Mineralization dynamics and biochemical properties following application of organic residues to soil

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Abstract
The reliability of soil application of organic residues as an effective strategy for sustainable management of soil organic matter requires a thorough evaluation of the impact of amendment on C and N mineralization and size and activity of soil microbial biomass. In this work three soils were amended with three plant residues and five animal by-products and analysed for CO_2 evolution, extractable NH_4^+ and NO_3^-, water extractable C and N, microbial biomass C and protease and β-glucosidase activities. Mineralization patterns depended on the nature of the residues and the properties of soils. Cumulative extra respiration was higher (16-24% of added C) for animal residues than for plant residues (9-12 % of added C). Animal by-products caused a significant increase in the content of mineral N and water soluble C and N, while plant residues produced an immobilization of mineral N. The application of wastes caused an increase in the size and activity of soil microbial biomass, indicating an enhanced capacity of the soil to carry out ecosystem functions. Overall results suggest that plant residues are more effective soil amendments and favour C sequestration, while animal residues are effective organic fertilizers.

Key Words
Organic residues, soil organic matter, mineralization, soil microbial biomass, enzyme activity

Introduction
Soil organic matter (SOM) is a critical component of both natural and managed ecosystems. The decline of SOM caused by the intensification of agricultural practices is among the main threats to soil fertility and quality (Matson *et al.,* 1997). In the Mediterranean area the decrease of SOM during last decades is estimated at around 50% of the original content, with 74% of the land covered by soils containing less than 2% of organic C (Van Camp *et al.,* 2004).
The maintenance of soil agronomical and environmental functions implies a sustainable management of SOM. Among the management practices aimed to the preservation and increase of SOM, application of organic residues represents a valuable option because it allows for soil fertility enhancement, soil quality conservation, environmental protection and sustainable recycling of organic residues. Nevertheless, the suitability of soil application of organic residues requires a thorough evaluation of the impact of exogenous organic matter on C and N mineralization and size and activity of soil microorganisms. Dynamics and amount of mineralization plays a key function for availability of nutrients, release of toxic elements and soil C sequestration, while soil microorganisms exert fundamental functions determining the degree of soil quality, such as improvement of soil structure, decomposition of organic compounds, synthesis of humic substances, C and nutrient cycling, enhancement of nutrients and water uptake, protection of crops from pest and disease, bioremediation of toxic metals and other harmful compounds. In this work a series of laboratory assays was designed to study mineralization dynamics and chemical and biochemical properties of soil following amendment with different plant and animal residues. In particular, the impact of organic residue characteristics and soil properties was evaluated in order to optimise soil amendment as effective strategy for sustainable management of SOM and soil conservation.

Methods
Three plant residues (straw, cotton and olive mill waste) and five animal by-products (meat bone meal, two different blood meals, horn and hoof meal and hydrolyzed leather) were added (0.5% on dry weight basis) to three moist soils and incubated at 20 ºC for one month. Main properties of soils and residues are reported on Table 1 and 2, respectively.

Table 1. Chemical and biochemical properties of the selected soils.

Site	Sand	Silt	Clay	pH	$CaCO_3$	C_{ORG}	N_{TOT}	C_{MIC}
		(%)				(%)		(mg kg^{-1})
S. Martino	69	28	3	8.3	74	0.57	0.05	114
Jumilla	52	21	27	8.0	42	1.04	0.10	119
Lodi	67	21	12	6.7	-	20	0.21	205

Table 2. Main properties of organic residues.

Organic residues	Abbreviation	pH	C_{ORG}	N_{TOT}	C_{ORG}/N_{TOT}	K	P
			(%)			(%)	
Meat and Bone Meal	MBM	5.9	46.0	11.1	4.2	0.3	2.7
Blood Meal	BLM	6.7	52.6	16.4	3.2	0.7	0.2
Blood Meal 2	BLM2	6.6	49.3	15.6	3.2	0.3	0.4
Horn and Hoof Meal	HHM	7.5	51.3	17.0	3.0	0.1	0.2
Hydrolysed Leather	HL	5.2	42.0	13.2	3.2	0.4	1.4
Straw	STRAW	6.5	49.6	0.2	201	0.4	0.0
Cotton	COTTON	6.2	45.2	1.5	30.5	1.5	0.2
Olive Mill Waste	OMW	5.2	55.1	1.1	48.7	2.4	0.1

During incubation the CO_2 evolution of the amended soils was measured every four hours by means of an automatic chromatographic system for gas sampling and measurement (Cayuela et al., 2006). At the end of incubation, soil samples were analysed for water extractable C and N, K_2SO_4-extractable NH_4^+ and NO_3^-, microbial biomass C (Wu *et al.,* 1990), protease (Alef and Nannipieri, 1995a) and β-glucosidase activity (Alef and Nannipieri, 1995b).

Results

On the whole the addition of the residues to the soil produced, after a short lag-phase, an exponential increase in the soil respiration rate, reflecting the growth of microbial biomass, followed by a steady decrease, indicating the depletion of available substrates (Figure 1). Cumulative extra CO_2-C (Cumulative CO_2-C from amended soil minus cumulative CO_2-C from control soil) ranged from 9.1 to 24% of added C (Table 3).

Table 3. Cumulative extra CO_2-C in amended soils (% of added C).

Organic residue	Soil			Mean
	San Martino	Jumilla	Lodi	
MBM	19.3	21.3	27.7	22.8
BLM	13.3	11.8	22.1	15.7
BLM2	15.5	17.0	21.6	18.0
HHM	24.3	23.2	24.4	24.0
HL	15.0	17.0	21.2	17.7
STRAW	8.0	5.6	20.1	11.2
COTTON	8.3	7.9	19.2	11.8
OMW	6.1	6.6	14.6	9.1

The dynamics and amount of mineralized C were affected by the nature of chemical constituents of residues. Cumulative extra respiration was higher (16-24% of added C) for animal residue (mainly constituted by proteins) with respect to plant residues (mainly constituted by ligno-cellulosic components - 9-12 % of added C) (Table 3). Carbon mineralization was also affected by the complexity of chemical constituents of residues as the different dynamics of BLM, MBM and HHM (Figure 1) reflected the predominant kind of proteins (globular, collagen, keratin) present in the residues.

Also soil properties greatly affected C mineralization. For instance cumulative extra CO_2-C derived from straw was about four times higher in the Lodi soil with respect to S. Martino (Table 3). Microbial biomass, pH and texture were the main soil properties affecting C mineralization.

All residues caused a significant increase in water soluble organic C (data not shown), an indicator of soil quality for plant growth (Zsolnay, 1996).

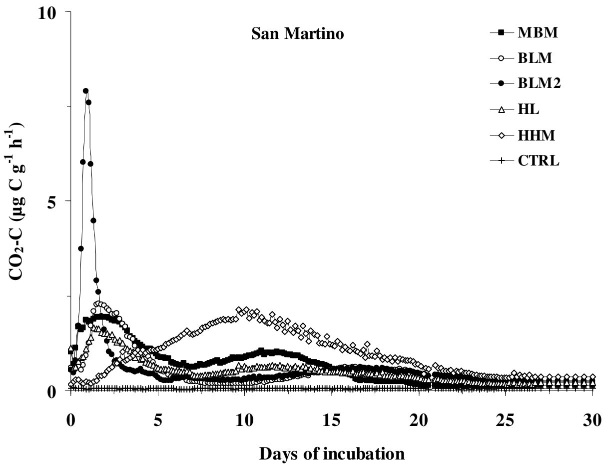

Figure 1. Dynamics of CO_2 evolution in S. Martino soil amended with animal residues.

Water soluble N was increased with respect the control in the animal residues treated soils, while it was decreased in the soils treated with plant residues (data not shown).
Animal by-products caused a significant increase in the content of net extractable mineral N (extractable mineral N from amended soil minus extractable mineral N from control soil) ranging from 13 to 33% of the N added with the residue, indicating an increase in the mineral N available for plant, but also an increased risk of nitrate leaching. On the contrary, plant residues caused an immobilization of mineral N and therefore a possible N supply deficiency for plants (Table 4).

Table 4. Net extractable mineral N in amended soils (% of added N).

Organic residue	Soil			Mean
	San Martino	Jumilla	Lodi	
MBM	47.9	40.2	9.8	32.6
BLM	29.0	22.3	22.7	24.6
BLM2	1.4	27.2	8.1	12.3
HHM	7.5	19.2	12.6	13.1
HL	5.1	23.9	9.1	12.7
STRAW	-394	-172	-221	-262.5
COTTON	-63.1	-29.1	-36.7	-43.0
OMW	-90.9	-38.5	-57.6	-62.3

The application of wastes caused an overall increase in the size and activity of soil microbial biomass, indicating an enhanced capacity of the soil to carry out ecosystem functions. The importance of the characteristic of amendments was evident in the case of the two blood meals; despite they derived from the same starting material their soil application caused the minimum and maximum increase in the size of microbial biomass (Figure 2).

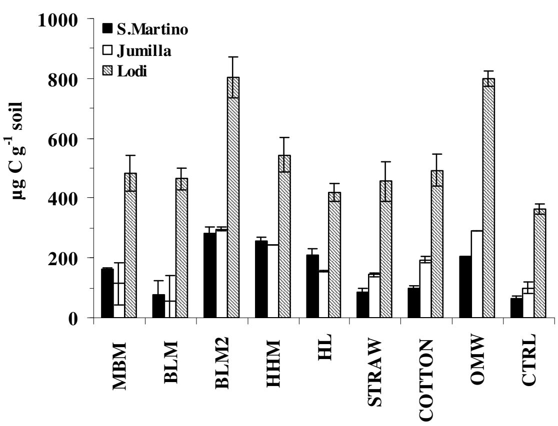

Figure 2. Microbial biomass C in control and amended soils after 1 month incubation. Bars represent standard deviation.

All residues caused an increase in the enzymatic activity. In particular animal by-products caused the highest increase in the protease activity (3-10 fold increase), a key enzyme in protein degradation (Alef and Nannipieri, 1995a), while β−glucosidase activity, the rate limiting enzyme in the microbial degradation of cellulose to glucose (Alef and Nannipieri, 1995b) was mostly stimulated by straw and cotton (1.4-3 fold increase) (Figure 3).

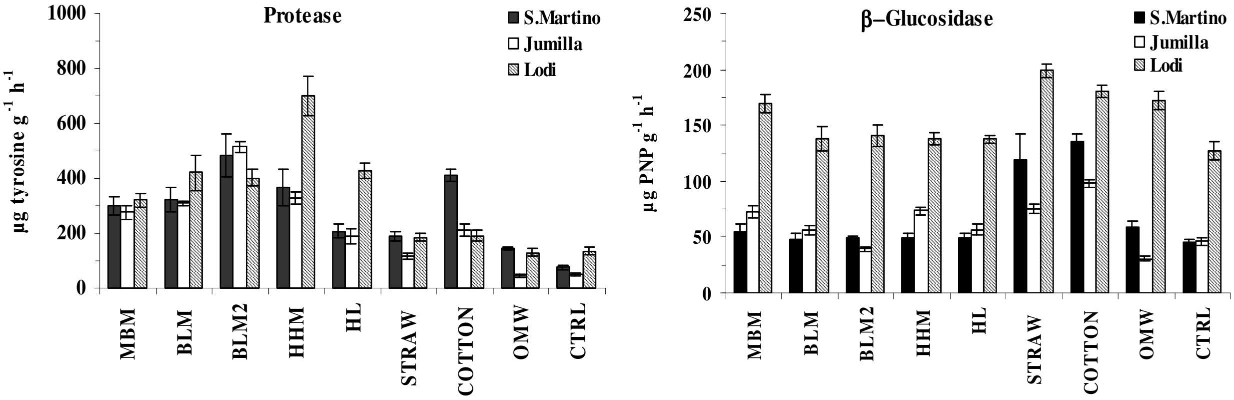

Figure 3. Protease and β-glucosidase activity in control and amended soils after 1 month incubation. Bars represent standard deviation. PNG: para nitro phenol.

Conclusion

Results showed that the decomposition of organic residues varied greatly according to the characteristic of the residues and was soil specific and largely related to the soil biochemical and textural characteristics. Mineralization data suggest that plant residues are best suited as soil amendment and for promoting soil C sequestration, while animal residues are more indicated as organic fertilizers.

The general increase in microbial size and activity represents an enhancement of soil capacity to carry out fundamental ecosystem functions.

Results of the present study underline the importance of researches for the optimization of soil addition of organic residues in order to increase beneficial effects of soil amendment (enhancement of soil fertility and quality, substrate for soil microorganisms, soil C sequestration, closure and proper functioning of elements cycle, environmental decontamination) and avoid negative environmental impacts (NO_3^- leaching, soil N deficiency). In this perspective laboratory studies can provide rapid assessment of the effect of several factors on mineralization and biochemical properties. Results from these studies can be used as the first step to design appropriate field management strategies.

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