1st Spanish National Conference on Advances in Materials Recycling and Eco – Energy
Madrid, 12-13 November 2009
S05-12

ORGANIC WASTES AS AMENDMENTS TO AVOID SOIL DEGRADATION IN SEMIARID ZONES

C. Garcia, F. Bastida and T. Hernandez

CEBAS-CSIC. Campus Universitario de Espinardo, P.O. Box 164, 30100-Espinardo (Murcia), Spain

Abstract

A three-year experiment was set up under field conditions to test the potential of two organic amendments (sludge and compost) to improve soil quality and plant growth in a semiarid degraded Mediterranean area. Since little is known about N dynamics in such assisted ecosystems, we investigated the effects of this practice on key processes of the global N cycle (nitrification). Organic amendments influence resource availability, the size and the activity patterns of microbial populations in the long-term and may therefore play a key role to assist sustainable restoration practices in semiarid degraded areas.

Keywords: Organic Wastes, Microbial Activity, Soil Degradation

INTRODUCTION

During recent decades great efforts have been made to increase food production. This has led to great pressure being put on natural resources, particularly water and SOIL. An additional problem affects large areas of soils in Spain: degradation and desertification, usually as a result of aggressive human activity in combination with adverse (semi-arid) climatological conditions. These factors, which low levels of available organic matter aggravate, have led to a gradual decline in the natural fertility of the soils in question (1). Since in Spain and many other European countries, particularly the most southerly lying, the traditional sources of organic matter (peats and manure) are in short supply, it has been proposed that the above problems concerning Organic Wastes and Soils may be lessened by considering them both together. The possible solution would involve using the organic matter contained in given organic wastes as a source of organic matter in degraded soils, thus improving their fertility and rationally eliminating the wastes through recycling (2).

In the recently published Strategy for Protecting oilshttp://ec.europa.eu/environment/soil/pdf/com_2006_0231 in pdf), which is the precursor of a new directive, the loss of organic matter is identified as one of the main threats for soil degradation.The maintenance of suitable levels of organic matter in the soil favours the implantation of a stable vegetal cover, which, in turn, ensures the future supply of organic elements to that soil, and is considered one of the most effective methods in the fight against erosion and associated degradative processes (3).

In the present study, we set up an experiment to test the potential of organic amendments under field conditions to improve the soil status and vegetation cover in a semiarid Mediterranean degraded area. As little is known about N dynamics in "seminatural" managed ecosystems in arid or semiarid environments, we aimed at evaluating the impact of incorporating stabilized sludge and biosolid compost on key processes of the N cycle (nitrification) three years after addition.

EXPERIMENTAL

The study was carried out in an experimental area agriculturally abandoned 10 years ago and largely eroded, situated in the province of Murcia (Southeastern Spain, 38º1'N 1º12'W). The climate is semiarid Mediterranean (mean annual rainfall of 333.2 mm and a mean annual temperature of 17.2 ºC) with mild rainy winters and very hot, dry summers. The soil was classified as loam, Aridic calcisol (4).

Experimental plots (4m x 5m) were arranged in a complete randomised block design with two amended treatments and one control (unamended). Each treatment was replicated three times. The amendments tested were: sewage sludge (S) from a wastewater treatment plant (Murcia, SE Spain), digested anaerobically and stabilized through removal of ammonia and methane, and biosolid compost (CM) made from the same material with straw as bulking agent. Amendments were incorporated into the topsoil (15 cm) at a rate of 12 kg m^{-2} using a rotovator in March 2004. The analytical characteristics of the organic materials are shown in Table 1. Control plots were also tilled using a rotovator. During the experimental period, plots were left under natural conditions without irrigation. Plots were sampled in June 2007. Four surface soil samples (0-15 cm), each consisting of 8 soil cores, were randomly collected within each plot. Subsamples for molecular determinations were frozen *in situ* on dry ice and then stored at -80°C until analysis (one month after the sampling). Bulk soil samples were returned to the laboratory and subsamples for microbial biomass and biochemical determinations were sieved to a particle size of less than 2 mm and stored at 4°C until analysis (within two weeks after the sampling). The rest was air dried for two days and sieved to a particle size of less than 4 mm diameter and then chemical properties and heavy metal concentrations were determined. The analysis of amendments was performed in the same way.

Table 1. Characteristics of organic materials (dry weight basis)

		Sludge	Compost
pH		6.6	6.8
EC	(dS m^{-1})	2.85	2.46
Total Organic C	(g kg^{-1})	378	406
Total N,	(mg kg^{-1})	43000	30300
Total P,	(mg kg^{-1})	1600	1700
Total K ,	(mg kg^{-1})	3900	4000
Total Cd	(mg kg^{-1})	< 2.5	< 2.5
Total Cr	(mg kg^{-1})	14.0	11.0
Total Cu	(mg kg^{-1})	247	187
Total Ni	(mg kg^{-1})	14.8	11.9
Total Pb	(mg kg^{-1})	80.8	54.9
Total Zn	(mg kg^{-1})	718	510
C/N Ratio		8.73	13.5

Soil properties and heavy metals were analysed by standard methods. Microbial biomass C (MBC) was determined by the fumigation-extraction method (5). Soil respiration and dehydrogenase activity were analyzed as reported by Garcia et al., (6). Soil urease activity was estimated by the method of Kandeler and Gerber (7). For determination of potential nitrification rate the method of Beck (8) was used.

Total DNA from soil samples (0.5g dw) was extracted using the method cited by Bastida et al. (9). Quantification of *amoA* genes via quantitative PCR (qPCR) were quantified according to Sharm et al. (10).

RESULTS AND DISCUSSION

The incorporation of amendments into the soil had no relevant effect on soil pH, which remained near neutrality (approximately 7.5) in all treatments. The electrical conductivity was significantly higher in amended soils than in control plots, but below 1 dS cm^{-1}. Hence no salinity problems were expected in treated soils (Table 2).

One of the most important aspects of incorporating amendments into degraded soils is the durability of the treatment. This will determine the need for future applications (doses and rate) and the success of restoration practices. In this study, the effects of organic amendments on soil fertility were still remarkable three years after their incorporation into the soil (Table 2).

Table 2. Characteristics of the amended soils (values on dry weight basis) at the end of the experiment

	Control	S[2]	CM[3]	Limits[4]
pH	7.55a	7.87b	7.52a	
EC (dS m^{-1})	0.34a	0.43b	0.94c	
Bulk density (g cm^{-3})	2.61b	2.57b	2.40a	
Water holding capacity (g $100g^{-1}$)	40.2a	47.6b	55.3b	
Total Organic C (g kg^{-1})	15.3a	21.0b	27.6b	
Total N (g kg^{-1})	1.80a	3.50b	4.32b	
Total P (mg kg^{-1})	535a	692b	741b	
Total K (g kg^{-1})	5.68a	6.24b	6.41b	
NO_3–N (mg kg^{-1})	0.92a	5.28b	4.40b	
NH_4^+-N kg^{-1})	3.89a	25.3b	23.2b	
C/N ratio	8.51b	6.01a	6.39a	
Total Cd (mg kg^{-1})	< 2.5	< 2.5	< 2.5	3.00
Total Cr (mg kg^{-1})	37.5a	38.9a	37.8a	150
Total Cu (mg kg^{-1})	40.0a	52.3b	55.9b	210
Total Ni (mg kg^{-1})	6.20a	7.89b	7.11b	112
Total Pb (mg kg^{-1})	<5.0	< 5.0	< 5.0	300
Total Zn (mg kg^{-1})	24.9a	39.9b	32.1ab	540
Percentage vegetal cover	68.0a	93.7b	92.5b	
Microbial biomass C (mg C kg^{-1})	300a	385b	441c	
Basal resiration (mg CO_2-C g^{-1} d^{-1})	41.7a	71.1ab	85.8b	
Dehydrogenase activity (µg INTF g^{-1} h^{-1})	7.53a	10.4b	13.9c	
Urease activity (µmol NH_4^+-N g^{-1} h^{-1})	0.90a	1.28a	1.80b	

For each parameter, data followed by the same letter are not significantly different according to the LSD test (P ≤0.05). [1] EC, electrical conductivity; [2] S (sewage sludge); [3] CM (compost); [4] Heavy metal limits for soil (European Directive 86/278/CEE).

Total organic C and total nutrient (N, P and K) concentrations were significantly higher in amended soils compared to control plots (Table 2).These results are even more valuable assuming that soils with a total organic C below 2% are in a pre-desertification stage, which is the case of the original soil. Given the low nutrient content of semiarid areas, improving soil fertility may be crucial to enhance plant colonization at the first stages of the restoration process. Amendments did not only improve N, P and K contents but also those of readily available N forms (N-NO_3^- and NH_4^+), which can be directly used by plants and microbes. In addition, it is important to stress that these effects are noticeable just with only one amendment application. Madejón et al. (11) observed better plant colonization and growth under field conditions in bare acid semiarid soils following incorporation of organic amendments. These authors suggested that amended soils performed better due to soil alkalinization and improved nutrient content. Another interesting feature of organic treatments relevant to plant cover is that they can reduce the bulk density and increase the water holding capacity of the soil (by 1.2, sludge, and 1.4 fold, compost).

Given that low rainfall is the primary constraint on biological activity in arid and semiarid environments (12), improving water retention in the soil may ameliorate conditions for plant survival and even for microbial development. Colonization of soils through wild plants was better in amended plots than in controls as reflected by higher vegetal cover densities (Table 2).

As it has been observed in other degraded areas, amended soils resulted in higher microbial biomass and enhanced microbial activity (13) (Table 2). Sludge increased microbial biomass C in the soil by 30% and compost by almost 50%. As a consequence larger CO_2 production was measured in amended soils, being these values significantly different to those observed in controls. Amended plots also showed higher potential dehydrogenase and urease activities. The addition of sludge resulted in a 1.5 fold increase in these activities, whereas plots treated with compost showed a 2 fold increase.

It has been suggested that the stimulatory effect of amendments on biochemical properties is mainly related to larger availability of labile C sources (13). In addition, García et al. (6) pointed that a substantial amount of microbial biomass is already present in the amendments, although the fraction originally active remains unclear. It is interesting to indicate that an organic amendment not only increase the microbial biomass but also could affect to microbial community structure and plant diversity, and these effects should take into account in longer times. Bastida et al. (13) showed a change in the microbial community structure of these amended soils compared to control ones by analysing phospholipid fatty acids (PLFAs). Bastida et al., (9) observed differences in the microbial community of a contaminated degraded soil following the application of various amendments. Although the authors did not reveal if such changes were due to a shift in the original microbial community or the introduction of new individuals through the amendments or a combination of both, other studies suggest that the incorporation of amendments does not leave a direct microbial imprint in the soil. Regardless from a direct or indirect influence of amendments on the soil microbial community structure, organic treatments can improve soil fertility and enhance microbial activity triggering nutrient cycling and accelerating vegetation growth in semiarid soils. Once plants start colonising the soil, they release labile C compounds through the root system, which serve as substrates for soil microorganisms. Although competition between microorganisms and plants for nitrate may also exist, the global result is that both parts benefit and recovery of such soils can be achieved in a low-cost and sustainable fashion.

amoA *gene copy numbers and potential nitrification rates*

Since organic matter decline is of particular concern in Mediterranean areas, research efforts have been mainly focused on C and N dynamics. Our results showed higher number of *amoA* copies per gram of soil and hence of potential ammonia oxidizers in amended soils compared to the controls (Figure 1a). Similar results were observed when *amoA* was expressed on the basis of total DNA in soil (Figure 1b). Therefore the incorporation of amendments resulted in a quantitative and significant change of ammonia oxidisers with regard to the original soil microbial community. From our results it is evident that higher availability of organic compounds and ammonium in amended soils independently from their origin (plant or amendments) could stimulate ammonia oxidisers. Hence, positive correlations coefficients were observed between ammonia content and potential nitrification and *amoA* copy numbers. It is also possible that ammonia oxidising bacteria (AOB) had been incorporated with the amendments contributing to larger *amoA* yields in treated soils. Kowalchuk et al., (14) showed that different groups of AOB are present in composts and postulated that these materials are not biologically inert to nitrification and consequently the fate of nitrogen during composting and compost storage may be affected by the presence of these organisms. However, Innerebner et al. (15) observed that the AOB community of various composts did not reflect that found in compost-treated soils. These authors suggested that composts affected indirectly the original soil microbial community through changes in soil organic matter decomposition and/or different allocation of plant material to the soil. Such changes are not only detectable in the short-term, but can persist in time (16).

Concomitantly with an increase in the number of ammonia oxidisers larger potential nitrification rates were observed in amended soils than in controls. The differences between amended plots and controls were significant (Figure 1). This is not surprising as it may be expected that higher organic N and ammonia stimulate the growth of ammonia oxidisers.

This pattern indicates that lower availability of suitable substrates results in more efficient nitrification rates. In semiarid regions, microorganisms are adapted to respond to resource pulses coinciding with infrequent rain events that provide access to energy and nutrients (carbon and nitrogen) (17).

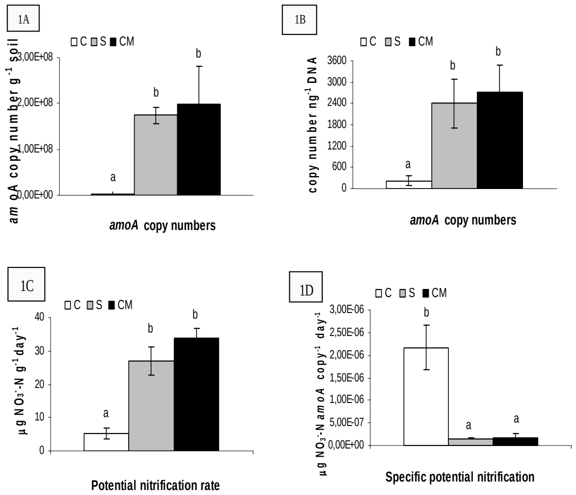

Figure 1. Mean values and standard deviations of A) *amoA* copy numbers (per gram of soil), B) *amoA* copy numbers (per ng of DNA), C) potential nitrification rate and D) specific potential nitrification rate: *amoA* copy numer ratio in control and amended plots. For each parameter, data followed by the same small letter are not significantly different according to the LSD test ($P \leq 0.05$).

CONCLUSIONS

The utilization of organic wastes as resources to restore degraded semiarid areas increases biological soil quality. In addition, it has key implications for predicting the response of ecosystem N dynamics. While the incorporation of organic amendments may enhance important microbial processes such as nitrification on a global basis, the specific activity of the microorganisms responsible for these reactions may be reduced. Incorporating amendments into the soil seems an effective measure to enhance plant growth in semiarid areas. Assuming its low cost and the elevated erosion risk of these areas, the benefits of this technique seem to be greater than its drawbacks. The use of stabilized or composted amendments with low-metal content will ensure the sustainability of this practice.

REFERENCES

(1) Ros M., Pascual J.A., García C., Hernández M.T., Insam H., 2006. Hydrolase activities, microbial biomass and bacterial community in a soil alter long-term amendment with different composts. *Soil Biology & Biochem*istry 38, 3443-3452.
(2) Pascual J.A., García C., Hernández T., Ayuso, M., 1997. Changes in the microbial activity of an arid soil amended with urban organic wastes. *Biology and Fertiity of. Soils* 24, 429-434.
(3) Burton C.H., Turner C., 2003. Manure Management. Treatment Strategies for Sustainable Agriculture. Silsoe Research Institute, Silsoe, U.K., 490 pp.
(4) FAO-ISRIC-ISSS, 1998. World reference base for soil resources. FAO, Rome, 145 pp.
(5) Vance E.D., Brookes P.C., Jenkinso, D.S., 1987. An extraction method for measuring soil microbial biomass-C. *Soil Biology & Biochem*istry 19, 703-707.
(6) García C., Hernández T., Albaladejo J., Castillo V., Roldán A., 1998. Revegetation in semiarid zones: influence of terracing and organic refuse on microbial activity. *Soil Science Society American Journal.* 62, 670-676.
(7) Kandeler E., GerbesH., 1988. Short-term assay of soil urease activity using colorimetric determination of ammonium. *Biology and Fertility of Soils* 6, 68-72
(8) Beck T.H., 1976. Verlauf und Steuerung der Nitrifikation im Bodenmodellversuch, *Landwirtsch Forsch Sonderh*. 33, 85–94.
(9) Bastida F. et al. 2008, Application of fresh and composted organic wastes modifies structure, size and activity of soil microbial community under semiarid climate, *Applied Soil Ecology*, doi: 10.1016/j.apsoil.2008.05.007.
(10) Sharm, S., Rad, V., Hai B., Kloos K., Mrkonjic M., Schloter M., 2007. Quantification of functional genes in soil by PCR. *Journal of Microbiology Methods* 68, 445-452.
(11) Madejón E., Pérez-de-Mora A., Felip, E., Burgos P, Cabrera, F., 2006. Soil amendments reduce trace element solubility in a contaminated soil and allow regrowth of natural vegetation. *Environmental Pollution* 139, 40-52.
(12) Schaeffer S.M., Evans A.R.D., 2005. Pulse additions of soil carbon and nitrogen affect soil nitrogen dynamics in an arid Colorado Plateau shrubland. *Oecologia* 145, 425–433.
(13) Bastida F., Moreno J.L., García C., Hernández T., 2007. Addition of urban waste to semiarid degraded soil: long-term effect. *Pedosphere* 17, 557-567
(14) Kowalchuk G.A., Naoumenko Z.S., Derikx P.J.L., Felske A., Stephen J.R., Arkhipchenko I.A., 1999. Molecular analysis of ammonia-oxidizing bacteria of the □ subdivision of the class *proteobacteria* in compost and composted materials. *Applied Environmental Microbiology,* 65, 396–403.
(15) Innerebner G., Knapp B., Vasara T., Romantschuk M., Insam H., 2006. Traceability of ammonia-oxiding bacteria in compost-treated soils. *Soil Biology & Biochemistry*. 38, 1092-1100.
(16) Okano Y., Hristova K.R., Leutenegger C.M., Jackson L.E., Denison R.F., Gebreyesus B., Lebauer D., Scow K.M., 2004. Application of real-time PCR to study effects of ammonium on population size of ammonia-oxidizing bacteria in soil. *Applied Environmental Microbiology* 70, 1008-1016
(17) Gebauer R.L.E., Ehleringer J.R., 2000. Water and nitrogen uptake patterns following moisture pulses in a cold desert community. *Ecology* 81, 1415–1424.