

SHORT-TERM CARBON AND NITROGEN MINERALISATION IN SOIL AMENDED WITH WINERY AND DISTILLERY ORGANIC WASTES

M. A. Bustamante, M. D. Pérez-Murcia, C. Paredes, R. Moral, A. Pérez-Espinosa, J. Moreno-Caselles

Department of Agrochemistry and Environment, Miguel Hernández University, EPS-Orihuela, Ctra. Beniel Km 3.2, 03312-Orihuela (Alicante), Spain. marian.bustamante@umh.es

ABSTRACT

The aim of this work was to study the influence of organic wastes derived from winery and distillery industry on the carbon and nitrogen mineralisation in amended soils. The influence of soil type was also monitored. Incubation experiments with three different calcareous soils (clay-loam, loam and sandy textured) mixed with four winery and distillery organic wastes (grape stalk, grape marc, wine lees and exhausted grape marc) were made to monitor the organic C, the specific respiration ($q\text{CO}_2$) and different forms of nitrogen produced by these wastes. The evolution of C mineralisation fitted a first-order kinetic for all amended soils. An initial increase was observed in the $q\text{CO}_2$ values, after tending towards the values of the control, showing the pattern of the soil to recover its initial equilibrium status. The addition of these wastes in the soils produced a slight increase of the inorganic nitrogen, observing an inhibition in the N mineralisation in the soils amended with grape stalk. Organic matter mineralisation was probably influenced by soil type, the sandy soil favouring more the N and C mineralisation processes than the clayey-loam and loam soils.

INTRODUCTION

Wine production of Mediterranean countries represents ca. 60% of the entire world-wide production. Grape stalk and marc, wine lees and exhausted grape marc are the main by-products and wastes generated by wine and alcohol-producing industries. The main problem of all these organic wastes is their disposal and treatment because of their seasonal character, low pH and a high content of phytotoxic and antibacterial phenolic substances, which resist biological degradation. However, these organic wastes have also high organic matter and potassium contents and significant levels of nitrogen and phosphorus, important factors in soil fertility (Vogt et al., 1986). Nowadays, the recycling of organic wastes in soil could be a way of disposal, thus, the addition of the winery and distillery organic wastes could result in a method for reducing disposal costs and recycling the organic matter and nutritive elements of these wastes in the soil-crop system. Therefore, the aim of the present work was to study the influence of the organic wastes derived from winery and distillery industry and the characteristics of the used soil on the carbon and nitrogen mineralisation in the amended soils.

MATERIALS AND METHODS

For this study surface layer (0-25 cm) samples of three different calcareous soils were collected at Orihuela (S1), Ribera de Molina de Segura (S2) and Guardamar (S3) (SE Spain), being clayey-loam, loam and sandy textured, respectively. The main characteristics of these soils were: S1, 30 % clay; 35 % silt; 35 % sand; 8.52 pH; 0.16 dS m^{-1} electrical conductivity (EC); 8.1 g kg^{-1} oxidizable organic carbon (C_{org}); 1.3 g kg^{-1} Kjeldahl total N (KTN), 4.8 mg kg^{-1} $\text{NH}_4^+\text{-N}$

and 16.7 mg kg⁻¹ NO₃-N; S2 had 19 % clay; 36 % silt; 45 % sand; 8.17 pH; 0.37 dS m⁻¹ EC; 4.0 g kg⁻¹ C_{org}; 0.6 g kg⁻¹ KTN, 6.1 mg kg⁻¹ NH₄⁺-N and 10.7 mg kg⁻¹ NO₃-N; S3 showed 11 % clay; 12 % silt; 77 % sand; 8.53 pH; 0.11 dS m⁻¹ EC; 5.6 g kg⁻¹ C_{org}; 0.7 g kg⁻¹ KTN, 9.4 mg kg⁻¹ NH₄⁺-N and 4.6 mg kg⁻¹ NO₃-N. The winery and distillery wastes used in this work were samples of grape stalk (GS), grape marc (GM) and wine lee (WL) from a winery and a sample of exhausted grape marc (EG) from a distillery. Some characteristics of these wastes were 3.97 pH; 4.67 dS m⁻¹ EC; 335 g kg⁻¹ C_{org} and 9.7 g kg⁻¹ KTN for GS. GM had 4.48 pH; 3.40 dS m⁻¹ EC; 348 g kg⁻¹ C_{org} and 19.1 g kg⁻¹ KTN. EG showed 3.93 pH; 2.04 dS m⁻¹ EC; 316 g kg⁻¹ C_{org} and 18.8 g kg⁻¹ KTN. Finally, WL had 3.63 pH; 4.99 dS m⁻¹ EC; 376 g kg⁻¹ C_{org} and 38.2 g kg⁻¹ KTN. Winery and distillery wastes were mixed with soils at the rate of 40 g residue kg⁻¹ soil (d.w.). Amended and control soils were placed in plastic pots for incubation in aerobically controlled non-leached conditions at 25 °C during 119 days. The soil moisture content was maintained at 60% WHC of the soils. Microbiological parameters (soil respiration and microbial biomass, performed as the metabolic quotient, qCO₂), different forms of nitrogen (Kjeldahl total nitrogen, organic N, NO₃-N and NH₄⁺-N) and waste mineralised nitrogen were studied at 0, 5, 12, 19, 26, 68 and 119 days of incubation. These parameters were determined according to the methods described by Hernández et al. (2002) and Sánchez-Monedero et al. (2004). The amount of CO₂-C evolved from wastes mineralisation was calculated by subtracting the amount produced by the control soils from that produced by the residue-treated soil and expressed as a percentage of the organic C added. Data concerning CO₂-C evolution was fitted to kinetic functions by a non-linear least-square procedure (Marquardt-Levenberg algorithm). First order kinetic model was used for organic C mineralisation (Bernal et al., 1998); $C_m = C_o(1 - e^{-Kt})$, where C_m is the carbon mineralised (%C) at time t (d) and C_o and K are the potentially mineralisable C (%C) and rate constant (d⁻¹), respectively. Residual mean square (RMS) and F-values were calculated to compare the fittings of different functions and the statistical significance of curve fitting.

RESULTS AND DISCUSSION

Table 1. Carbon mineralised after 119 d of incubation (C_m), potentially mineralisable carbon (C_o), residual mean square (RMS) and F-values for carbon mineralisation of grape stalk (GS), grape marc (GM), exhausted grape marc (EG) and wine lee (WL) in the treated soils.

| Soils | Samples | C _m (%C) | C _o (%C) | K (d ⁻¹) | C _o xK | RMS | F |
|---------------------|---------|---------------------|---------------------|----------------------|-------------------|-------|---------|
| S1 (clayey-loam) | GS | 9.43±0.27 | 9.46±0.64 | 0.046±0.008 | 0.43 | 0.599 | 124*** |
| | GM | 10.16±0.12 | 10.20±1.15 | 0.045±0.013 | 0.46 | 1.888 | 52*** |
| | EG | 9.94±0.07 | 10.09±1.21 | 0.034±0.010 | 0.34 | 1.544 | 59*** |
| | WL | 13.24±0.16 | 13.24±0.64 | 0.099±0.017 | 1.31 | 0.944 | 146*** |
| S2 (loam) | GS | 16.03±1.16 | 16.03±0.38 | 0.087±0.007 | 1.39 | 0.313 | 671*** |
| | GM | 17.68±0.12 | 17.68±0.37 | 0.077±0.005 | 1.36 | 0.282 | 942*** |
| | EG | 16.96±0.59 | 16.96±0.39 | 0.067±0.005 | 1.14 | 0.295 | 822*** |
| | WL | 16.22±0.74 | 16.22±0.27 | 0.114±0.007 | 1.85 | 0.188 | 1143*** |
| S3 (sandy) | GS | 18.08±1.40 | 18.09±0.29 | 0.082±0.004 | 1.48 | 0.177 | 1539*** |
| | GM | 17.59±0.46 | 17.59±0.31 | 0.085±0.005 | 1.50 | 0.202 | 1261*** |
| | EG | 16.49±0.06 | 16.49±0.48 | 0.072±0.006 | 1.19 | 0.451 | 523*** |
| | WL | 21.76±0.69 | 21.76±0.39 | 0.125±0.009 | 2.72 | 0.399 | 966*** |

*** Significant at the probability levels $P < 0.001$. Standard deviation from $n = 3$.

The cumulative CO₂-C evolution with time for all treatments followed a first-order kinetic model (Table 1). Although all equations were significant at $P < 0.001$, the results of S2 and S3 fitted this equation better than the results obtained for S1, which showed lower F and higher RMS values than the others. The lowest mineralised C values after 119 days (C_m) and rate of C_{org} mineralisation, as the K and C_oxK values showed,

were observed in the clayey-loam soil in all treatments, suggesting the influence of soil type on

residue organic matter mineralisation. Other authors also found that soil clay content influences organic matter mineralisation, clay protecting organic matter from mineralisation (Hernández et al., 2002; Moral et al., 2003). In general, all soils amended with WL showed higher C_m and potentially mineralisable C (C_o) values than those found for the rest of treatments.

The addition of the winery and distillery wastes to the different soil types produced an initial increase and a notable variability in the qCO_2 values (Fig. 1), which could be attributed to the disturbance (temporary environmental change) of the soil microbial biomass due to external inputs of organic matter (Anderson and Domsch, 1990). After the initial increase, in general, the qCO_2 tended towards the values of the control, showing the pattern of the soil to recover its initial equilibrium status. The time needed to reach the new equilibrium was more than 60 days in most of the amended soils, depending on the type of waste added and the texture of the soil. This evolution has been also observed by Sánchez-Monedero et al. (2004) in an incubation of soil with composted sewage sludge at different stabilisation degrees.

The inorganic N ($NO_3^- - N + NH_4^+ - N$) evolution in the control and in the amended soils during the 17 weeks of incubation is shown in Fig. 2. In general, the highest increase in inorganic N in all soils was observed from the day 26 of incubation for all treatments, before which no changes or even a decrease in inorganic N content was observed. The inorganic N tended to increase in all amended soils during the following weeks until the end of the incubation.

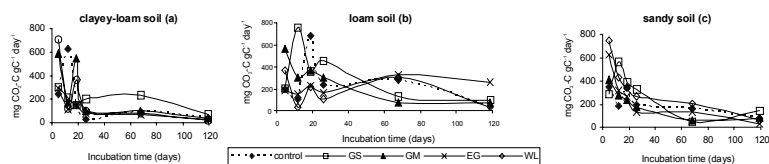


Figure 1. Evolution of specific respiration activity (qCO_2) in treated soils.

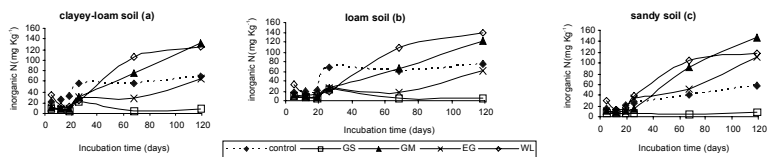


Figure 2. Evolution of inorganic N contents in treated soils.

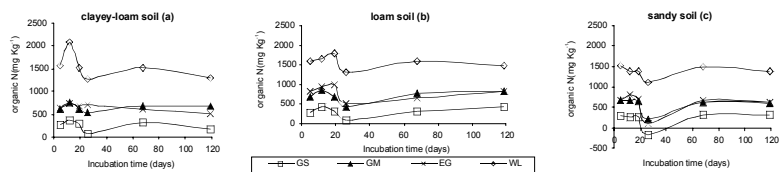


Figure 3. Evolution of the residue organic N in the treated soils.

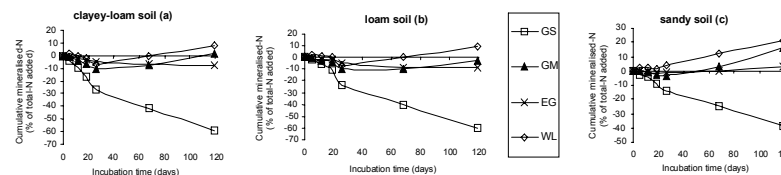


Figure 4. Evolution of cumulative N mineralisation from residues in the treated soils.

However, in the soils amended with GS, the inorganic N was below the values in the control soils, which could indicate immobilisation processes. At the end of the experiment, inorganic N content was higher in all amended soils, except for GS in all soils and EG in the clayey-loam and loam ones.

Waste organic N in clayey-loam and loam treated soils increased throughout the first three weeks of experiment, which indicated that immobilisation processes could have produced in more degree than N losses by ammonia volatilisation or by denitrification processes (Fig. 3). However, during this period in the amended sandy soils was observed a maintenance or even decrease in the organic N values depending on the residue used, possibly because of losses of organic N are greater in soils of light texture where aeration and permeability accelerate organic N decomposition (Hernández et al., 2002). The N mineralisation-immobilisation turnover was influenced by the type of soil and residue used, being higher the N mineralisation in S3 for all treatments and GS the material which produced a higher immobilisation of N in all soils (Figure 4). The immobilisation of mineral N in amended soils with winery and distillery wastes could be due to the toxicity effect of their polyphenolic compounds on the soil microbial biomass involved in the process of N mineralisation because of their capacity to bind proteins through their strong affinity for amide groups (De Neve et al., 2004). This inhibition of N mineralisation could produce the immobilisation of inorganic N by the soil microbial biomass when these wastes are degraded.

From the obtained data it can be concluded that organic matter mineralisation was the lowest in the clayey-loam soil. A low N mineralisation of these wastes, even a N immobilisation, was observed, especially in the soils amended with GS. Although these wastes did not show a high N fertilising capacity, an agronomic use could be possible due to the C mineralisation and qCO_2 evolution followed the same pattern as other wastes usually used with an agricultural purpose, being only GS not recommended through its high N immobilisation capacity.

REFERENCES

- Anderson, J.P.E., Domsch, K.H. 1990. Application of ecophysiological quotients (qCO_2 and qD) on microbial biomasses from soil of different cropping histories. *Soil Biol. Biochem.* 22: 251-255.
- Bernal, M.P., Navarro, A.F., Sánchez-Monedero, M.A., Roig, A., Cegarra, J. 1998. Influence of sewage sludge compost stability and maturity on carbon and nitrogen mineralization in soil. *Soil Biol. Biochem.*, 30: 305-313.
- De Neve, S., Gaona-Sáez, S., Chaves-Daguilar, B., Sleutel, S., Hofman, G. 2004. Manipulating N mineralization from high N crop residues using on- and off-farm organic materials. *Soil Biol. Biochem.*, 36: 127-134.
- Hernández, T., Moral, R., Pérez-Espinosa, A., Moreno-Caselles, J., Pérez-Murcia, M.D., García, C. 2002. Nitrogen mineralisation potential in calcareous soils amended with sewage sludge. *Biores. Technol.*, 83: 213-219.
- Moral, R., Paredes, C., Pérez-Murcia, M.D., Pérez-Espinosa, A., Moreno-Caselles, J., Rufete, B., Agulló, E. 2003. Influence of stabilisation treatment of sewage sludge on the release of plant available nitrogen. In: Schnug, E., Nagy, J., Németh, T., Kovács, Z., Dövényi-Nagy, T. (eds.): *Proc. 14th International Symposium of Fertilizers*, Debrecen, Hungary, pp. 690-696
- Sánchez-Monedero, M.A., Mondini, C., de Nobili, M., Leita, L., Roig A. 2004. Land application of biosolids. Soil response to different stabilization degree of the treated organic matter. *Waste Manag.*, 24: 325-332.
- Vogt, E., Jakob, L., Lemperle, E., Weiss, E. 1986. *El vino, obtención, elaboración y análisis*. Ed. Acribia, S.A. Zaragoza.