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Organic and Nitrogen Fertilization of Soil under 'Syrah' Grapevine: Effects on Soil Chemical Properties and Nitrate Concentration

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ABSTRACT: Viticulture is an activity of great social and economic importance in the lower-middle region of the São Francisco River valley in northeastern Brazil. In this region, the fertility of soils under vineyards is generally poor. To assess the effects of organic and nitrogen fertilization on chemical properties and nitrate concentrations in an *Argissolo Vermelho-Amarelo* (Typic Plinthustalf), a field experiment was carried out in Petrolina, Pernambuco, on Syrah grapevines. Treatments consisted of two rates of organic fertilizer (0 and 30 m^3 ha^{-1}) and five N rates (0, 10, 20, 40, and 80 kg ha^{-1}), in a randomized block design arranged in split plots, with five replications. The organic fertilizer levels represented the main plots and the N levels, the subplots. The source of N was urea and the source of organic fertilizer was goat manure. Irrigation was applied through a drip system and N by fertigation. At the end of the third growing season, soil chemical properties were determined and nitrate concentration in the soil solution (extracted by porous cups) was determined. Organic fertilization increased organic matter, pH, EC, P, K, Ca, Mg, Mn, sum of bases, base saturation, and CEC, but decreased exchangeable Cu concentration in the soil by complexation of Cu in the organic matter. Organic fertilization raised the nitrate concentration in the 0.20-0.40 m soil layer, making it leachable. Nitrate concentration in the soil increased as N rates increased, up to more than 300 mg kg^{-1} in soil and nearly 800 mg L^{-1} in the soil solution, becoming prone to leaching losses.

Keywords: fertigation, soil solution, carbon, micronutrients, *Vitis vinifera*.

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INTRODUCTION

Viticulture is an activity of great social and economic importance in the lower-middle region of the São Francisco River valley in northeastern Brazil. Although the number of wineries is small, this valley is currently the second largest region for production of fine wines in Brazil, accounting for annual production of 7 million liters of wine, which is 15 % of Brazilian production (Instituto do Vinho do Vale do São Francisco, 2014).

Apart from irrigation, vine cultivation in the semiarid region requires soil management techniques, fertilization, canopy management, and pest and disease control (Leão and Soares, 2009). Continual use of fertilizers and pesticides, particularly for control of fungal vine diseases, can result in nutrient accumulation in the soil, causing contamination by metals such as Cu (Casali et al., 2008; Komárek et al., 2008).

Soil fertility in vineyards in the lower-middle São Francisco River valley is generally low, characterized by low levels of organic matter (around 10 g kg^{-1}), resulting in low N and P levels. The Ca, Mg, and K contents range from low in *Neossolos Quartzarênicos* (Entisols - Quartzipsamments) to high in *Vertissolos* (Vertisols). Deficiencies of B and Zn and possible Mo deficiency were observed (Albuquerque et al., 2009). The same authors reported that winegrowers in the region apply about 20 to 60 m^3 ha^{-1} of goat manure, corresponding to 100 to 400 kg ha^{-1} N per crop cycle, thus contributing to an increase in organic matter and other nutrients in these soils.

Organic fertilization plays an essential role in vineyards. The application of different composts derived from wine-production waste, sewage sludge, and manure increased organic N concentration in the soil, stimulating microbial activity and raising macro- and micronutrient levels, as well as inorganic N release in a calcareous soil of a vineyard with the 'Monastrell' grapevine (Bustamante et al., 2011). The application of compost increased soil levels of organic matter and nitrate, compared with mineral fertilization, and also ensured stable mean production over nine experimental years with the 'Chardonnay' grapevine (Mugnai et al., 2012).

Mineralization of N from the organic compost applied to vineyard soil is better synchronized with the nutrient requirements of grapevine than N from mineral sources (Lorensini et al., 2014). This is because vines tend to use only small amounts of N derived from mineral fertilizer, according to information from Brunetto et al. (2006) in a ^{15}N study. According to these authors, a higher amount of N accumulated in young vines was due to different forms of ^{15}N provided earlier at vine transplanting. Thus, an increase in mineral N available in the soil solution can meet plant demand by mineralization of the N contained in soil organic matter.

A lack of synchronization between N release from fertilizers and plant uptake may intensify N loss to the environment (Brunetto et al., 2009). Appropriate soil texture and mineralogical characteristics are important for preventing losses, especially when applying high rates of organic fertilizers and, or, high concentrations of readily available N (Fioreze et al., 2012). In the case of annual crops, a few applications of sewage sludge at high rates pose the risk of groundwater contamination with nitrate in the short term (Dynia et al., 2006).

Nitrogen is one of the nutrients most required by grapevine and is frequently applied through fertigation in vineyards of the lower-middle São Francisco River valley (Silva and Soares, 2009). Thus, N fertilizers are frequently used in fertigation of this crop, most commonly in the forms of nitrate, ammonium, amide, or amino acid. The response of grapevine to N is related to crop requirements at a given stage of development, soil texture, organic matter content, mineral N content, soil pH, and the properties of the fertilizer applied (Silva and Soares, 2009).

The presence of nitrate in the soil solution depends on the chemical properties of the soil, the N source, the amount applied, and the concentration of N fertilizer in the irrigation water (Coelho et al., 2014). However, Andrade et al. (2009) pointed out that some factors inherent to soil physical properties, agricultural practices, and water management can maximize NO_3^- leaching and cause groundwater contamination.

Given the importance of organic matter in building and maintaining soil fertility as it influences numerous soil properties and being N management important to balance the N release from fertilizers, plant uptake and nitrate losses, this study aimed to evaluate the effects of organic and N fertilization on chemical properties and nitrate concentrations in a vineyard soil with 'Syrah' grapevine, after three production cycles.

MATERIALS AND METHODS

The experiment was conducted at the Bebedouro experimental station of Embrapa Semi-Arid in Petrolina, PE, Brazil (latitude 09° 08' 08.9" S; longitude 40° 18' 33.6" W; 373 m asl). Grapevine (*Vitis vinifera* L.) seedlings, Syrah cultivar, were grafted onto 'Paulsen' 1103 rootstock and planted in a trellis system on April 30, 2009, in rows spaced 3 m apart and 1 m between plants.

The soil of the area was classified as *Argissolo Vermelho-Amarelo Eutrófico plintossólico,* medium texture (Santos et al., 2013), a Typic Plinthustalf (Soil Survey Staff, 2014), with 810 g kg^{-1} sand, 130 g kg^{-1} silt, and 60 g kg^{-1} clay in the 0.00-0.20 m layer (for soil chemical properties, see Table 1).

Drip irrigation at a flow rate of 2.5 L h^{-1} was applied by emitters spaced at 0.5 m in the plant row. Irrigation management consisted of replenishing a water level corresponding to that of crop evapotranspiration, determined by multiplying the reference evapotranspiration (ETo) estimated by Penman-Monteith FAO, based on parameters measured by the weather station 60 m away from the experimental area, by the crop coefficient for each phenological stage of the grapevine, estimated by Bassoi et al. (2007).

Treatments consisted of two organic fertilizer rates (0 and 30 m^3 ha^{-1}, equivalent to 15 Mg ha^{-1}) and five N rates (0, 10, 20, 40, and 80 kg ha^{-1}). The experiment was arranged in randomized blocks in split plots, with five replications. The organic fertilizer (OF) rates represented the main plots and N the subplots. Each experimental unit consisted of 16 plants, of which 8 were evaluated. Organic fertilizer, consisting of goat manure (Table 2), was applied before production pruning in each production cycle. Nitrogen fertilization in the form of urea (45 % N) was applied for 10 weeks, beginning one week after pruning, by fertigation with an injection pump at a flow rate of 300 L h^{-1}.

Table 1. Chemical soil properties of an Argissolo Vermelho-Amarelo (Typic Plinthustalf) in a vineyard with 'Syrah' grapevine

Layer	OM[1]	$pH(H_2O)$	EC	P	K^+	Ca^{2+}	Mg^{2+}	Na^+	H+Al	CEC	V	Cu	Fe	Mn	Zn
m	g kg^{-1}		dS m^{-1}	mg dm^{-3}			$mmol_c$ dm^{-3}				%		mg dm^{-3}		
0.00-0.20	10.4	6.7	0.45	88.8	3.7	25.4	9.8	0.3	9.8	49.1	80	4.5	86.1	42.4	46.2
0.20-0.40	4.9	6.2	0.27	74.4	3.2	19.8	7.8	0.3	10.8	41.9	74	3.0	71.3	26.5	29.0

[1] OM: organic matter, by oxidation with $K_2Cr_2O_7$; EC: electric conductivity, by saturation extract; P, K, Na, Cu, Fe, Mn, Zn: extractor Mehlich-1; Ca^{2+}, Mg^{2+}: extractor KCl 1 mol L^{-1}; H+Al: extractor calcium acetate 0.5 mol L^{-1}, pH 7.0; CEC: cation exchange capacity at pH 7.0; V: bases saturation.

Table 2. Chemical composition of goat manure and amounts of nutrients added in 15 mg ha^{-1} goat manure

C	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
			g kg^{-1}						mg kg^{-1}		
241.9	14.02	1.76	8.22	20.1	6.9	1.7	50.4	24.7	4,760.0	313.7	57.2
					kg ha^{-1}						
3,628.5	210.3	26.4	123.3	301.5	103.5	25.5	0.76	0.38	71.4	4.70	0.86

After three production cycles (April 13 to August 9, 2010; November 10, 2010 to February 28, 2011; and May 10 to September 9, 2011), soil samples were collected from the 0.00-0.20 and 0.20-0.40 m layers in all experimental units for chemical analysis according to the methods described by Claessen (1997). The NO_3^- soil content was determined by KCl extraction and distillation by the Kjeldahl method, as proposed by Tedesco et al. (1995), in samples collected after the first and third production cycles.

To assess NO_3^- concentrations in the soil solution, porous cups were installed as extractors at depths of 0.40 and 0.80 m. This evaluation was conducted only in the third crop cycle and in plots not fertilized with OF (zero rate OF), for 10 weeks after fertigation with urea. To collect the soil solution, a vacuum of 80 kPa in the extractors was applied after each fertigation event. The soil solution was sampled 24 h after vacuum application, packed in plastic flasks and stored in the refrigerator until analysis. The NO_3^- concentrations were determined by a technique described by Yang et al. (1998).

The results were subjected to analysis of variance and, in the case of significance, regression analyses were performed, testing the linear and quadratic models, selecting those with significant coefficients by the F test and with higher R^2 value.

RESULTS AND DISCUSSION

The increase in nutrient quantities supplied by OF (Table 2) to the soil was considerable. The application of OF for three crop cycles promoted significant changes in soil chemical properties in the 0.00-0.20 and 0.20-0.40 m layers (Tables 3 and 4). This result confirms the effect of organic matter on the maintenance and improvement of soil chemical properties (Tisdale et al., 1985).

Organic fertilizer added 3.6 Mg ha^{-1} C per crop cycle (Table 2) by increasing the levels of soil organic matter (SOM) at the end of the third cycle from 6.87 to 17.09 g kg^{-1} and from 3.96 to 8.97 g kg^{-1} in the 0.00-0.20 and 0.20-0.40 m layers, respectively (Table 3). However, these amounts are still considered low for grapevine cultivation, even for soils in the semiarid region. In this environment, the values for this crop ideally exceed 20 g kg^{-1}. The great challenge is to maintain this level, due to the intense SOM mineralization process, resulting from weather conditions, along with irrigation management. Furthermore, sandy textured soils have a higher organic matter decomposition rate, due to the smaller amount of variable-charge clay minerals, providing less physical protection of organic matter. Chemical stability of aggregates in these soils is also affected by low Fe levels, favoring organic matter mineralization. Consequently, practices that promote SOM input and conservation are essential for the sustainability of these sandy soils. Increases in SOM by composts and other organic residues, with lower or higher values according to the climate and soil conditions of each region, were also reported by other authors (Damatto Júnior et al., 2006; Clemente et al., 2012; Mugnai et al., 2012; Silva et al., 2013).

Soil pH increased in the range of 6.1 to 6.8 in response to organic fertilization, but within the range for maintaining adequate plant nutrient availability. Soil pH increased possibly due to the alkaline effect of manure and by the complexation of exchangeable Al in the organic matter; this effect was more evident at a pH below 5.5 (Damatto Júnior et al., 2006).

Electric conductivity (EC) also increased, since the manure collected in the semi-arid region is rich in soluble salts for not having undergone the ripening and stabilization processes. However, the EC values were low, causing no plant injuries. Under similar conditions, Jiménez Becker et al. (2010) observed that compost application raised soil EC to such a high level that soil use would be restricted to salt-tolerant plants.

Soil P content increased significantly in the presence of OF in both layers, since in OF alone, 26.4 kg ha^{-1} P was added per production cycle, corresponding to 302 kg ha^{-1} of simple

Table 3. Chemical properties of the soil samples collected from the 0.00-0.20 and 0.20-0.40 m layers after the third crop cycle of ‘Syrah’ grapevine as a function of organic fertilizer (OF) rates applied to the soil, and nitrogen applied in irrigation water

OF	N	OM	pH(H_2O)	EC	P	K^+	Ca^{2+}	Mg^{2+}	SB	CEC	V
m^3 ha^{-1}	kg ha^{-1}	g kg^{-1}		dS m^{-1}	mg dm^{-3}	mmol$_c$ dm^{-3}					%
						0.00-0.20 m					
0	0	7.97	6.5	0.26	95.40	1.4	26.6	17.6	46.0	73.8	62.78
0	10	5.40	6.4	0.17	67.05	1.3	23.6	11.0	36.2	65.5	55.49
0	20	7.47	6.6	0.22	89.10	1.3	24.2	15.2	41.0	67.9	60.69
0	40	6.89	6.4	0.28	79.90	1.4	23.6	12.4	37.7	63.7	58.80
0	80	6.63	6.0	0.23	79.50	1.2	21.2	11.6	34.2	67.2	51.24
	Mean	6.87	6.4	0.23	82.19	1.3	23.8	13.6	39.0	67.6	57.80
30	0	21.45	6.9	0.44	141.30	4.8	43.2	20.8	69.4	86.5	80.40
30	10	13.32	6.9	0.28	98.70	3.1	36.2	21.8	59.6	77.0	77.91
30	20	18.89	7.0	0.43	143.40	4.3	42.2	21.6	68.7	88.8	77.74
30	40	14.62	6.7	0.40	118.94	3.4	33.4	21.4	58.8	83.8	69.87
30	80	17.17	6.6	0.34	107.55	3.0	36.4	21.2	61.2	85.2	73.32
	Mean	17.09	6.8	0.38	121.98	3.7	38.3	21.4	63.5	84.3	75.85
Effect											
OF		**	**	*	**	**	**	**	**	**	**
N		ns	ns	ns	ns	*	*	ns	**	ns	ns
OF×N		ns	ns	ns	ns	ns	ns	*	ns	ns	ns
						0.20-0.40 m					
0	0	3.54	6.2	0.15	65.85	1.1	21.4	11.4	34.3	62.9	54.91
0	10	4.94	6.1	0.12	51.13	1.3	21.0	14.8	38.9	58.4	70.62
0	20	3.21	6.2	0.11	52.20	1.0	20.0	8.0	29.2	59.6	49.93
0	40	3.87	6.0	0.13	63.60	1.0	21.0	11.2	33.4	68.4	49.16
0	80	4.22	5.8	0.14	51.87	0.9	23.8	14.6	39.6	70.2	56.34
	Mean	3.96	6.1	0.13	56.93	1.1	21.4	12.0	35.1	63.9	56.19
30	0	9.73	6.9	0.36	117.30	4.5	34.6	18.6	58.4	80.1	72.09
30	10	8.89	6.7	0.20	82.65	2.9	25.6	14.2	43.1	67.6	63.65
30	20	10.01	6.9	0.34	107.85	3.6	33.6	18.4	56.4	81.3	70.00
30	40	8.55	6.4	0.23	98.40	2.8	30.0	19.6	53.0	81.3	65.20
30	80	7.68	6.3	0.25	90.00	2.8	28.8	17.2	49.3	74.7	65.85
	Mean	8.97	6.6	0.28	99.24	3.3	30.5	17.6	52.0	77.0	67.36
Effect											
OF		**	**	*	**	**	**	**	**	**	**
N		ns	**	ns	ns	*	ns	ns	ns	ns	ns
OF×N		ns	ns	ns	ns	ns	ns	*	*	ns	*

** and *: significant at 1 and 5 %, respectively, by the F test; ns: not significant.

superphosphate. Increases in P concentrations because of organic fertilizer were also reported by Damatto Júnior et al. (2006), Jiménez Becker et al. (2010), and Bustamante et al. (2011).

The application of organic residues to the soil reduces P adsorption and increases the availability of soil P due to the release of organic anions during decomposition, resulting in competition for P adsorption sites (Nziguheba et al., 1998).

The mechanism by which P is linked to soil organic matter is similar to how P is adsorbed by Fe and Al oxides and hydroxides (Silva and Mendonça, 2007). Thus, management systems that prioritize organic inputs can increase P cycling and the availability to plants either by blocking Fe and Al oxyhydroxides from P adsorption sites, by competition for adsorption sites of the mineral fraction by soluble P, or by displacement of adsorbed P by the mineral fraction.

Organic fertilization increased K, Ca, and Mg in both layers. The quantities of these nutrients released from OF corresponded to 296 kg ha^{-1} of potassium sulfate, 1,587 kg ha^{-1} calcium nitrate, and 1,067 kg ha^{-1} of magnesium sulfate per production cycle (Table 2). This increase was reflected in the sum of bases, CEC, and base saturation. Effects of compost and other organic waste on increasing K levels in the soil were also reported by Jiménez Becker et al. (2010), Bustamante et al. (2011), and Clemente et al. (2012). Organic fertilization increased Ca, sum of bases, CEC, and base saturation in the 0.00-0.20 m layer of soil under banana (Damatto Júnior et al., 2006). The amount of nutrients added annually with manure in the semiarid region exceeds crop requirements and results in significant accumulation of C, N, P, K, Ca, and Mg in the 0.00-0.20 m layer as reported by Galvão et al. (2008). In the case of greater nutrient mobility in the soil, as in the cases of N and K, the possibility of leaching losses should be taken into account.

Soil Fe and Zn contents were not affected by the treatments, although the available Fe quantities from OF were considerably higher (Table 2). However, exchangeable Cu and Mn were affected differently by the OF, with reduction in Cu concentration and increased Mn content due to increased SOM (Table 4). In relative terms, Cu content reduced an average of 91 and 118 % in the 0.00-0.20 and 0.20-0.40 m layers, respectively. The Mn levels increased an average of 35 to 41 % in the 0.00-0.20 and 0.20-0.40 m layers, respectively.

Since total Cu contents in the organic fertilizer were not excessively high, the highest contribution to the increase in total Cu content in the soil resulted from the cumulative effect of continuous application of copper fungicides, essential to control the plant health of grapevine. Positive and significant correlation between total Cu contents and organic matter in vineyard soils in the lower-mid São Francisco basin was found by Costa (2009).

The reduction in exchangeable Cu was related to the significant increase in the levels of organic matter in OF treatments. Soil availability of Cu can be reduced by complexing the element in the organic matter, particularly in soils with low contents of Al, Fe, and

Table 4. Concentrations of Cu, Fe, Mn, and Zn in soil samples collected from the 0.00-0.20 and 0.20-0.40 m layers after the third crop cycle of 'Syrah' grapevine as a function of organic fertilizer (OF) rates applied to the soil, and nitrogen applied in irrigation water

OF	N	Cu	Fe	Mn	Zn	Cu	Fe	Mn	Zn
		0.00-0.20 m				0.20-0.40 m			
m^3 ha^{-1}	kg ha^{-1}	mg dm^{-3}							
0	0	4.86	95.20	50.96	70.60	3.68	70.60	27.02	33.04
0	10	4.64	88.20	44.96	54.66	3.20	79.00	21.88	32.38
0	20	4.18	86.80	42.76	41.35	2.72	73.60	26.04	36.78
0	40	4.26	100.40	44.92	56.20	3.06	80.40	26.46	31.02
0	80	3.70	96.20	41.88	73.68	3.12	67.00	37.58	24.76
	Mean	4.33	93.36	45.10	59.30	3.16	74.12	27.80	31.60
30	0	1.64	110.60	58.76	105.60	1.32	67.20	40.96	26.08
30	10	3.40	85.40	61.64	85.26	1.54	76.20	40.50	50.88
30	20	2.50	84.74	64.54	96.44	1.36	71.60	42.92	38.48
30	40	1.88	88.00	60.14	49.50	1.64	65.80	34.54	19.70
30	80	1.90	81.60	58.42	75.60	1.38	66.00	37.26	26.34
	Mean	2.26	90.07	60.70	82.48	1.45	69.36	39.24	32.30
Effect									
OF		**	ns	**	ns	**	ns	*	ns
N		ns	ns	ns	ns	ns	ns	ns	ns
OF×N		ns	ns	ns	ns	ns	ns	ns	ns

** and *: significant at 1 and 5 %, respectively, by the F test; ns: not significant.

Mn oxides. Copper is associated with organic matter through inner sphere complexes, resulting in lower phytotoxicity of total Cu compared to Cu^{2+} (Komárek et al., 2008). Organic matter is mainly responsible for Cu complexation in weathered soils (Casali et al., 2008). Regardless of the adsorbent material in soils under grapevine, the complexed Cu is easily desorbable and in equilibrium with the Cu solution.

Total content of Mn in OF contributed to increase soil concentrations after three cycles of cultivation and fertilization (Table 2), considering that the soil pH values are within a suitable range of Mn availability. Similar effect of application of compost and other organic wastes was described by Bustamente et al. (2011) and Clemente et al. (2012). Addition of organic materials such as peat, organic compost, and crop residues increase the fractions of water-soluble Mn, exchangeable Mn, and non-exchangeable Mn in the soil (Tisdale et al., 1985).

The mineralogy of Argisol leads to Mn accumulation, since the source material always supplies very high levels. The increase of Mn in the presence of organic matter must also be related to the increase in redox potential, i.e., reduction in the oxidation state (Eh) of the soil. Reducing conditions are created by the combination of restricted oxygen entry and an abundant organic substrate susceptible to microbial decomposition. In this case, Mn moves from the oxide form (MnO_x) to free Mn^{2+} in the aqueous phase, becoming more available in solution (Sparrow and Uren, 2014). Irrigation creates momentary conditions of aeration restriction and, especially in the deeper soil layers with greater water availability; the combination with organic matter makes the environment prone to reduction in Mn. Higher Mn uptake was observed by Pierce et al. (2010) in *Leersia oryzoides* (L.) Sw plants, under partial and intermittent flooding.

With regard to the effects of mineral N, differences were less evident and only significant for some variables, similar to the interaction between OF and N rates (Tables 3 and 4). Therefore, the N effects were not partitioned for every OF level. The highest NO_3^- contents in the soil were observed in the first production cycle (>300 mg kg^{-1}), whereas in the third crop cycle, values were below 200 mg kg^{-1} (Table 5). The difference between these values may be related to the mineral and organic fertilizers applied at planting of the vineyard, contributing to greater accumulation of N and other nutrients prior to the first crop cycle. In the third cycle, the treatment effect was more evident. The effect of OF on increasing NO_3^- levels was significant, mainly in the deeper layer (0.20-0.40 m), with the application of 210.3 kg N in OF, i.e., 467 kg ha^{-1} urea per cycle.

Reserves of total potentially mineralizable N in a vineyard soil can meet the N requirements of grapevine (Lorensini et al., 2014). For irrigated maize, applications of 60 m^3 ha^{-1} pig slurry was sufficient to sustain production, whereas 200 kg ha^{-1} mineral N induced no response to N fertilization (Berenguer et al., 2008). In addition, high residual concentration of NO_3^- in the soil increases the risk of ion leaching during the rainy season, which may cause environmental problems.

There was an effect of N rates on the NO_3^- soil content in the cycles and layers assessed (Table 5). For the interaction between OF and N rates, the effect was only significant in the 0.00-0.20 m layer in the first cycle. As the differences were significant for N, these effects were partitioned for each OF level. Regression equations were adjusted (Table 6) according to the increasing NO_3^- concentrations in the soil due to N rates within each level of OF application.

In the first production cycle, in the 0.00-0.20 m layer, the highest NO_3^- concentration was 421.8 mg kg^{-1}, in response to a rate of 34.3 kg N ha^{-1} in the absence of OF (Table 6). For the OF rate of 30 m^3 ha^{-1}, the highest NO_3^- concentrations in the 0.00-0.20 and 0.20-0.40 m layers were 428.4 and 448.2 mg kg^{-1}, respectively. At the end of the third cycle, in the 0.00-0.20 m layer, the highest NO_3^- concentration was 185.1 mg kg^{-1}, in the absence of OF. For the OF rate of 30 m^3 ha^{-1}, the highest NO_3^- concentrations in the 0.00-0.20 and 0.20-0.40 m layers were 207.3 and 223.3 mg kg^{-1}, respectively. Although the values obtained in the third cycle were lower, the soil nitrate concentrations were very high, with a potential risk of nitrate

Table 5. Nitrate concentration in the first and third crop cycles in soil from the 0.00-0.20 and 0.20-0.40 m layers of a vineyard with ‘Syrah’ grapevine as a function of organic fertilizer rates applied to the soil, and nitrogen rates applied in irrigation water

Organic fertilizer	N	1st cycle		3rd cycle	
		0.00-0.20 m	0.20-0.40 m	0.00-0.20 m	0.20-0.40 m
$m^3\ ha^{-1}$	$kg\ ha^{-1}$	$mg\ kg^{-1}$			
0	0	287.35	379.33	74.86	115.39
0	10	299.57	360.86	90.85	56.56
0	20	597.65	241.53	125.04	80.98
0	40	302.94	412.46	168.81	101.61
0	80	249.95	362.73	167.87	149.89
	Mean	347.49	351.37	125.48	100.88
30	0	331.11	197.84	138.78	118.02
30	10	267.91	361.79	129.18	93.25
30	20	280.44	175.35	153.05	114.93
30	40	360.55	392.61	156.49	150.65
30	80	438.23	436.59	212.97	231.66
	Mean	335.64	312.83	158.09	141.70
Effect					
OF		ns	ns	ns	*
N		*	*	**	**
OF×N		**	ns	ns	ns

** and *: significant at 1 and 5 %, respectively, by the F test; ns: not significant.

Table 6. Regression equations for nitrate concentration in soil samples collected after the first and third crop cycle of ‘Syrah’ grapevine in the 0.00-0.20 and 0.20-0.40 m layers as a function of nitrogen rates in irrigation water at two levels of organic fertilizer

Cycle	Depth	Organic fertilizer	Equation	R^2
	m	$m^3\ ha^{-1}$		
1st	0.00-0.20	0	$\hat{y} = 315.17 + 6.2155^{*} x - 0.0906^{**} x^2$	0.30
		30	$\hat{y} = 279.98 + 1.855^{**} x$	0.73
	0.20-0.40	0	$\hat{y} = \bar{y} = 351.38$	-
		30	$\hat{y} = 231.60 + 2.707^{*} x$	0.52
3rd	0.00-0.20	0	$\hat{y} = 89.72 + 1.192^{**} x$	0.76
		30	$\hat{y} = 128.57 + 0.984^{*} x$	0.91
	0.20-0.40	0	$\hat{y} = \bar{y} = 100.88$	-
		30	$\hat{y} = 92.69 + 1.633^{**} x$	0.90

** and *: significant at 1 and 5 %, respectively, by the F test.

leaching. Some factors, such as the prevalence of the sand fraction in soil texture, low-activity clay minerals, and intense organic and mineral soil management practices, contribute to this situation.

Application of organic waste to soils with different textures showed that in treatments without organic waste, there was a higher rate of mineralization of organic matter in sandy soil, explained by increased aeration and lower chemical protection in this soil with lower clay content. In the soil with higher clay content, NH_4^+ was initially protected, which can enhance the synchronization of nitrification with the crop N absorption rate (Fioreze et al., 2012).

The NO_3^- concentrations in the soil solution, determined by extraction in porous cups, increased with N rates applied by fertigation (Figure 1), in agreement with Coelho et al. (2014). These authors observed that urea induced a 100 % increase in nitrate concentration to a depth of 0.60 m, whereas potassium nitrate resulted in an increase of 169 %. Reduction in the movement of urea in the soil profile occurs due to the reactions to which this amide is subjected, from solubilization, protonation,

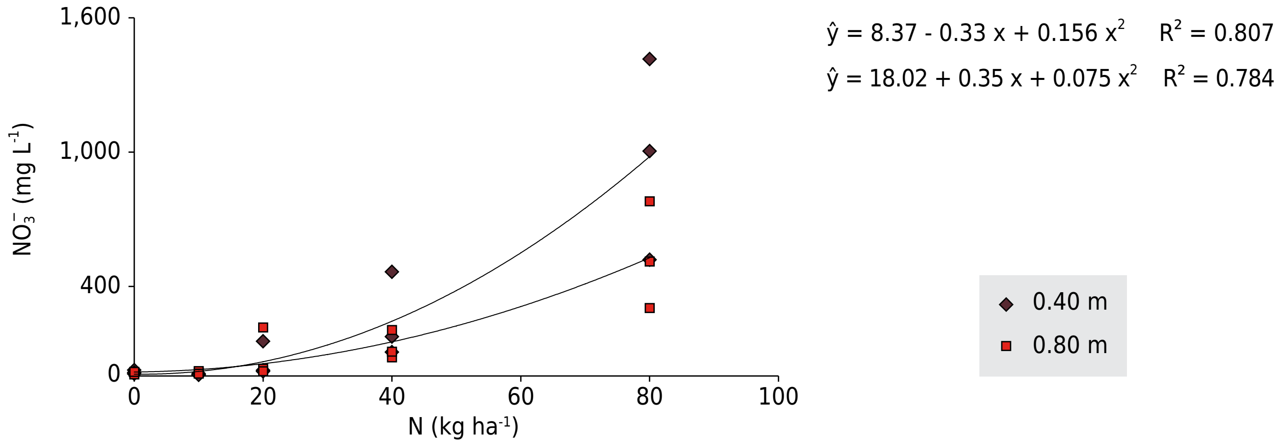

Figure 1. Nitrate concentrations in the soil solution sampled at depths of 0.40 to 0.80 m in a vineyard with ‘Syrah’ grapevines as a function of N rates in irrigation water. ** and *: significant at 1 and 5 %, respectively, by the F test.

and ammonification to nitrification. Urea can also be adsorbed by soil particles after transformation into ammonium. Thus, the potential for leaching losses of potassium nitrate, applied at a rate equal to urea, is greater.

The highest NO_3^- concentrations in the soil solution were found at a depth of 0.40 m, reaching 800 mg L^{-1}. Since the effective depth of the vine root system is 0.60 m (Bassoi et al., 2007), the NO_3^- contents found at a depth of 0.80 m were very high (Figure 1), and they are of no avail to the plant, indicating that this ion is lost due to the application of extremely high rates of mineral and, or, organic fertilizers.

Nitrate leaching into the water table is increased by soil properties such as sandy texture, low SOM, high permeability and low nitrate retention capacity, application of high N rates (510 kg ha^{-1} yr^{-1} N in the form of mineral and organic N fertilizers), and high irrigation water allocation (application of excessive wastewater levels) (Andrade et al., 2009). Under these factors, the risk of nitrate groundwater contamination is higher.

CONCLUSIONS

The application of organic fertilizer to the soil increases OM, pH, EC, P, K, Ca, Mg, Mn, NO_3^-, SB, CEC, and V; decreases soil concentration of exchangeable Cu by complexing the element in organic matter; and raised the nitrate concentration in the 0.20-0.40 m layer, making it prone to leaching.

Nitrate concentration in the soil increased with increasing N rates, up to more than 300 mg L^{-1} in soil and almost 800 mg L^{-1} in the soil solution, becoming prone to losses by leaching.

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