Phosphorous and nitrogen changes in compost-amended schist soils in vineyards in the D.O. Priorat wine-producing area (NE Spain)

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Abstract

The impact, on nitrogen and phosphorous dynamics, of applying compost at different rates was investigated in soils developed on schist in new terraced vineyards (NTV) and in undisturbed areas (NC). Repacked soil columns amended with 0 (control), 50 t ha^{-1} (T1) and 100 t ha^{-1} (T2) of compost were studied under laboratory conditions simulating both situations. The columns were maintained for 1 year, during which time a total of 300 mm of simulated rainfall was applied in ten 30 mm applications. Soil organic matter (OM), nitrogen and phosphorous contents were analysed at the end of the study period and leachates were analysed after each simulated rainfall event. Significant differences in nitrate leaching were observed between the control and the treated soils and these differences were greater in the NC (control = 1.368 g, T1 = 1.526 g and T2 = 1.686 g) than in the NTV soils (control = 0.61 g, T1 = = 1.068 g and T2 = 1.283 g). The relative effect was greater in the NTV soils (T1/control = 1.11 *vs.* 1.75 and T2/control = 1.23 *vs.* 2.1 for NC and NTV, respectively). The nitrate concentration in the leached water reached up to 400 mg L^{-1}, which implied a risk of groundwater pollution. Phosphorous losses through leaching were very low with concentrations of < 0.15 mg L^{-1}, without any significant differences between treatments. The phosphorous concentrations in the surface horizon increased by 50.8% in T1 and by 66.8% in T2 in the NC soils, compared with increases of 20.3% and 38%, respectively, in the NTV soils. Due to the high infiltration capacity of the study soils, leaching effects must be considered in order to prevent groundwater pollution.

Additional key words: land terracing; leaching; nutrients; soil properties.

Resumen

Cambios en las concentraciones de fósforo y nitrógeno en suelos desarrollados sobre esquistos tratados con compost en viñedos de la region vitícola del Priorat (NE de España)

Se analizan los efectos de la aplicación de diferentes dosis de compost en la dinámica del nitrógeno y el fósforo en suelos no alterados (NC) y de viñedos aterrazados (NTV) desarrollados sobre esquistos. Para cada suelo se montaron tres series de columnas (control y dos dosis de compost: 50 t ha^{-1} (T1) y 100 t ha^{-1} (T2)), que se mantuvieron durante 1 año. Se aplicaron 300 mm de lluvia simulada en 10 sucesos de 30 mm. Después de cada lluvia se recogieron los lixiviados y se analizó el nitrógeno y el fósforo disuelto. Al final del estudio, se analizó el contenido de materia orgánica, nitrógeno y fósforo en el suelo a diferentes profundidades. La concentración de nitratos en los lixiviados llegó a ser de 400 mg L^{-1}. El nitrato total lixiviado fue significativamente mayor en los suelos NC (control = 1,368 g, T1 = 1,526 g y T2 = 1,686 g) que en los NTV (control = 0,61 g, T1 = 1,068 g y T2 = 1,283 g), siendo el efecto relativo mayor en los suelos NTV (T1/control = 1,11 *vs.* 1.75; T2/control = 1,23 *vs.* 2,1 en NC y NTV, respectivamente;). Las pérdidas de fósforo por lavado fueron muy pequeñas, con concentraciones < 0,15 mg L^{-1}, sin diferencias significativas entre tratamientos. La concentración de fósforo aumentó en el horizonte superficial hasta en un 50,8% en T1 y un 66,8% en T2 en los suelos NC, frente a un 20,3% y un 38% respectivamente en los suelos NTV. Debido a la alta capacidad de infiltración de estos suelos se debe tener en cuenta la lixiviación para evitar la contaminación de las aguas subterráneas.

Palabras clave adicionales: aterrazamientos; lixiviación; nutrientes; propiedades de los suelos.

Introduction

The Priorat region (NE Spain), which is located in a depression formed by a split in the southern part of the Montsant mountain range, is an area with a long tradition of wine production. Vines have been cultivated there since the 12th century and production reached its maximum level in the late 19th century. Vines were originally planted on steep slopes, with terracing systems being limited to well-integrated small stone walls that did not cause any significant topographic transformations of the landscape (Cots-Folch *et al*., 2006).

In the early 20th century, due to phylloxera and a wine-production crisis, this land use was widely abandoned. However, since the 1990s there has been a significant recovery, with the transformation of previously abandoned areas into new vineyards with linked terraces. Terracing work, which is carried out with heavy machinery, modifies soil characteristics; for example, bulk density tends to increase as a result of the use of heavy machinery, while the water retention capacity, available water content and hydraulic conductivity all tend to decrease (Ramos *et al*., 2007). On the other hand, despite the steep slopes, most of the water tends to infiltrate and no runoff is produced (Abreu, 2005). To improve soil conditions and counteract the depletion of organic matter (OM) after land terracing, composted OM is applied just after land movement and before the establishment of new vineyards. Organic matter inputs improve the physical and chemical soil properties and soil structure and increase the amount of water-stable aggregates (Caravaca *et al*., 2001; Ouédraogo *et al*., 2001; Whalen and Chang, 2002) and the infiltration and water retention capacities (WRC) (Sommerfeldt *et al*., 1988; FAO, 2000; Morgan, 2005). Compost applications also reduce subsequent fertilization requirements (Carpenter-Boggs *et al*., 2000).

However, over-fertilizing crops on sites that have a relatively high nutrient supply and an imbalance between demand and supply substantially reduces their recovery efficiency. In general, nitrogen recovery efficiency is high when fertiliser use is relatively low and crop demand is high (Krauss, 2004). On the other hand, when the input of phosphorous into the soil exceeds phosphorous removal by the crop, most of the surplus phosphorous accumulates in the soil (Hooda *et al*., 2001). Some of this phosphorous will be gradually transformed into less reactive forms, but it may be sus-

ceptible to transport processes (Sharpley and Menzel, 1987).

In the past, strategies for the application of organic fertilisers (animal manure or compost) were based on crop nitrogen needs in order to minimise nitrate losses due to leaching (Sharpley *et al*., 1994). Excessive application rates or the inappropriate timing of applications can cause a significant threat to water quality, particularly in sandy soils (Sharpley and Menzel, 1987; Shreve *et al*., 1995). While nitrate is readily soluble and easily leached from soil (Kessavalou *et al*., 1996), surface runoff is a major pathway for phosphorous loss from soils to surface waters (Daniel *et al*., 1998). Phosphorous retention by soils is believed to reduce the risk of phosphate leaching due to its sorption onto soil colloids such as Fe/Mn oxides and OM (James *et al*., 1996) and its precipitation with $CaCO_3$ (Chen *et al*., 2003). Chemical precipitation is a slower process than adsorption and therefore the elimination of phosphorous depends on the degree of contact between the soil matrix and the water volume applied. Moreover, the mobility of phosphorous within soils increases with the soil water content (Chen *et al*., 2003).

Compost applications can load soils with high quantities of phosphorous. The equilibrium between the different forms in which phosphorous may be present in soils (adsorbed onto soil particles, complexed, or dissolved in soil solutions) may be modified. Phosphorous input may, however, be environmentally hazardous in the long term. The risk involved has been analysed for various different soil types (Korboulewsky *et al*., 2002; Whalen and Chang, 2002) and a series of thresholds have been established in order to prevent losses. A good example is provided by the studies of Fang *et al*. (2002), who determined the critical levels of Mehlich-III and Olsen soil phosphorous to be 65 to 85 mg kg^{-1} and 40 to 55 mg kg^{-1}, respectively.

The aim of this study was to evaluate the effects on nitrogen and phosphorous dynamics (accumulation and leaching) of the application of composted cattle manure at different rates in soils which had been disturbed by land terracing operations [new terraced vineyard (NTV) soils]. This situation was compared with that observed in undisturbed soils [old vineyards or abandoned areas with natural vegetation (NC)]. The study was conducted in soils developed on schist, which are very characteristic of the Priorat vineyard region, packed into soil column trials which were subjected to simulated rainfall under laboratory conditions.
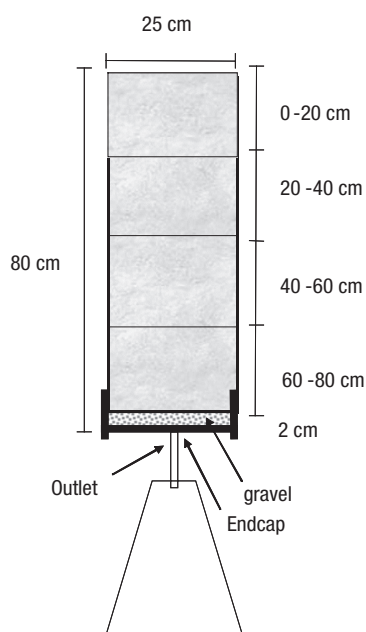
Material and methods

Experimental design and analysis

The soils used in the study were collected from two plots located in the Priorat area of Tarragona province, northeast Spain (41° 13' N 000° 46' E, 304 m asl). The area is located in a depression formed by a split in the southern part of the Montsant mountain range. One location was located in an NTV and the other was in an NC (an abandoned vineyard).

The soils were classified as *Lithic Xerorthents* (Soil Survey Staff, 1999) developed on schist, which are known locally as «llicorell». Soil characteristics, including: particle size distribution without the extraction of carbonates (Gee and Bauder, 1986); OM content (Allison, 1965); pH (determined in a solid-to-liquid ratio of $1:2.5_{water}$ using a pH meter); electrical conductivity determined in a water suspension of soil using a 1:5 soil/solution ratio ($EC_{1:5 \ water \ extract}$) with an EC meter; bulk density (Pla, 1983); and WRC of the fine material (< 2 mm) at –33 kPa and –1,500 kPa (using Richard plates), were determined for each soil. N-Kjeldahl (TNK) (Bremner and Mulvaney, 1982) and total phosphorous (TP) (Olsen and Sommers, 1982) levels were also analysed.

Eighteen 80-cm-high columns (PVC tube) with an internal diameter of 25 cm and a basal outlet (Fig. 1) were prepared with soils from both plots, conserving the different soil layers found in the field. The experimental design consisted of three replications of three treatments for each soil (NC and NTV). The treatments were: 1) control (columns without treatment); 2) T1 (columns treated with 50 t ha^{-1} (250 g/column) of a commercial compost (cow manure compost) mixed in the upper 10 cm); and 3) T2 (columns treated with 100 t ha^{-1} (500 g/column) of compost mixed in the upper 10 cm of the soil profile). Compost characteristics such as dry matter, pH, total carbon, nitrogen and phosphorous were evaluated following the methods proposed by Peters *et al*. (2003) and Ciavatta *et al*. (1990). The results were contrasted and completed with information about compost characteristics provided by the company that supplied the compost. The compost characteristics are shown in Table 1.

The soils were packed into columns. A gravel layer was placed at the bottom of each column and then different soil layers (horizons: 0-20, 20-40, 40-60 and 60-80 cm) were formed above it with soil from the corresponding depth of the soil profile in the field. The soil used for each layer was weighed, after first eliminating any large stones, and sieved, to a maximum particle size of 12 mm. The soil fraction that is < 12 mm represents about 85% of the soil. This soil fraction was packed and compacted as necessary to reach the required density (in kg m^{-3}: $\rho_{0-20}=1,540$, $\rho_{20-40}=1,620$, $\rho_{40-60}=1,690$, $\rho_{60-80}=1,754$ in the NC soils and $\rho_{0-20}=1,680$, $\rho_{20-40}=1,710$, $\rho_{40-60}=1,770$, $\rho_{60-80}=1,850$ in the NTV soils). One column per treatment was also equipped with a tube that ran through the whole column and

Figure 1. Soil column design used in the experiment.

Table 1. Characteristics of the applied compost: electrical conductivity (EC), pH, cation interchange capacity (CIC), dry matter, organic matter content (OM), humic and fulvic acids, stability degree, total nitrogen and total phosphorous

Variable	Concentration[a]
$EC_{1:5}$ (dS m^{-1})	1.65 ± 0.50
$pH_{1:5}$	7.4 ± 0.5
CIC (meq/100 g)	52.8 ± 2.0
Moisture content (%)	48 ± 3
Dry matter (%)	52 ± 3
Stability degree (%)	53.2[b]
Organic matter (%)	57.0 ± 3.0
Total humic extract (%)	12.3[b]
Humic acids (%)	8.8[b]
Fulvic acids (%)	3.5[b]
Total Nitrogen (%)	2.0 ± 0.5
Total Phosphorous (%)	1.7 ± 0.2

[a] Ref. to dry weight. [b] Information given by the compost supplier enterprise.

was used to measure soil moisture at different depths (0-20, 20-40, 40-60 and 60-80 cm) with a time domain reflectometer TDR-INKO probe.

The columns were subjected to wet and dry conditions in order to simulate field dynamics. Firstly, the columns were wetted to homogenise the soil moisture conditions until percolation occurred. After this first step, 300 mm of rainfall (simulated using deionised water) was applied in ten, 30 mm applications from April 5th to November 6th; this was consistent with local conditions (Ramos *et al*., 2007). Rainfall in the area is irregularly distributed over the year, occurring mainly in spring and autumn, and it is often concentrated in a small number of events. Extreme events providing similar total amounts of rainfall to those used in the experiment are recorded every year in the study area. After each water application, the leachates were collected. The columns were then left to dry until their soil moisture contents reached levels of around 10% v/v. During August, no water was applied in order to simulate dry, high-temperature conditions similar to those observed in the field. Leachates were analysed as follows: organic nitrogen (TNK) (Kjeldahl method; Bremner and Mulvaney, 1982), phosphorous (TP) (Olsen and Sommers, 1982) and nitrates (using the Merckoquant test strips and a Nitracheck reflectometer (Wetselaar *et al*., 1998).

Column soil analyses

After one year, the soil columns were cut into layers, replicating the same layers that had been used in packing

(0-20, 20-40, 40-60 and 60-80 cm). A representative soil sample of 2 kg was then taken from each layer of each column and homogenised, air-dried and sieved to separate the < 2 mm fraction. The sieved samples were similarly analysed for: pH, EC, total OM content, total nitrogen-Kjeldahl (TNK) and total phosphorous (TP).

Statistical analysis

One-way analysis of variance was performed at the 95% significance level ($p < 0.05$) for each soil property associated with each treatment. Mean values were compared using least significant difference. The data processing was conducted using the StatGraphics Centurion XV software.

Results

Soil characteristics

The chemical properties of the soils from each land use, including texture, pH, EC, OM content, TNK and TP, are presented in Table 2. The soils were slightly acid (pH about 6) and the OM content in the surface horizon was less than 2%. The soil texture was between loam-clay-sandy and loam-sandy and the most notable characteristic was the high percentage of coarse elements (65-70%).

The main differences between the two soils studied were the lower OM content in the surface layer of the NTV soils in relation to the NC soils; this was probably

Table 2. Mean value and standard deviation of different soil properties [texture (USDA, < 2mm fraction, in %), coarse elements (> 2 mm, in %), water retention capacity (WRC, < 2 mm fraction, in %), organic matter content (OM, in %), pH and electrical conductivity (EC, in dS m^{-1}), bulk density (in kg m^{-3}), total nitrogen Kjeldahl (TNK, in mg kg^{-1}), and total phosphorous (TP, in mg kg^{-1})] in both land use treatments: new terraced vineyards (NTV), non- cultivated soils (NC)

Land use (depth)	Texture			Coarse elements	WRC		OM	pH	EC1.5	Bulk density	TNK	TP
	Sand	Clay	Silt		–33 kPa	–1,500 kPa						
NTV												
(0-20)	74.1	16.4	9.5	69.3	14.3	9.0	0.57	6.4	0.17	1,540	1,115	263.5
(20-40)	70.9	19.2	9.9	74.0	13.4	8.6	0.48	6.2	0.18	1,620	1,050	265.7
(40-80)	65	21.0	14.0	68.8	15.0	11.0	0.42	6.5	0.12	1,720	1,000	240.5
NC												
(0-20)	72.3	7.2	20.5	66.2	16.3	13	2.20	5.5	0.12	1,680	650	410.4
(20-40)	69.2	8.9	21.9	63.6	16.0	12	1.47	6.2	0.11	1,710	675	387.5
(40-80)	67	14.0	19.0	71.5	17.6	12.3	1.00	6.9	0.12	1,810	800	275.7

due to the terracing work, which would have eliminated or bared the soil surface, and also to the lower pH of the NC soils (abandoned areas). However, in deeper layers, no significant differences were found.

WRC at –33 kPa ranged from 13% in NTV to 17% in NC soils. WRC at –1,500 kPa ranged from 12.8% in NTV to 9% in NC soils. In both cases no significant differences between layers were observed. After one year, no significant differences in WRC were found in any of the layers.

Effects of compost application on soil chemical properties

Changes in pH: After compost application an increase in the pH of the surface layer (0-20 cm) was observed in both soils. The pH increased from 5.50 in the control to 6.2 with the greatest compost dose (100 t ha^{-1}) in the NTV soils and from 6.8 to 7.2 in the NC soils. The changes were significantly different ($p = 0.04$) near the surface (0-20 cm) in the NTV soils, but in deeper layers (20-40 and 40-60 cm), the application of compost produced no pH effect.

Changes in EC: The EC also increased in the surface horizons in line with the rate of compost applied. In NTV soils amended with 50 t ha^{-1} of compost, EC increased from 0.12 to 0.17 dS m^{-1}, while in those amended with 100 t ha^{-1}, it increased from 0.12 to 0.24 dS m^{-1}. In NC soils amended with 50 t ha^{-1} of compost, EC increased from 0.17 to 0.22 dS m^{-1}, and in those amended with 100 t ha^{-1}, it increased from 0.17 to 0.32 dS m^{-1}. However, in the deeper horizons, the amended soil EC remained at similar levels to that found in the control samples. Differences between the control soil

and the treated soils were significant at the 95% level ($p < 0.05$). However, the EC values observed were much lower (about 0.6 dS m^{-1} in saturated extract) than the critical level (1.5 dS m^{-1} in saturated extract), at which vines could suffer negative effects (Carter, 1981). For vines, a 9.5% reduction in yield per EC unit has been estimated (Carter, 1981). Despite the observed change, there was therefore no risk to the crop.

Changes in OM content: The compost amendment increased the OM in the surface layer (0-20 cm) of both soils. The increase in OM produced by compost application was greater in the NTV soils (T1/control = 1.42 and T2/control = 2.17) than in the NC soils (T1/control = 1.27 and T2/control = 1.29). Some differences were also observed in the 20-40 cm (T1/control = 1.18 and T2/control = 1.38) and 40-60 cm layers (T1/control = 1.25 and T2/control = 1.13) in the NC soils. However, the compost did not affect the OM content of the 20-40 and 40-60 cm layers of NTV soils.

Changes in nitrogen concentration (Kjeldahl) (TNK): Figure 2 shows the mean TNK concentration in each soil after the different treatments and for each separate layer (0-20, 20-40 and 40-60 cm). The TNK concentration was higher in the NC soils and increased with the amount of compost applied in both land use treatments (NC soil: 1,200 mg kg^{-1} in the control, 1,600 mg kg^{-1} in T1 and 18 mg kg^{-1} in T2; NTV soil: 700 mg kg^{-1} in the control, 700 mg kg^{-1} in T1 and 900 mg kg^{-1} in T2). The relationship between TNK and OM spanned a wide interval according to the different treatments (Fig. 3). Furthermore, there were significant differences at the 95% confidence level between the TNK levels in the soil surface layer and those found in deeper layers.

Changes in total phosphorous (TP): The total phosphorous concentration in the surface horizon gradually
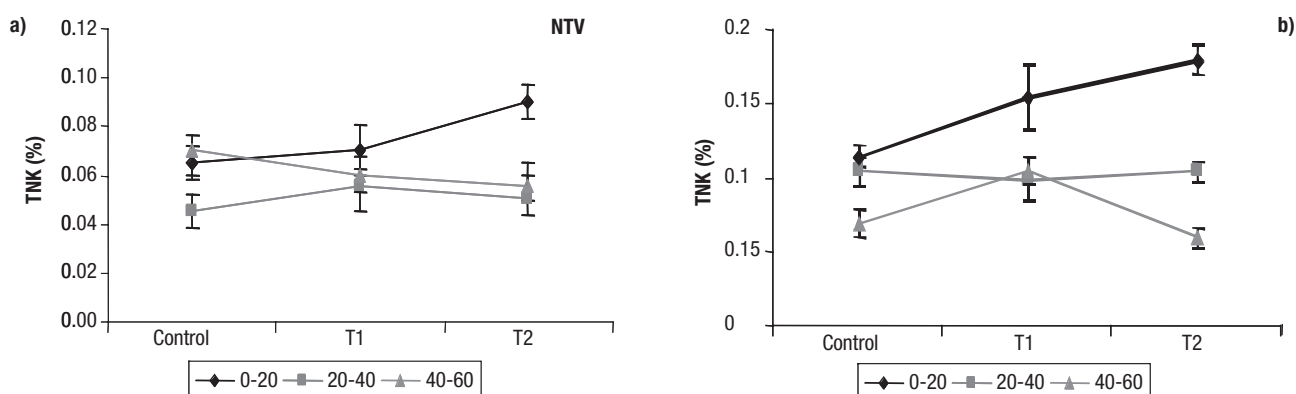
Figure 2. Nitrogen concentration (Kjeldahl method-TNK) in each soil layer (0-20 cm; 20-40 cm; 40-60 cm) after the different treatments: a) NTV soils and b) NC soils.
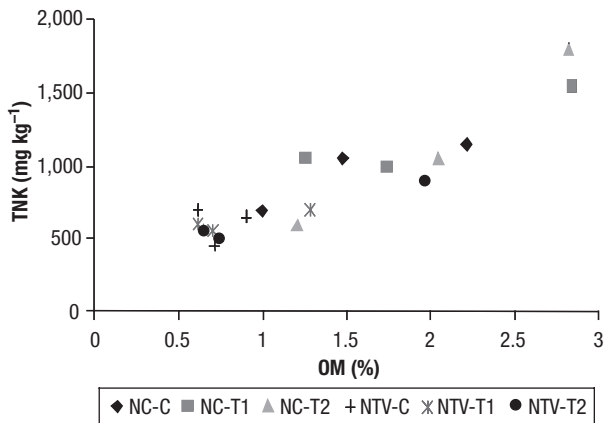
Figure 3. Relationship between organic matter (OM) content and total nitrogen (TNK) in the soil for the different land uses and different treatments: NTV -C: NTV control; NTV -T1 (NTV with 50 Mg ha^{-1} treatment); NTV-2 (NTV with 100 Mg ha^{-1} treatment); NC-C Control; NC-T1 (NC soils with 50 Mg ha^{-1} treatment); NC-T2 (NC soils with 100 Mg ha^{-1} treatment).

increased as the rate of compost application increased, for both the NC and the NTV soils. Significant differences between the treatments were observed at the 95% level. The phosphorous concentration in the NC soils increased by 50.8% in T1 and by 66.8% in T2, whereas in the NTV soils it increased by 20.3% in T1 and by 38% in T2 (Fig. 4). However, no significant effects were observed in deeper layers.

Nutrient leaching

Nitrates (NO$_3^-$): The volumes of water leached after the study period were similar in both NTV and NC soils in the control (5 L on average), but significantly higher in NTV soils (5.3 L) than in NC soils (4.7 L). However,

the total amounts of nitrate leached after the study period were significantly higher ($p < 0.05$) in the NC than in the NTV soils (Fig. 5). In both soils, nitrate leaching was greater in the soil columns amended with compost than in the controls. Nitrate concentrations in leaching showed high variability over the sampling period. Concentrations progressively increased during the first stage of the test, reaching maximum values after two months. In the NTV soils, the nitrate concentrations decreased thereafter, reaching similar values at the end of the experiment to those observed in the initial leaching (about 100 mg L^{-1} in the control and about 240 mg L^{-1} in T2). In the NC soils, nitrate concentrations initially decreased but then levelled off at about 290 mg L^{-1} in the control and at around 400 mg L^{-1} in T2. In the NC soils, the total amounts of nitrate leached in the amended columns were about 1.1 and 1.23 times greater than those observed in the respective controls for T1 and T2. The differences between treatments were greater in the NTV than in the NC soils.

Phosphorous (P): Phosphorous leaching also depended on the land use and the treatment, although it was very low in all cases (Fig. 6). Phosphorous concentrations in leachates were highest after the first rainfall. They were below 0.1 mg L^{-1} in NC soils and below 0.15 mg L^{-1} in NTV soils. In NC soils, the amounts of phosphorous leached after the first three rainfall simulations were smaller for T2 than for T1 or the control; this was probably attributable to the higher OM content, which would have fixed the phosphorous; even so, after the three first rainfall events, phosphorous leaching increased and was greater in T2 than in the other treatments. In the NTV soils, the differences between treatments were greater after the first water application, but the values reached at the end of the
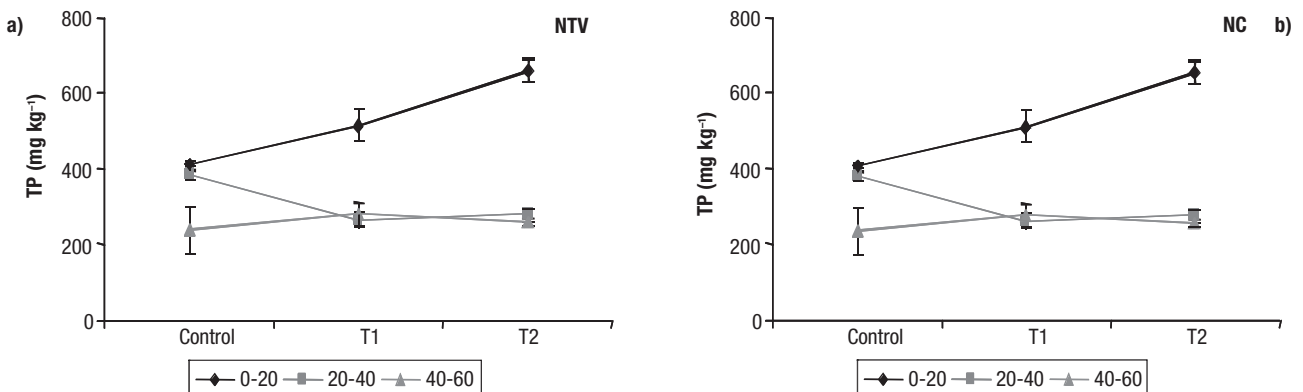
Figure 4. Total phosphorous (TP) concentration in each soil layer (0-20 cm; 20-40 cm; 40-60 cm) after the different treatments: a) NTV soils and b) NC soils.
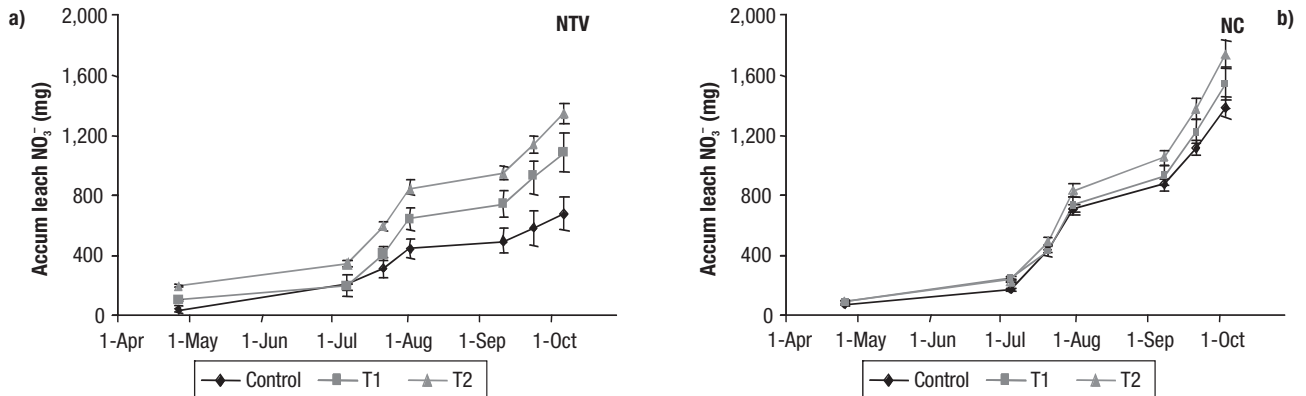
Figure 5. Accumulated nitrate leaching amount after each treatment: a) NTV soils and b) NC soils.

study period were similar for all treatments and greater than those recorded in the NC soils.

Discussion

The application of compost to the soils studied produced a beneficial effect in terms of OM content and an increase in nutrients (organic nitrogen and phosphorous). Shindo *et al.* (2006) pointed out that repeated compost applications have a cumulative effect which could become significant, particularly due to the resulting improvements in soil properties. However, Martinia *et al.* (2004) observed that increases in yield after repeated applications of OM may be due to increasing management experience rather than improvements in soil quality.

The most degraded soils were able to fix more OM than the original soils. Similar results have been reported by other authors (Korboulewsky *et al.*, 2002). On the other hand, although the electrical conductivity

increased, the observed values were below the threshold for vine toxic effects. The observed differences between the control and the treatments were greater in more disturbed soils that had been subjected to terracing. Some authors attribute the increase in EC to the extensive decomposition of OM, which results in a high salt concentration (Epstein, 1997). Vine crops are sensitive to changes in salinity, with yields declining when EC increases (Carter, 1981). Reductions in yield of 9.5% per unit of EC have been reported (Ayers and Westcot, 1976; Carter, 1981).

The results related to changes in pH were similar to those reported by other investigators using other types of compost (Mkhabela and Warman, 2005). The increase in pH in both soils could be attributed to the application of compost, which would have increased the OM content of the soil surface horizon. This in turn would have led to the release of hydrogen ions as a result of cation exchanges and/or solubilisation of OM (Mustin, 1987).

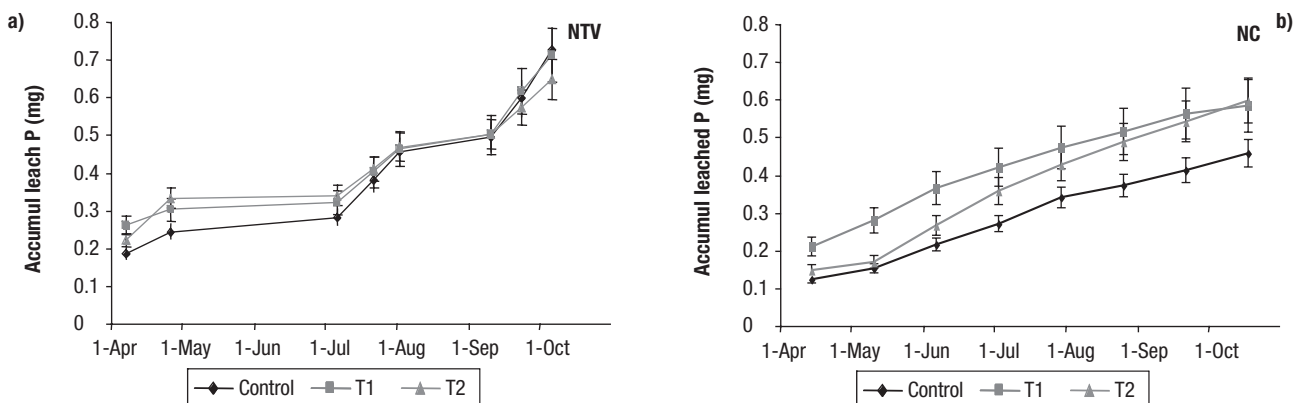The higher pH value in the NTVs was consistent with that found in the deeper layers of the NCs. The

Figure 6. Accumulated phosphorous leaching amount after each treatment: a) NTV soils and b) NC soils.

results obtained were in agreement with those reported by Sevink *et al*. (1998) for mountain areas close to the study area.

The phosphorous concentrations in the surface horizon were higher than in the deeper layers due to the adsorption of added P and the greater biological activity and accumulation of OM in the surface layer (Sharpley, 1995). Phosphorous concentrations in the surface horizon of the NC soils increased by 50.8% in T1 and by 66.8% in T2, whereas in the NTV soils, they increased by 20.3% in T1 and 38% in T2. T1 was similar to the compost rate applied in the field which, according to the results obtained, represented an excess supply in relation to the amount of phosphorous needed by the vine. According to MAF-NZ (1996), the amount of phosphorous required by the plant is 0.4 g kg^{-1} (estimated for Müller-Thurgau, Riesling × Sylvaner variety), while Van Schoor *et al*. (2000) stated that during harvest, 700 mg of phosphorous are removed for each kilogram of grapes produced. Taking into account the production of the area studied (up to 2,300 kg ha^{-1}), about 1 kg-P ha^{-1} would be removed annually. The excess of phosphorous would accumulate at the soil surface. In this respect, Van Schoor *et al*. (2000) pointed out that it is important not to apply excessive amounts of phosphorous since this may limit potassium uptake. Phosphate contents of more than 50 mg kg^{-1} in sandy soils, 60 mg kg^{-1} in loamy soils, and 70 mg kg^{-1} in clayey soils, may be problematic.

However, due to the high infiltration capacity of the soils studied, in which there was no surface runoff despite the steep slopes (Abreu, 2005), the most relevant effect was that related to the amount of nitrate leached. The quantities of water applied were similar to those from the rainfall events that normally occur in the study area (Ramos *et al*., 2008). Over the last 10 years, 7-9 events bearing total rainfall of between 25 and 50 mm have been recorded every year (some extreme events have produced more than 75 mm, with a 2-year return period). The leached volumes in our study were slightly higher in the NTV than in the NC soils; this was in agreement with results observed in the field and attributable to the lower WRC of the terraced soils (Ramos *et al*., 2007).

The nitrate concentrations in the leachates were very high, ranging from an average of 100 mg L^{-1} in the control to 240 mg L^{-1} in T2 for the NTV soils, and up to 400 mg L^{-1} in T2 for the NC soils. There would be a risk to groundwater if these compost rates (50 and 100 t ha^{-1}) were applied in this area.

A progressive increase in the nitrate concentrations in the leachates was observed during the simulation; this was due to the transformation of nitrogen to nitrate. The nitrate concentrations subsequently decreased, but with higher values in the NC than in the NTV soils. The amount of nitrate leached decreased to reach similar values at the end of the experiment to those observed in initial leaching. According to Lee *et al*. (2004), wet conditions may foster the rapid stimulation of microorganisms that favour mineralisation. After the dry conditions of August, the amount of leached nitrate was smaller, wet conditions favoured mineralization. Amlinger *et al*. (2003) found that mineralisation is independent of water content over a wide range and that significant reductions tend to occur under extremely wet or dry conditions.

Although the responses were similar in the two soils, the amount of nitrate leached was higher in the NC than in the NTV soils. However, significant differences were observed between the control and the treated soils: in the NTV soils, the levels of nitrate leaching in T1 and T2 were respectively 1.75 and 2.1 times that recorded in the control, while in the NC soils, the differences between the treatments were smaller (1.1 and 1.23 times the control values for T1 and T2, respectively). This may have been caused by differences in OM, which were also smaller between the control and treated soils in the NC than in the NTV soils. On the other hand, WRC was lower in the NTV than in the NC soils and this possibly favoured water passing through the column more quickly and washing away fewer nitrates in solution. These processes were favoured by the high infiltration capacity of the soils in question. The observed increase in nitrate leaching in the treated soils *vs*. the control may also be explained by the increase in nitrogen in all of the soil layers and not only at the surface. In treatment T1, nitrate leaching under the conditions studied accounted for up to 7.6% of the applied N in the NC soils and for up to 4.8% in the NTV soils. In treatment T2, it accounted for about 3% of the applied N in both soils.

The amount of dissolved P leached from the soil columns was very small for both soils. As previously stated, P leaching was lower in the NC than in the NTV soils, even though the total amount of phosphorous on the surface of the NC soils was greater. This may have been because the amount of OM was greater in the NC than in the NTV soils, thus increasing P adsorption. Similar results have been reported by other researchers using cattle slurry (Núñez-Delgado *et al*., 1997).

Despite the higher phosphorous concentrations in the leachates recorded in the NC soils, due to the larger volume of water leached from the NTV soils, the total amount of phosphorous removed was relatively higher in the NTV than in the NC soils for a given application of water. In this case leaching was greater in the control (1.73 mg) than in the treated soils (0.714 mg in T1 and 0.656 mg in T2).

As observed in this study, the quantity of OM present in the soil has a direct impact on soil nitrogen and phosphorous but it had an opposite effect on the amount of nitrates and phosphorous found in leachates. Organic matter in the soil helps to fix phosphorous near the soil surface, so phosphorous concentrations leachates are lower in soils with a higher OM content. For nitrogen, however, higher soil concentrations result in greater amounts of nitrates being leached.

In conclusion, this study shows the positive effects that applying compost can have on soils with low OM contents, particularly after terracing operations in vineyards. Compost application enhances the amounts of OM and nutrients (phosphorous and nitrogen) on the soil surface. Increases in OM were almost double in soils from terraces than in undisturbed soils. Phosphorous levels in the surface layer increased nearly twice as much in the NC than in the NTV soils, with an increase of up to 66.8% in the former for higher dose applications; however, no significant differences were found in deeper layers. Total nitrogen (TNK) concentrations were also higher in non-terraced soils, with significant differences in surface layers (both between soils and with respect to the deeper layers). TNK was related to OM.

However, given the high infiltration capacities of the soils studied, leaching effects must be taken into account before compost applications can be generalised throughout the area. The quantities of nitrate leached were greater in the NC than in the NTV soils and this was particularly favoured by wet conditions. Nitrate leaching increased with compost dose, with the concentrations leached reaching 240 mg L^{-1} in the NTV soils and 400 mg L^{-1} in the NC soils, which implies a risk of groundwater pollution.

Phosphorous concentrations in leachates were generally very low (below 0.15 mg L^{-1}), but due to the lower WRC of the NTV soils, a greater total of P was leached from the NTV than the NC soils for a given application of water, and this amount increased with the dose of compost applied.

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