Identification of the critical levels, sufficiency ranges and potential response to nutrient fertilization in vineyards by the DRIS method

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Abstract

Brazil is a significant global grape producer (*Vitis* spp.). The state of Rio Grande do Sul produces 59% of the national output. Despite the large national production, the grapevine has not yet been tested sufficiently to obtain data from long-term experiments in both production as well as suitable nutritional management. The DRIS method is one of the useful tools required to assess plant quality. The normal nutrient ranges were determined from 63 commercial fields, in order to interpret the concentrations of N, P, K, Ca, Mg, S, B, Cu, Fe, Mn and Zn in the culture through statistical analysis and regression. The DRIS indices were related to the respective contents present in the leaf dry matter samples collected during the veraison and opposite to the first bunch of the fruiting branch. Although the general index of the nutritional balance of the DRIS did not permit the establishment of a relationship with productivity, it enabled, based on the standards, the determination of the normal ranges for the nutrients evaluated. The results were in accordance with those reported in the literature. The potential response to fertilization was proven ineffective as an interpretive methodology.

Keywords: *Vitis* spp., mineral nutrition, foliar diagnosis, nutritional balance

INTRODUCTION

Viticulture is an agricultural activity high in cost, but extremely profitable, with a higher profitability than many annual grain crops. In fact, in terms of financial sustainability vine-growers are affected by the product yield and quality. However, viticulture involves fertilizer application: in Brazil, for instance, nearly 44% of the expenses are utilized for soil amendments such as acidity correctives accounting around 13% for the total cost of vineyard maintenance and production (>4 years) (IEG/FNP, 2017). Therefore, the fertilizer application must be monitored and used only when needed, and in judicious doses, to raise the soil nutrient availability necessary to maintain the requisite nutritional status (Ciotta et al., 2016) and to ensure a high quality and compensatory harvest (Piccin et al., 2017).

Using the integrated diagnosis and recommendation system (DRIS) the nutritional condition of vines can be estimated. This system includes the bivariate relationships, between nutrients and facilitates the classification of nutrients to easily identify the ones which are the most limiting (either by excess or lack), as well as to assess the indices that reveal the relative nutrient balance. The DRIS methodology has been used for vines (Teixeira et al., 2015) worldwide (Carneiro et al., 2015; Martín et al., 2016) and in Brazil revealing its effect in the creation of nutritional standards. This implies that a part of the dissimilarities in vineyard productivity could be linked to the nutritional balance.

The goal of this research was to establish the DRIS standards, critical level and the nutrient sufficiency range, as well as to confirm the efficiency of the potential response to fertilizer application in *Vitis vinifera* L.

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MATERIAL AND METHODS

Eighty-one vineyards involved in the commercial production and cultivation of *Vitis vinifera* L. were identified from the Gaucho Campaign region of the Rio Grande do Sul, in the southern part of Brazil, on the Uruguay border, with the following coordinates (30°53'27") S and 55°31'58" longitude W, at an altitude of 208 m. The vineyards were characterized as having 'SO4' hypobionts, with the epibiotes of Cabernet Franc, Cabernet Sauvignon, Sauvignon Blanc, Merlot, Pinotage, Sémillon, with an average age of eight years. The driving system included a 3-m line spacing between the 1.20 m plants. Based on the Köeppen classification, this region experiences the Cfa type of climate.

Each vineyard was identified by a composite leaf sample, represented by groups of 25 single leaf samples. Whole leaf sampling (limbus + petiole) was performed and the leaf opposite the first bunch of the fruiting branch, at the commencement of maturation/change in berry color (veraison) was gathered. This was done in accordance with the method of the commission of chemistry and soil fertility states of Rio Grande do Sul and Santa Catarina (CQFS-RS/SC, 2016). Leaves were first washed in running water, then with a solution of deionized water and neutral detergent (0.1%), consequently with a hydrochloric acid solution (0.3%) and finally in deionized water. The leaves were then oven-dried in a forced air ventilation oven at 60±5°C until constant mass was reached. Next, leaves were ground in a Willey mill, passed through a 0.841 mm (20 mesh) sieve and stored. The tissue was then subjected to digestion (Tedesco et al., 1995). The N content was ascertained using the Micro-Kjeldahl apparatus, by colorimetry (Murphy and Riley, 1962), K by flame photometer, and the Ca, Mg, Cu, Fe, Mn and Zn contents via atomic absorption spectrophotometry (Tedesco et al., 1995). The B content was assessed by colorimetry (Tedesco et al., 1995), post calcination, by maintaining the tissue in a muffle oven at 550°C for 3 h.

In each vineyard, the grape yield was calculated by weighing all the fruit bunches in 20 plants. The DRIS standards were established for the nutrient contents and productivity, applying the log-transformed bivariate relations proposed by Beverly (1987). The high productivity populations or reference population, as well as the low productivity populations were estimated by the cumulative function (Khiari et al., 2001). The indices determined through the DRIS norms were explained in terms of their potential response to fertilization (PRA), using five response classes: positive (p), positive or nil (pz), null (z), negative or nil (nz) and negative (n), as indicated by Wadt (2005). The classes obtained were grouped and denominated, considering their effect on productivity, as follows: limiting by lack (LF = p + pz), limiting by excess (LE = n + nz), or nonlimiting (NL = n), as suggested by Silva et al. (2005). The occurrence frequencies of each nutrient in the LF, LE and NL classes were analyzed using the chi-square test (χ^2), at 5% probability, to test the hypothesis that the frequencies (FO) observed showed no statistical difference from the expected frequencies (FE) (Urano et al., 2006). The frequencies observed were calculated using the equations:

FO = number of plots of class p, pz, z, nz or n

expected frequency: FE (for p or n) = (total of evaluated plots/total of evaluated nutrients)

(pz, z and nz) = (total of evaluated plots/total nutrients evaluated)*3

where factor 3 is the number of factors that constitute a class (pz, z and nz). Applying the χ^2 test, no more than 20% of the expected frequencies below 5 and none equal to zero were permissible, and the classes were categorized under LF, LE and NL.

To ascertain the pertinent levels of each nutrient, its relationship with its respective nutritional balance index was calculated. Evaluation of the foliar concentrations for each nutrient was carried out through regression analysis, and equations relating the nutrient contents with their respective DRIS indexes were obtained. By equalizing the statistical models to zero, the lower (LI) and upper (LS) limits of the normal range were determined; by subtracting and adding the value found, the 2/3 ratio of the value of the standard deviation of the contents of each nutrient was calculated (Souza et al., 2015). Values of the critical level (NC) or adequate content were assessed by assigning null value to the indices of the equations for each of the nutrients.

RESULTS AND DISCUSSION

The yield showed variations from 69 to 0.4 t ha^{-1}, with an average of 14 t ha^{-1}, and standard deviation of 12 t ha^{-1}. Thus, after excluding 18 outliers from the Mahalanobis distance (Parent et al., 2009) of the database, 63 observations showing variations from 22 to 0.4 t ha^{-1} in productivity remained. A mean of 16 t ha^{-1} and standard deviation of 4 t ha^{-1} were recorded. Prior to data analysis, data were checked for their Gaussian distribution (n=63), and normality was determined by the Shapiro-Wilk test (W = 0.96433; p=0.0648), thus accepting Ho, indicating the normal distribution of the data.

The dual relations were transformed to the logarithmic scale per the requirements of the Beverly (1987) DRIS standard, to eliminate the extent of flattening of the distribution of the values in relation to the normal curve (effect of kurtosis) on the coefficient of variation. Table 1 lists the means of the bivariate relations and their respective standard deviations that were used to establish the norm.

Table 1. Mean ($\bar{x}$) and standard deviations (σ) of the association between the constituents of two nutrients found in the samples of foliar dry matter, obtained from the increased vine yields (*Vitis vinifera* L.) to establish the DRIS standard.

	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
N /										
$\bar{x}$	0.92	0.34	0.29	0.97	0.89	-0.08	0.35	-0.62	-1.25	-0.87
σ	0.09	0.12	0.12	0.11	0.06	0.16	0.09	0.13	0.13	0.16
P /										
$\bar{x}$	-0.92	-0.58	-0.62	0.05	-0.03	-1.00	-0.56	-1.54	-2.17	-1.78
σ	0.09	0.13	0.11	0.09	0.07	0.13	0.07	0.12	0.15	0.19
K /										
$\bar{x}$	-0.34	0.58	-0.05	0.63	0.55	-0.42	0.01	-0.96	-1.59	-1.21
σ	0,12	0.13	0.14	0.12	0.12	0.14	0.12	0.13	0.15	0.18
Ca /										
$\bar{x}$	-0.29	0.62	0.05	0.67	0.59	-0.38	0.06	-0.91	-1.55	-1.16
σ	0.12	0.11	0.14	0.06	0.09	0.12	0.11	0.15	0.14	0.16
Mg /										
$\bar{x}$	-0.97	-0.05	-0.63	-0.67	-0.08	-1.05	-0.62	-1.59	-2.22	-1.84
σ	0.11	0.09	0.12	0.06	0.09	0.12	0.10	0.13	0.15	0.16
S /										
$\bar{x}$	-0.89	0.03	-0.55	-0.59	0.08	-0.97	-0.54	-1.51	-2.14	-1.76
σ	0.06	0.07	0.12	0.09	0.09	0.13	0.07	0.13	0.11	0.15
B /										
$\bar{x}$	0.08	1.00	0.42	0.38	1.05	0.97	0.44	-0.54	-1.17	-0.78
σ	0.16	0.13	0.14	0.12	0.12	0.13	0.13	0.18	0.17	0.20
Cu /										
$\bar{x}$	-0.35	0.56	-0.01	-0.06	0.62	0.54	-0.44	-0.97	-1.60	-1.22
σ	0.09	0.07	0.12	0.11	0.10	0.07	0.13	0.12	0.13	0.18
Fe /										
$\bar{x}$	0.62	1.54	0.96	0.91	1.59	1.51	0.54	0.97	-0.63	-0.25
σ	0.13	0.12	0.13	0.15	0.13	0.13	0.18	0.12	0.15	0.16
Mn /										
$\bar{x}$	1.25	2.17	1.59	1.55	2.22	2.14	1.17	1.60	0.63	0.38
σ	0.13	0.15	0.15	0.14	0.15	0.11	0.17	0.13	0.15	0.19
Zn /										
$\bar{x}$	0.87	1.78	1.21	1.16	1.84	1.76	0.78	1.22	0.25	-0.38
σ	0.16	0.19	0.18	0.16	0.16	0.15	0.20	0.18	0.16	0.19

This technique, based on the work of Urano et al. (2006), delineated parameters to identify differences in the event of a positive response to fertilizer application, i.e., the frequency with which the nutrients assessed were limiting due to either deficiency or excess for the vines (Table 2). After analyzing the data distribution it was possible to reject the hypothesis which purported that the frequencies observed for the nutrients were statistically similar to the expected frequencies in all the classes, because the calculated χ^2 value was greater than the χ^2 tabulated ($p=0.05$), revealing that PRA as an interpretation method was inadequate (Table 3). Boron and Mn were the only exceptions for the high productivity population in which the PRA in LE was competent.

Table 2. The recorded frequency and categorization of the fertilization response potential for the high and low productivity populations, on the basis of the leaf samples of the vine (*Vitis vinifera* L.).

PRA	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
High productivity population (*n*=29)											
p	3	3	3	2	1	1	5	1	5	3	2
pz	2	3	4	5	4	2	2	4	2	6	4
z	17	18	15	14	15	21	13	18	17	13	15
nz	5	3	3	3	9	4	3	5	3	5	4
n	2	2	4	5	0	1	6	1	2	2	4
LF	5	6	7	7	5	3	7	5	7	9	6
NL	17	18	15	14	15	21	13	18	17	13	15
LE	7	5	7	8	9	5	9	6	5	7	8
Low productivity population (*n*=34)											
p	2	6	3	1	1	0	7	1	4	3	6
pz	3	4	6	4	3	1	4	2	9	1	8
z	21	20	18	25	27	28	19	17	14	21	9
nz	4	3	6	3	2	4	1	6	2	6	5
n	4	1	1	1	1	1	3	8	5	3	6
LF	5	10	9	5	4	1	11	3	13	4	14
NL	21	20	18	25	27	28	19	17	14	21	9
LE	8	4	7	4	3	5	4	14	7	9	11

PRA: potential response to fertilization; p: positive, with high probability; pz: positive, with low probability; z: null; nz: negative, with low probability; n: negative, with high probability; LF: limit for missing; NL: non-limiting; LE: limit for excess.

Table 3. Nutrient frequency as a limiting factor for excess (LE = n + nz), equilibrium (NL = z) and limiting for deficiency (LF = p + pz), PRA and chi-square (χ^2) for high subpopulations and low vine productivity (*Vitis vinifera* L.).

Nutrient	High productivity				Low productivity			
	LE	NL	LF	χ^2	LE	NL	LF	χ^2
N	1.2	10.4	2.9	14.6	1.5	14.8	4.4	20.8
P	2.9	12.9	2.0	17.8	5.7	12.4	0.5	18.5
K	1.2	6.4	1.2	8.7	2.3	8.2	0.9	11.5
Ca	0.6	4.7	1.2	6.5	5.7	26.7	4.4	36.7
Mg	0.2	6.4	2.9	9.5	7.1	33.9	5.7	46.6
S	2.9	21.7	5.4	30.0	4.4	37.8	10.4	52.7
B	0.2	3.3	1.2	4.7	5.7	10.2	0.2	16.0
Cu	2.0	12.9	2.9	17.8	0.2	6.4	7.1	13.7
Fe	2.9	10.4	1.2	14.6	2.3	2.4	0.0	4.8
Mn	1.2	3.3	0.2	4.7	0.9	14.8	5.7	21.4
Zn	0.6	6.4	2.0	8.9	0.2	0.0	0.2	0.4
χ^2	16.0	98.6	23.1	31.4	35.9	167.7	39.4	243.1

X^2 tabulated at p=0.05: 6.0, 18.3 and 31.4 for 2, 10 and 20 degrees of freedom.

Once the high and low probability classes were grouped to depict the deficiency and excess conditions, (p + pz and n + nz, respectively), a frequency of occurrence was observed for the deficiency of nutrients (LF) or higher PRA as well as a reducing frequency of excess nutrient limitation (LE) or lower PRA. The high productivity population showed the order of the LF nutrients for the vine as given: S>N = Mg = Cu>P = Zn>K = Ca = B = Fe>Mn; and the order of the LE as: Mg = B<Ca = Zn<N = K = Mn<Cu<P = S = Fe. The low productivity population revealed the order of the LF nutrients as follows: S>Cu>Mg = Mn>N = Ca>K>P>Zn>B>Fe; and that of the order of LE: Zn>Cu>Mn>N>K = Fe>S>P = Ca = B>Mg (Table 3).

The IBNm values recorded for the nutrients in terms of the productivity for all the plots revealed a linear equation with a Pearson correlation coefficient, r=0.0072 (R^2=0.0052), that is practically null. The regression model highlights the fact that the IBNm fails to give the information essential for determining whether the fruit production is significantly associated with the nutritional balance index as evaluated using the DRIS method. However, the DRIS indices for the nutrients (Table 4) supplied mathematical models with moderate correlation coefficients only S and strong (r>0.7000) for the other nutrients, which is in line with the classification of Dancey and Reidy (2013).

Table 4. Statistical models enabling the critical nutrient levels among the DRIS indices of the grape vine (*Vitis vinifera* L.) to be determined.

Nutrient	Models[1]	R^2	r	Critical nutrient[2]
N	IN = 0.1025N - 2.7552**	0.53	0.73	27 g kg^{-1}
P	IP = 0.8245P - 2.7849**	0.70	0.84	3.4 g kg^{-1}
K	IK = 0.2462K - 3.0871**	0.68	0.82	13 g kg^{-1}
Ca	ICa = 0.1948Ca - 2.7112**	0.64	0.80	14 g kg^{-1}
Mg	IMg = 0.8147Mg - 2.3743**	0.54	0.73	2.9 g kg^{-1}
S	IS =0.5991S - 2.0676**	0.47	0.69	3.5 g kg^{-1}
B	IB = $-0.0008(B)^2$ + 0.1354B - 3.5404**	0.84	0.92	32 mg kg^{-1}
Cu	ICu = 0.2199Cu - 2.5729**	0.66	0.81	12 mg kg^{-1}
Fe	IFe = $-0.000029(Fe)^2$ + 0.030088Fe - 3.068095**	0.83	0.91	115 mg kg^{-1}
Mn	IMn = $-0.0000026(Mn)^2$ + 0.00803Mn - 3.2770**	0.81	0.90	484 mg kg^{-1}
Zn	IZn = $-0.000020(Zn)^2$ + 0.020383Zn - 3.308115**	0.88	0.94	203 mg kg^{-1}

**Significance at 1% for the Kolmogorov-Smirnov constant variance test.

[1]Statistical model of regression analysis, associating the nutrient contents with their respective indices.

[2]Critical level (NC) values or adequate content, drawn by assigning null value to the indices of the equations for each nutrient.

Table 4 shows the critical levels once the indices of each equation were equated to zero. Then, to the resultant findings of the mathematical models, 2/3 of the standard deviations of the nutrient contents from each sample were added and subtracted. This facilitated the establishment of the normal distribution ranges for the nutrients, and therefore enabled a comparison of these ranges with the other values observed (Table 5). From the levels noted in the DRIS standard (Table 5), close relationships could be observed to those verified for grapevine cultivation in Brazil by CQFS-RS/SC (2016); Quaggio and van Raij (1997) and Malavolta et al. (1997). The greatest divergences from the standards of CQFS-RS/SC (2016) are evident for the contents of N, Ca, Mn and Zn. The greater discrepancy observed in the normal ranges between the Mn and Zn contents is most likely due to the constant and current pesticide applications. In fact, many agrochemicals contain Cu, Mn and Zn, which are essential in the production bases of the cultivation of the culture. The differences noted in the reference values could still be credited to the different edaphoclimatic and cultivar conditions used to ascertain the ranges.

Table 5. Normal ranges (adequate levels) of the nutrients in the vine leaf samples (*Vitis vinifera* L.) in relation to the recommendations of the contents according to the Brazilian bulletins.

References	N	P	K	Ca	Mg	S
	(g kg^{-1})					
DRIS – Videiras[1]	24-30	2.9-3.9	11-14	12-16	2.6-3.3	3.1-3.8
CQFS-RS/SC (2016)[2]	16-24	1.2-4.0	8-16	16-24	2.0-6.0	
Quaggio and van Raij (1997)[2]	30-35	2.4-2.9	15-20	13-18	4.8-5.3	3.3-3.8
Malavolta et al. (1997)[3]	25-27	2-3	15-20	30-40	3-4	2-3
	B	Cu	Fe	Mn	Zn	
	(mg kg^{-1})					
DRIS – Videiras[1]	26-39	10-14	89-140	390-578	150-256	
CQFS-RS/SC (2016)[2]	30-65		60-150	30-300	25-60	
Quaggio and van Raij (1997)[2]	45-53	18-22	97-105	67-73	30-35	
Malavolta et al. (1997)[3]	30-40			40-100	25-40	

[1]The equations provided the normal ranges from 0±2/3 of the standard deviation for the constituents of each nutrient.

[2]Samplings performed at the commencement of berry ripening (veraison).

[3]Sampling done on the petiole.

Generally, the DRIS method revealed a lower amplitude range than the ones reported in the literature (Table 5). Similar findings were recorded for other fruits like orange (Camacho et al., 2012), guava (Souza et al., 2015) and atemoieira (Santos and Rozane, 2017). Serra et al. (2010) considered this narrower amplitude as positive, due to the greater accuracy in understanding the results of the foliar contents, minimizing the possibility of obtaining low yields, but with the requisite plant nutrient levels.

CONCLUSIONS

The following conclusions can be drawn from the study:

- The relationships between the mean nutrient balance index and vineyard productivity (high and low productivity) were found to be inadequate to conclusively identify a relation between fruit production in terms of the nutritional status of the vines and the potential of reactions to fertilizer application.
- The DRIS indices of the nutrients isolated for N, P, K, Ca, Mg, B, Cu, Fe, Mn and Zn, were effective in establishing the nutrient status as deficient, excessive or balanced.

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