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Guidelines for fertilizer use in vineyards based on nutrient content of grapevine parts

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ABSTRACT

Plant analysis plays a major role in fertilizer recommendations for perennial tree crops and vines. Plant analysis, however, does not quantify the rate of nutrients to apply. The approach developed in this work takes into account the content of the nutrients in grapevine parts and their dynamic within the plant to assist in the estimation of the amount of fertilizer to apply. Groups of three vines were cut at ground level on four different dates from September 14th to November 28th. On the first sampling date the vines were separated into trunk, cordons, canes, leaves and clusters for determination of dry matter content and elemental composition. On the following dates the vines were separated into the plant parts that were still present, since the clusters were only present on the first sampling date and the leaves on the first two. To assess the mobility of nutrients within the plant, samples of phloem vessels and sawdust of the entire trunk were taken as well as samples of chlorotic and green leaves. Nitrogen (N), potassium (K), phosphorus (P) and boron (B) showed mobility within the plant whereas calcium (Ca) and magnesium (Mg) did not. The removal of nutrients in clusters is critical for estimating N and K fertilizer rates. Clusters removed 19.9 kg N ha^{-1} and 28.7 kg K ha^{-1}. In the case of N, it is also important to assess the system's ability to recycle the nutrient contained in the leaves and canes which amounted to 49.4 kg N ha^{-1}. Phosphorus, calcium and magnesium applications might not justify being taken into account in the annual fertilization plan. Thus, the establishment of the fertilization programme should be a nutrient-specific exercise which takes into account all sources of information, including target yield and nutrient content in clusters, the vineyard management strategies influencing nutrient use efficiency from fallen leaves and prunings and soil testing and plant analysis.

1. Introduction

Adequate nutrition is essential for the growth and yield of grapevines as for any crop. Nitrogen is the major nutrient affecting grapevine vigour and must quality (Brunetto et al., 2007; Akin et al., 2012; Pérez-Álvarez et al., 2013). The addition of K can increases grape yield, as the result of increased cluster number and weight (Amiri and Fallahi, 2007). A strong correlation between K grapevine nutritional status and must attributes has also been observed. Excess K levels in grape berries can result in a high juice pH, with a detrimental impact on wine quality (Mpelasoka et al., 2003; Fogaça et al., 2007; Assimakopoulou and Tsougrianis, 2012; Cuéllar et al., 2013).

In vines, as in other crops, any excess of fertilizer use must be avoided. The price of fertilizers has increased, particularly those containing N and P. The price of N has been directly influenced by the increase the price of crude oil, and the price of P has reflected the price instability associated the finite supply of phosphate rocks from which P fertilizers are obtained (Smil, 2001; Gilbert, 2009). It should also be stressed the environmental impact potentially associated to the excessive use of fertilisers, particularly of those containing N (Powlson, 1993).

Soil analysis has been routinely used to assess soil conditions for plant growth and the need for supplemental fertilizers (Havlin et al., 2005). Chemical soil analysis indicates the potential availability of some nutrients that roots may take up under conditions favourable for plant growth (Römheld, 2012). Soil analysis can also be informative concerning possible toxicities of salt and boron. Soil pH can also be useful in predicting mineral nutritional problems. In spite of the importance of soil analysis in the fertilizer recommendation programmes for annual crops, it has lost favour over the

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Table 1
Selected soil properties in September 2012 in the 0–20 cm soil layer.

Soil properties	
Sand (%)	62.7
Silt (%)	19.5
Clay (%)	17.8
Organic C (Walkley–Black) (g kg^{-1})	1.4
pH (Soil:water, 1:2.5)	6.7
Exchangeable bases[a]	
K ($Cmol_c$ kg^{-1})	1.16
Na ($Cmol_c$ kg^{-1})	0.15
Ca ($Cmol_c$ kg^{-1})	7.51
Mg ($Cmol_c$ kg^{-1})	4.79
Exchangeable acidity ($Cmol_c$ kg^{-1})	0.23
Cation exchange capacity ($Cmol_c$ kg^{-1})	13.85
Extractable P (mg kg^{-1})[b]	66
Extractable K (mg kg^{-1})[b]	196
Extractable B (mg kg^{-1})[c]	1.1

[a] Ammonium acetate, pH 7.
[b] Extracted by ammonium lactate plus acetic acid, buffered at pH 3.7.
[c] Boiling water and azomethine-H procedures.

years for perennial deep-rooted crops, such as fruit trees and vines, because of the difficulty in defining with sufficient accuracy the root zones from which deep-rooting plants take up most of their nutrients (Winkler et al., 1974; Römheld, 2012).

Plant analysis is often the most reliable method of assessing crop nutritional status, currently being the basis of the fertilizer recommendation programmes for tree crops and vines. Several studies have been done in order to establish the most appropriate tissue for analysis. Leaf blade and petiole have been the major competing ones (Brunetto et al., 2007; Assimakopoulov and Tsougrianis, 2012; Benito et al., 2013). Although the preference for petioles has been increasing, leaf blade analysis continues to be used. Several different sampling dates have also been used. The sampling date is of major importance, since tissue nutrient concentrations vary greatly during the growing season (Römheld, 2012). In vines, the most popular sampling dates are flowering and veraison (Winkler et al., 1974; Porro et al., 1995; Mullins et al., 2007; Benito et al., 2013). Other researchers consider the issue even more complex. According to Porro et al. (1995), the choice of the sampling time should be made according to the diagnostic purpose. Benito et al. (2013) proposed the use of different tissues and different sampling dates depending on the nutrient to be analyzed. In spite of the effort that has been made in the standardization of the process of sampling, studies have shown that nutrient concentrations in plant tissues frequently fall outside the ranges currently considered normal or adequate in published standards (Winkler et al., 1974; Davenport et al., 2012). The great variability in plant analysis results has led to the establishment of standards for local growing conditions (Porro et al., 2001; Davenport et al., 2012; García-Escudero et al., 2013), important commercial cultivars (Fallahi et al., 2005; García-Escudero et al., 2013), or even rootstock-scion combinations (Lehoczky and Kocsis, 1998). However, the major limitation of plant analysis technology is its inability to provide quantified rates of nutrients to be applied.

The results of plant analysis are usually interpreted by comparing actual data with previous established critical values or sufficiency ranges (Mills and Jones, 1996). In order to improve the accuracy of the diagnosis of the nutritional status of crops, other forms of interpretation have been developed. DRIS (Diagnosis and Recommendation Integrated System) has probably been the most popular. DRIS uses ratios of nutrients, which reduces the sensitivity of tissue analysis to plant age (Römheld, 2012). Martín et al. (2013) established preliminary DRIS norms for leaf blade and petioles of Tempranillo cultivar grafted on Richter-110, at both flowering and veraison, in La Rioga, Spain. In spite of DRIS having been developed by Beaufils in 1973, and norms for several crops having been established (Summer, 1997; Beverly et al., 1984; Goh and Malakouti, 1992) most laboratories have not yet adopted it. The major problem is the regional sensitivity of the norms (Mackay et al., 1987). The output is also not easy to manage. DRIS orders the element nutrients according to their degree of deficiency, but it does not provide information on the fertilizer rates to apply.

In summary, there has been abundant work using plant analysis as a means of monitoring plant nutritional status. However, the effort in the quantification of the rates of nutrients to apply to the crops has been markedly less. The approach here developed tries to define the magnitude of fertilizer rates to apply, by estimating the nutrients removed in clusters at harvest and taking into account the capability of the system to recycle the nutrients contained in the fallen leaves and prunings.

2. Materials and methods

2.1. Experimental site

The experiment took place in the Sta Apolónia farm in Bragança (41.797288–6.766033) North-eastern Portugal. The region benefits from a Mediterranean climate with some Atlantic influence. Mean annual temperature and annual precipitation are 12.3 °C and 7583 mm, respectively. The vineyard is planted in a eutric Cambisol loamy textured. Selected soil properties recorded at the beginning of the experiment are presented in Table 1.

The grapevines used in this study were randomly selected from a non-irrigated vineyard of cv. Viosinho Blanc grafted on Richter-110. The cv. Viosinho had medium vigour, the clusters and berries are small and the pellicule is yellowish green. It is grown in Douro Valley in Port wine production and in other regions to produce table wine. The vineyard plantation dates from 1997. The vines were spaced at 2.5 m between rows and 1.4 m within rows (~2860 vines per hectare). The vineyard has been pruned as Guyot double, with an average crop load of 24 buds per vine. The shoots were supported by three horizontal wires placed at 60, 90 and 120 cm height from the soil. The farmer managed the winter weeds by an application of a glyphosate based herbicide by March. The weeds emerging in the spring have usually been controlled by May using a cultivator. The fertilization made by the farmer usually includes the application of a compound NPK fertilizer at an approximate rate of 20 kg (N, P_2O_5, and K_2O) ha^{-1} localized in a narrow strip of 1 m wide along the row. To control fungus diseases, namely powdery mildew (*Erisiphe necator*) and/or downy mildew (*Plasmopara viticola*), the farmer sprayed fungicides, differing in the active ingredient and in the number of applications from one year to another, according to the regional advisory system for vine protection.

2.2. Experimental set up and laboratory analysis

At veraison, three samples of leaf petioles were taken from the leaves opposite to the clusters in the plot where the study will take place to assess the vine nutritional status at the standardized date of sampling. At that time, twelve grapevines of similar vigour were marked for further experimental use. The pre-selected vines were thereafter cut at the ground level in groups of three distributed over four different dates from harvest until the leaves have completely fallen (September 14th, October 16th, November 2nd, and November 28th).

On all of the four sampling dates, the perennial structure of the vines was divided into trunk and cordons. Samples of sawdust were recorded from the entire section of trunk and cordons, after removing the dead bark, by using a handsaw. The sawdust was thereafter dried at 70 °C to be analyzed for elemental composition. Also from the trunk and the cordons, samples of the phloem vessels were