 2008. 222 p.

SUMNER, M.E. Use of the DRIS system in foliar diagnosis of crops at high yield levels. **Communications in Soil Science and Plant Analysis**, v. 8, n. 3, p. 251-268, 1977.

VITTI, G.C.; LIMA, E.; CICARONE, F. Cálcio, magnésio e enxofre. *In:* MANLIO, S.F. (Ed.). **Nutrição mineral de plantas**. Sociedade Brasileira de Ciência do Solo, Viçosa, 2006. p. 299-325.

WADT, P. G. S. **Os métodos da Chance Matemática e do Sistema Integrado de Diagnose e Recomendação (DRIS) na avaliação nutricional de plantios de eucalipto**. Viçosa: UFV, 1996. 123 p. Tese (Doutorado em Solos e Nutrição de Plantas) – Programa de Pós-graduação em Solos e Nutrição de Plantas. Faculdade de Agronomia, Universidade Federal de Viçosa.

WADT, P. G. S.; ALVAREZ V. H.; NOVAIS, R. F. *et al*. O método da Chance Matemática na interpretação de dados de levantamento nutricional de eucalipto. **Revista Brasileira de Ciência do Solo**, v. 22, n. 4, p. 773-778, 1998a. https://doi.org/10.1590/S0100-06831998000400023.

WADT, P. G. S.; NOVAIS, E. F.; ALVAREZ, V. H. *et al*. Valores de referência para macronutrientes em eucalipto obtidos pelos métodos DRIS e Chance Matemática. **Revista Brasileira de Ciência do Solo**, v. 22, n. 4. p. 685-692, 1998b.https://doi.org/10.1590/S0100-06831998000400014.

WÜRZ, D.A.; BEM, B.P.; ALLEBRANDT, R. *et al*. New wine-growing regions of Brazil and their importance in the evolution of Brazilian wine. **BIO Web of Conferences**, Les Ulis, v. 9, p. 01025, 2017.https://doi.org/10.1051/bioconf/20170901025.

YE, T.; XUE, X.; LU, J.*et al*. Yield and potassium uptake of rice as affected by potassium rate in the middle reaches of the Yangtze River, China. **Agronomy Journal**, v. 112, n.2, p. 1318-1329, 2019. https://doi.org/10.1002/agj2.20092.

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