Nitrogen fertilization of 'Chardonnay' grapevines: yield, must composition and their relationship with temperature and rainfall

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Abstract

In soils rich in organic matter (OM), such as those in the elevations of South Brazil, the mineralized N from organic matter does not always meet the N demands of grapevines, thus, N applications are necessary during vine growth. However, the optimal N rate to achieve satisfactory yield and desirable grape enological composition is not known. The study aimed to evaluate yield and must composition of grapevine subjected to N applications, in relation to temperature and rainfall. The experiment was conducted in a vineyard planted in 2003 in the city of Água Doce, located in the Midwest region of the state of Santa Catarina, southern Brazil. The cultivar 'Chardonnay' grafted on rootstock 1103 Paulsen, planted in clay, high-OM soil was trained as a spur pruned cordon system. From 2011 to 2014, the grapevines were submitted to the application of N as urea at the following rates: 0, 20, 40, 80 and 120 kg N ha^{-1} split at bud sprout and full bloom. Leaves, collected at flowering and veraison, were dried, milled and analyzed for total N. At harvest, the number of clusters per plant and yield were recorded. Total soluble solids, titratable acidity, pH and tartaric acid were evaluated on must. Temperature and rainfall data were collected throughout the experiment. The application of N increased N concentration in leaves but had little effect on yield and must composition. According to principal component analysis, a negative correlation between rainfall and N in must was found. The highest N concentration in must was observed in crop season 2011/2012 with low rainfall; the opposite occurred in 2013/2014.

Keywords: N, nutritional status, grape production, *Vitis vinifera* L., vineyards

INTRODUCTION

Brazil has approximately 80,000 ha cultivated with vines and 75% of this area is located in the southern region (Embrapa, 2015) that is the main wine region of the country. Some of the vineyards are located at altitudes between 900 and 1400 m. Soils are clayey and have high organic matter (OM) concentration (>5%), which hypothetically provides adequate availability of mineral nitrogen (N) to plants (CQFS-RS/SC, 2004). However, as temperatures are low throughout most of the year, the amount of mineralized N from OM and decomposing waste deposited on the soil surface does not usually meet N demands of grapevines (Agehara and Warncke, 2005; Brunetto et al., 2009). The effect of N supply on yield and grape composition over the years in OM-rich soils located at high altitudes is not sufficiently known (Zufferey et al., 2010; Reynard et al., 2011). According to several authors (Orlandini et al., 2009; Cheng et al., 2014), yield, must and wine composition of grapevines are influenced by climatic variables, such as rainfall and air temperature. In previous studies (Duchêne and Schneider, 2005; Brunetto et al., 2009), well-distributed high temperatures and rainfalls promoted plant growth, leaf transpiration, uptake of nitrate (NO_3^--N), consequently yield increased. However, if the berry skin is thin, the dilution of enological parameters, such as total soluble solids (TSS) and anthocyanins, may occur (De Beer et al.,

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2002; Ojeda et al., 2002). On the other hand, in years with high rainfall, during vegetative and productive periods, a greater leaching of NO_3^--N occurs, decreasing vine response to N application (Barlow et al, 2009; Lorensini et al., 2012). The present study aimed to evaluate yield and must composition of grapevines subjected to N application and relate them to temperature and rainfall.

MATERIALS AND METHODS

The study was conducted in a vineyard in the city of Água Doce, located in the Midwest region of the state of Santa Catarina, southern Brazil (latitude 26°59'S; longitude 51°33'W and altitude 969 m). The climate is humid mesothermal (Cfb) according to Köppen classification. The average annual temperature is 16.6°C and rainfall ranges from 1000 to 1900 mm year^{-1}. The soil is classified as an Inceptisol characterized by the following properties in the 0-0.20 m layer: sand 109 g kg^{-1}; silt 440 g kg^{-1}; clay 451 g kg^{-1}; OM 62.4 g kg^{-1}; water pH 6.14; Ca 7.05 cmol$_c$ dm^{-3} and Mg 5.75 cmol$_c$ dm^{-3} (extracted by KCl 1 mol L^{-1}); available P and K 2.32 and 122.4 mg kg^{-1}, respectively (extracted by Mehlich-1) (Tedesco et al., 1995). The vineyard of 'Chardonnay' (*Vitis vinifera*) grafted on rootstock 1103 Paulsen (*V. berlandieri* × *V. rupestris*) was installed in 2003 and trained as a spur pruned cordon system. The spacing between plants on the row was 1.50 m and between rows 2.90 m (plant density of 2299 plants ha^{-1}). From 2011 to 2013 the grapevines were submitted to applications of 0, 20, 40, 80 and 120 kg N ha^{-1} split at bud burst and flowering. The N source was urea (45% N), applied on the soil surface in the projection of the plant canopy without incorporation. The experimental design was a randomized block with five replications. Each replication consisted of five plants and the central three were used for data collection.

At flowering in 2011/12, 2012/13 and 2013/14 and also at veraison in 2012/13 and 2013/14, 10 leaves plant^{-1}, located opposite to the first cluster, were collected, dried to constant weight, ground, subjected to sulfuric acid digestion and used for total N analysis by micro Kjeldahl method (Tedesco et al., 1995). At harvest the number of clusters and yield plant^{-1} were recorded and on 5 clusters plant^{-1} randomly collected, berries from the top, middle and bottom part of each cluster were sampled and crushed. The obtained must was used to determine soluble solid concentration (SSC) (digital refractometer with temperature compensation, RTD 45, Instrutherm, São Paulo, Brazil); titratable acidity (TA) by titration (0.1 N NaOH) with phenolphthalein indicator (1%); pH (AD 1030 pH meter, ADWA, Szeged, Hungary) and tartaric acid by high-performance liquid chromatography. In the season 2012/13 excess rain damaged grape production and, therefore, assessments were not carried out.

The results were submitted to analysis of variance using Sisvar software version 5.6 (Ferreira, 2003), and when the effects were significant, regression equations were adjusted by testing the linear and quadratic models by F test and by choosing one with less than 5% significance ($P<0.05$). Principal component analysis (PCA) was carried out by CANOCO software version 4.5 (Ter Braak and Smilauer, 2002). The variables used were: averages of total N concentration in leaves at flowering, yield, cluster weight, number of clusters plant^{-1}; and in must: pH, TSS, tartaric acid and TA.

RESULTS AND DISCUSSION

In seasons 2011/2012 and 2013/2014, N concentration in leaves collected at flowering increased quadratically with the rate of N applied (Table 1). However, leaf N concentration at veraison was not affected by the application of N. The increase in leaf N concentration at flowering could be due to high emission of young roots (Scandellari et al., 2010; Bravo et al., 2012), which are responsible for the absorption of water and nutrients such as N. However, it could also be the consequence of leaf dry matter increase that becomes a sink for nutrients such as N (Schreiner and Scagel, 2006; Brunetto et al., 2014). Leaves collected at flowering had higher N levels than those collected at veraison, at all N rates and in all seasons evaluated in this study, because of the dilution of N in leaves collected at veraison and because part of the N contained in leaves was redistributed to other growing organs, such as clusters and shoots of the year (Brunetto et al., 2006, 2009; Yu et al., 2012). However, in 2012/2013, total leaf N concentration was not affected by N rates, probably because of the large volume of rainfall (1450 mm from September to February), which enhanced NO_3^--N leaching (Barlow et al, 2009; Lorensini et al., 2012).

Table 1. Total leaf N concentration at flowering and veraison, yield and must composition in 'Chardonnay' grapevines subjected to applications of 0, 20, 40, 80 and 120 kg N ha^{-1} year^{-1} in 2011/12, 2012/13 and 2013/14.

Variable	**N dose (kg N ha^{-1} year^{-1})**					**Equation**	**R^2**
	0	**20**	**40**	**80**	**120**		
Crop season 2011/2012							
Total N in leaf – flowering (g kg^{-1})	52.0	63.7	54.4	52.8	54.0	$y=55.88+0.031-0.00047x^2$	0.1*
Number of clusters plant^{-1}	18	20	21	19	19	-	ns
Average cluster weight (g)	306	306	329	307	324	-	ns
Yield (Mg ha^{-1})	13.0.	14.0	15.5	13.6	14.3	-	ns
Total soluble solids (°Brix)	17.2	17.4	17.5	17.7	17.6	$y=17.22+0.009x-0.000047x^2$	0.99*
pH	3.43	3.45	3.46	3.46	3.43	-	ns
Titratable acidity (meq L^{-1})	97.5	94.8	94.0	93.8	96.0	-	ns
Tartaric acid (meq L^{-1})	0.76	0.73	0.71	0.71	0.72	$y=0.76-0.0015x+0.00001x^2$	0.96
Crop season 2012/2013							
Total N in leaf – flowering (g kg^{-1})	55.2	55.4	56.4	56.8	58.8	-	ns
Total N in leaf – veraison (g kg^{-1})	40.9	42.9	43.1	43.1	43.4	-	ns
Crop season 2013/2014							
Total N in leaf – flowering (g kg^{-1})	35.0	43.0	44.1	44.2	47.1	$y=36.79+0.20x-0.001x^2$	0.81*
Total N in leaf – veraison (g kg^{-1})	34.8	35.7	36.5	39	38.2	-	ns
Number of clusters plant^{-1}	16	15	19	17	12	$y=15.26+0.10x-0.001x^2$	0.72*
Average cluster weight (g)	116	109	123	123	121.2	-	ns
Yield (Mg ha^{-1})	4.30	3.66	5.24	4.76	3.32	$y=3.91+0.036x-0.00034x^2$	0.57*
Total soluble solids (°Brix)	20.0	20.0	20.0	20.1	19.8	-	ns
pH	3.35	3.36	3.39	3.49	3.43	$y=3.33+0.0025x-0.000014x^2$	0.75*
Titratable acidity (meq L^{-1})	116	110	109	108	108	-	ns
Tartaric acid (meq L^{-1})	0.89	0.86	0.84	0.81	0.80	-	ns

ns = not significant; *significant with $P<0.05$.

The application of increasing rate of N stimulated grape yield quadratically in 2013/2013 (Table 1). This was primarily the result of the increase of the number of clusters plant^{-1}, since cluster weight did not differ statistically. However, the highest grape yield ha^{-1} was obtained with rates of up to 40 kg N ha^{-1}, while for higher rates a decrease of yield, number of clusters and average cluster weight was observed (Table 1). Excess of N stimulates vegetative growth, reduces radiation inside plants, thereby increases the incidence of fungal diseases and reduces flower fertility (Monteiro and Lopes, 2007; Brunetto et al., 2008) and yield. However, in 2011/2012, vine yield, number of clusters plant^{-1} and average cluster weight were not affected by N rate (Table 1). The lack of response to N application may have occurred because soil moisture conditions were adequate and the temperatures were mild throughout the year, favoring mineralization of soil OM and plant residues deposited on the soil surface, which increased the availability of mineral N to vines (Agehara and Warncke, 2005; Brunetto et al., 2008).

TSS increased quadratically with increasing N rates in 2011/2012 (Table 1), according to data obtained by Brunetto et al. (2009) in an experiment with the cultivar 'Cabernet Sauvignon' subjected to increasing rates of N (0, 15, 30, 45 and 60 kg N ha^{-1}). In 2013/2014, must pH values increased quadratically with increasing N dose (Table 1). This was because there is no stoichiometric relationship between medium pH and acidity, in fact while acidity depends on the concentration of acids in the medium, pH depends on their ionization capacity. Thus, pH is low when there is a predominance of strong acids, but the presence of weak acids generates higher pH (Brunetto et al., 2009).

Principal component analysis was carried out on data collected in 2011/12 and 2013/14; only the first two components were extracted, since together they explained 92.99% of the total variability of the data. We found the same opposite behavior between TA and tartaric acid, with pH and total N in the leaf collected at flowering, as evidenced by the negative correlation in PCA (Figure 1). The relationship between TA in must and N rate occurred inversely. Therefore, presumably the smaller the amount of N applied, the lower the vigor of the plants, which favors greater penetration of radiation and, consequently, degradation of organic acids such as tartaric and malic acid, which stimulates the reduction of TA (Spayd et al., 2002; Monteiro and Lopes, 2007). There was negative linear correlation between yield and variables such as accumulated rainfall and average temperature in PCA (Figure 1). This may be due to distribution of rainfall and variation in temperature in the two cropping seasons. In crop season 2013/14, there was 300 mm more rainfall than in 2011/12. This may be one explanation for the decrease of up to four times in grape yield compared to crop season 2011/12. Average temperatures were similar, but accumulated rainfall differed during the two seasons evaluated in this study. In the season with higher rainfall, lower production of assimilates was expected because of the higher number of days with diffuse radiation, resulting in lower vegetative and productive development (Cheng et al., 2014). Furthermore, high rainfall may have favored leaching of NO_3^--N, reducing the use of fertilizer N (Lorensini et al., 2012).

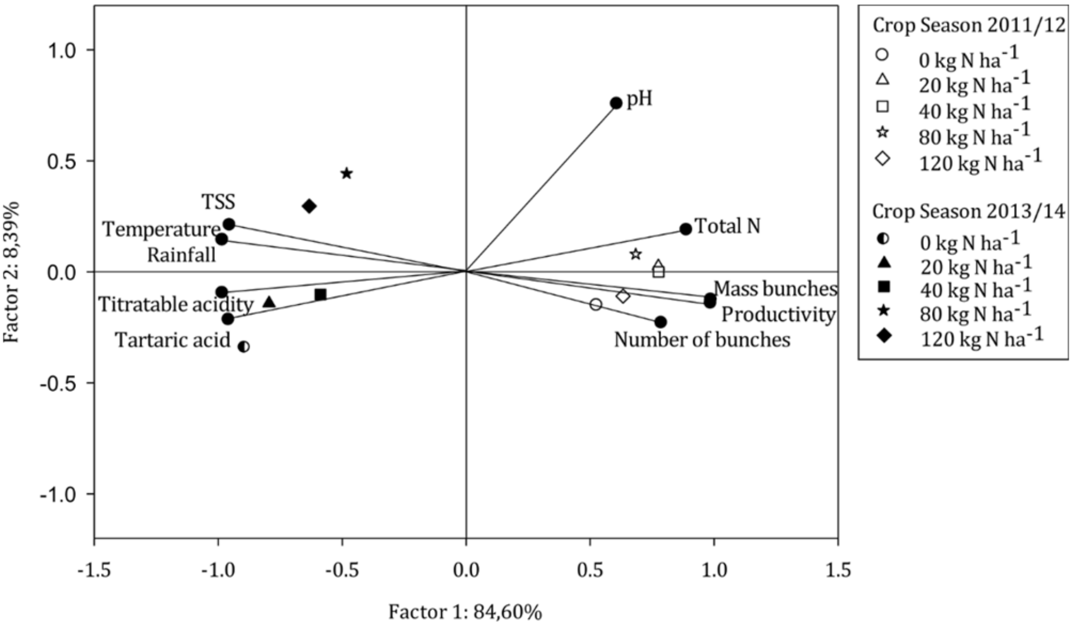

Figure 1. Relationship between principal component 1 (factor 1) and principal component 2 (factor 2) of the parameters of average yield, N leaf concentration, and must parameters during crop seasons 2011/12, 2013/14 and the influence of temperature and rainfall on 'Chardonnay' grapevine.

CONCLUSION

In the experimental conditions, 'Chardonnay' grapevines in soils with high OM content reached the highest yields with the application of 40 kg N ha^{-1}. Yield was a sensitive parameter to variations in rainfall in crop season 2013/14, when a higher cumulative rainfall was accompanied by a smaller number of clusters plant^{-1}, lower average cluster weight and, consequently, lower yield plant^{-1}, despite the N rate. Intensive rainfall, regardless of N rate, decreased yield and cluster size but increased TSS in must.

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