



SOIL, BIOWASTE AND COMPOST: POTENTIAL CONTRIBUTION TO TACKLE CLIMATE CHANGE

Enzo Favoino¹, Julio Berbel²

¹favoinomail@tin.it; Working Group on Composting And Integrated Waste Management

Scuola Agraria del Parco di Monza. Viale Cavriga, 3. I-20052 Monza ITALY.

Tel. +39-335-355446

²es1bevej@uco.es; ETSI Ingenieros Agronomos y Montes. Univ. Cordoba. Apdo 3048. 14080

CORDOBA tel. +34-95-7218457

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Introduction

In EU environmental policy, there is an outstanding opportunity to promote sustainable waste and land management. The Emission Trading Scheme (Dir 2003/87) implementing Kyoto protocols in Europe has just come into force; we're currently in the first implementation period and norms are still provisional and are set to be reviewed until 2007, which provides for opportunities to optimise them.

The Kyoto Protocol is the international frame agreement to combat global warming through reduction of greenhouse gases (GHGs) and allows to consider CO₂ fixation on soils in the national budget of CO₂ (and other greenhouse gases).

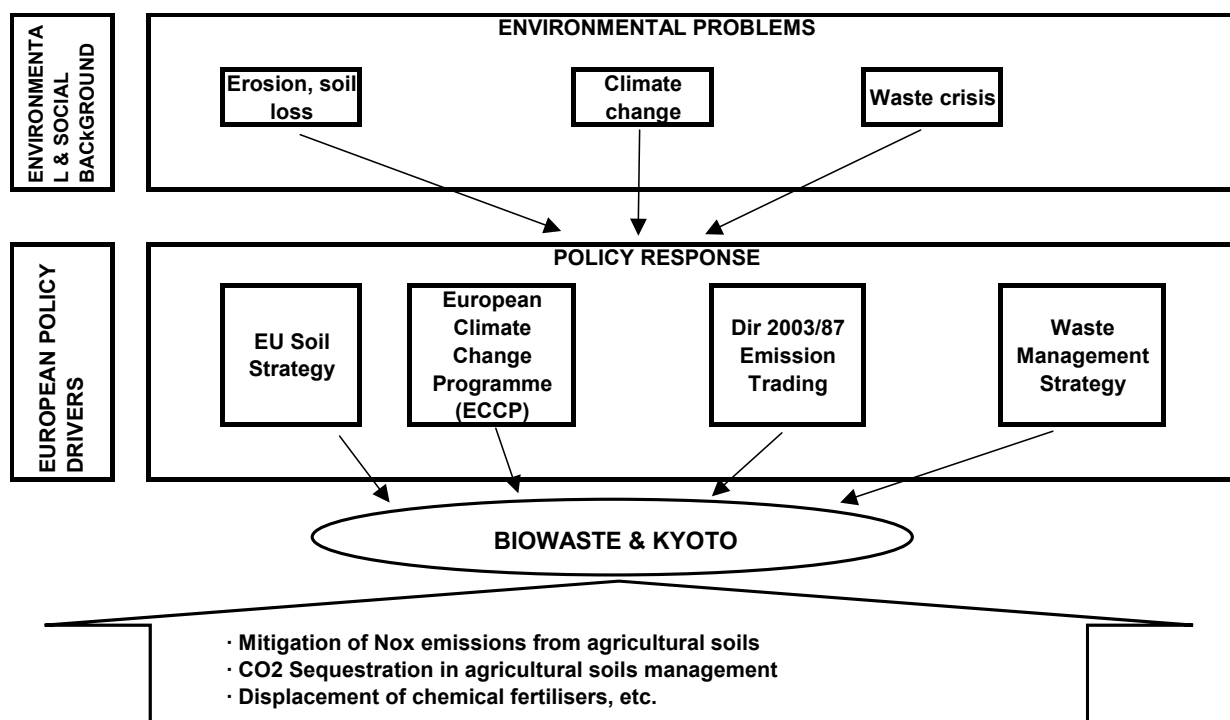
The purpose of this paper is to contribute to environmental sustainability through a science-based analysis of potential contributions of the recovery of organic matter in farmlands, and of composting as an optimised option for the management of biowaste.

Background: the political and regulatory context

As a consequence of growth and development related environmental problems should always be taken into account and properly addressed considering environmental sustainability of actions. Sustainable development should be the aim of environmental and economic policy at any level of governance (national, local, etc.).

The following picture sums up environmental problems related to the current models for economic growth, related possibilities in policy-making from the European Union as far as biowaste and soil management are concerned. It is clear from the picture the importance to seek integration of policies related to waste, soil and climate change.

Opportunities to promote the role of composting: the Emission Trading



Schemes (Dir 2003/87)

A Decision of the European Parliament regulates the 'Emission Trading Scheme' (ETS). This has come into force on March 10, 2004 making all other requirements of the 1997 Kyoto Protocol legally binding

Joint Implementation ("JI") and Clean Development Mechanism ("CDMs"), together with international emissions trading, are the innovative instruments provided for in the context of

fulfillment of the Kyoto Protocol. The rationale is that, from the global environmental point of view, the place where the emission reduction takes place is of minor importance, relative to the magnitude of reduction, provided that real emission reductions are achieved.

JI and the CDM are “project-based”, and allow the generation of credits when projects achieve emission reductions that are additional to what would have occurred in the absence of the action (the “baseline” scenario). Such projects/actions need to give real, measurable and long term benefits related to the mitigation of climate change, while contributing to the achievement of sustainable development in Countries where they take place.

Emission trading have been established in order to allow market-oriented efficiency of measures; it may therefore be said to *seek best achievement of the overall target at the least cost*.

European Emission Trading Scheme will start officially Jan, 1st 2005. The price will be the same across the E.U.; expected price range falls between 13 to 32 €/ton- CO₂. A reference price of 20 €/ton-CO₂ may be considered as an expected average price for short-term analysis. Remarkably, the Dutch plan for reduction of greenhouse gases estimates that for the Netherlands the domestic reduction target can only be fulfilled at an average reduction cost of more than EUR 100 per tonne CO₂-equivalent. The Netherlands will realise this objective, therefore, partly by purchasing CO₂ emission allowances abroad, and this sets wide opportunities for Emission Trading and for an overall cost-effectiveness of intended measures for global mitigation.

Unfortunately, the Community Trading Scheme looks biased since *it only considers technological solutions and long term emission abatement improvements from the energy and industrial sector*. The EU Commission have decided that JI and CDM credits that may be generated through land use, land use change and forestry (usually referred to as “LULUCF”) activities are not eligible – for the time being – for credits.

Carbon sinks – e.g. planting forests to soak up CO₂ - have been a contentious issue at UN level, in that many have argued they do not bring technology transfer, they are inherently temporary and reversible, and uncertainty remains about the effects of emission removal by carbon sinks. In addition, international negotiations on what types of forestry projects might be acceptable to governments have not yet been completed.

The arguments raised by the Commission have been the following [COM(2003) 403]

These activities can only temporarily store the carbon, which will at some time be released into the atmosphere.

(therefore) They are not covered by the Community emission allowance trading scheme, which aims at achieving permanent reductions from emission sources.

Recognising credits from agro-biological activities would not be consistent with the approach taken by the Council and the European Parliament on emissions trading.

Furthermore, there are still many uncertainties as to how to account for and monitor emission removals by sinks under the Kyoto Protocol.

To our opinion, the arguments adopted by the Commission to exclude afforestation and land use (and related changes) look contradictory. Point (3) of the Directive says *‘this will increase the diversity of low cost compliance options within the Community scheme leading to a reduction of overall costs of compliance with the Kyoto Protocol’*

But page 10 of COM(2003) 403 reads

(...) afforestation and reforestation activities do not bring technological transfer or development. Because sinks projects are expected to be cheaper than projects involving the transfer of technologies, allowing credits from such projects to be converted would be at the expense of promoting technological transfer to other industrialised and developing countries

The argument to exclude these activities is therefore the need to promote the technological transfer of JI's and CDM's, *even if this implies higher costs* – not to speak about the *wider environmental benefits of promoting better land use thereby preventing floods, landslides, improving the landscape, and enhancing the “buffer” role of soils.*

The foregoing looks particularly inconsistent. Political and economic consequences are fairly evident: from an economic standpoint, companies and related production sectors that may control and perform the intended “technological transfer” will be favoured over those managing forestry, land use and other ‘cheaper’ activities.

This paper is intended to argue for a thorough revision of concepts that exclude – for the time being - LULUCF from the Emission Trading Scheme, in particular as far as management of biowaste through composting and compost application are concerned.

The review of the Community Emissions Trading Scheme will take place in 2006; an implementation of mechanisms more in line with a science-based assessment of the potential contribution of farmlands and of biowaste management through composting is *an opportunity to influence European policy on this issue, making solutions more effective, viable and fair.*

The potential contribution of compost and soils to tackle climate change

The potential contribution of the agricultural sector to tackling climate change issues, widely neglected in the past, is now being acknowledged both under a scientific and a strategic (i.e. in policy-making) standpoint.

A starting point might be the following figures (taken from final reports of the WG Agriculture, European Climate Change Programme, 2001): in 1990, methane emissions from agriculture were 41% of all CH₄ emissions, while nitrous oxide emissions reached 51% of N₂O emissions. Together with carbon dioxide emissions agricultural greenhouse gas emissions were about 11% of all greenhouse gas emissions of the EU in 1990.

On the other hand, the absorption potential of agricultural soils could contribute significantly to fulfilling the reduction objective of the EU, which is -8% between 2008 and 2012 from a 1990 base. Considering the above, the 6th Conference Of the Parties (COP 6 bis) held in Bonn in July 2001 considered agricultural soils suitable as sinks for the storage of carbon.

Therefore, it is becoming more and more important a proper consideration, in policy-making, of potential mitigation measures in the agricultural sector; just to give a tentative list of main measures, the following have been singled out by the WG agriculture which has been constituted under the scope of the European Climate Change Programme:

- Mitigation potential of Nitrous Oxide emissions from agricultural soils
- Sequestration potential of agricultural soils
- Mitigation potential of Carbon Dioxide by providing renewable raw materials for the energy/industrial sector
- Mitigation potential of Methane emissions from enteric fermentation and
- Mitigation potential of Methane and Nitrous Oxide emissions from manure management

Among the measures listed above, *at least the first 2 might be properly tackled through a strategy aiming at proper reuse of composted organic waste.* Actually, in addition to the

measures listed above, many other possible side-effects of compost application may be considered, and have some relevance as to fighting climate change; we consider it important to mention at least

- displacement of chemical fertilisers (which implies avoidance of Greenhouse Gases and energy uptake related to their production)
- reduction of use of pesticides (which might imply avoiding emissions for their production),
- improved tilth and workability (which might lead to less consumption of fuels) etc.

We intend herewith to propose some numbers and (above all) strategic views for a *preliminary assessment of the contribution of composting to tackle climate change issues, which, albeit somewhat difficult and affected by various uncertainties, cannot be neglected any more once we come to strategic environmental policy-making.*

When considering organic matter only under the energetic standpoint, policy drivers run the risk to fail to consider the importance of Organic Matter (OM) in the soil both for the management of Greenhouse Gases (e.g. for the build-up of Soil Organic Carbon, SOC) and for the optimisation of cropping techniques and yields. *That is actually what happened with the Directive on Renewable Sources of Energy, which runs the risk to constitute an economic driver only for energetic exploitation of organic waste, with no consideration of its role in carbon sequestration and in enhancement of soil and land fertility.*⁶

In particular, under the standpoint of Greenhouse Gases (GHG's), assessments led in the past have neglected the important and positive effects of composting and compost application on:

- soil organic carbon and related sinks,
- its effects on improved uptake of nutrients,
- avoided energy uptake for the production of equivalent chemical fertilisers
- avoided release of nitrous oxide from chemical fertilisers when allowing for the nutrient release from organic amendments

All the points listed above need to be addressed, properly considered and hopefully quantified, at least through a tentative evaluation of the magnitude of their potential contribution.

In order to gain evidence on these aspects and to drive policy-making, for instance, in recent times DG ENV, has contracted a study on different options to manage biodegradable waste, whereby many of the aforementioned topics have been investigated.

Most of the following figures (unless otherwise specified) are largely taken and adapted from the Interim Report of that study, whose reference is:

⁶ These points are highly stressed, for instance, by the Final Report of the WG "Organic Matter" in the context of the EC Consultation on the Soil Strategy, which reads:

"Concerning the use of renewable energy sources, it should be recalled that any combustion of organic matter (biomass) necessarily impairs possibilities of incorporation of the residues into the stable pool of organic matter in soils. The EU Soil Thematic Strategy should therefore tend to mitigate the potential negative effects of such drawbacks, in particular when using biomass that was not harvested for energy purpose".

And

"The implementation of the Kyoto Protocol for forestry and land use represents also a new incentive tool in order to fulfil the sustainable management of Soil Organic Matter (...) and the surface area involved will be millions of ha".

ECOTEC Research & Consulting, ZREU, LDK, HDRA Consultants and Scuola Agraria del Parco di Monza: *“Economic analysis of options for managing biodegradable municipal waste” Interim Report*. The report may be downloaded at http://europa.eu.int/comm/environment/waste/compost/economicanalysis_finalreport.pdf

Reduced use of chemical fertilisers and related effects

Unlike mineral fertilisers, the use of organic fertilisers does not provide a specific amount of N, P or K that will be immediately available to the growing plant. Compared to mineral fertilisers, they provide low levels of N, P and K. However, their addition can provide essential trace minerals to the soil (calcium, sulphur, iron, boron, molybdenum and zinc) that are not supplied when mineral fertilisers are added.

Furthermore, the application of organic fertilisers can enhance nutrient uptake by reducing leaching of minerals. Losses of nutrients by leaching can be reduced by increasing the soil organic matter content. Some nutrients in the water soluble form required by plants are readily leached from mineral soil particles whereas they are effectively held on the surface of humified organic matter.

Displacement of alternative nutrient sources

When organic fertilisers get applied to the soil, they may displace nutrients which are otherwise applied through synthetic fertilisers.

We assume in the analysis that nutrients are displaced on a one-for-one basis from the perspective of plant uptake. Taking the view from the perspective of the plant is important since the rate at which nutrients are leached from humus is lower than the rate at which they might be leached from synthetic fertiliser. As such, *more of the nutrient in synthetic form would be required to be applied to have the equivalent mineral fertilisation effect*. The assumption of ‘one-for-one’ displacement is an unrealistic one to the extent that one is implying a perfect optimisation of the replacement process. On the other hand, the situation is more likely to approach the ideal one once farmers are well informed about the nutrient content of the matter being applied (which is anyway happening more and more frequently, above all in those Countries with a longer tradition in composting and compost application).

We have assumed that 10 tonnes of dry matter is applied through organic amendment per hectare. This is equivalent to approximately 16.7 tonnes of composted manure or other composted materials (CM, dry matter content 60%) or 25-33 tonnes of “traditional” manure (TM, 30-40% dry matter).

Specifically focusing on CM, we assume further that this material has the following composition in terms of nutrients:

Nitrogen:	1.5% dry matter
Phosphorous (as P ₂ O ₅):	1.0% dry matter
Potassium (as K ₂ O):	1.2% dry matter

In order to run a test assessment we assume a mineralisation rate of the nutrients in CM to be 30% for all nutrients; such a figure, which is fairly high, might be deemed as proper for weather and cropping conditions typical of Southern Europe (warm weather, intensive cropping, high tendency to mineralise any added organic fertiliser). This determines the time profile of the displacement effect.

In order to allow for the part of chemical fertilisers which is leached, we also considered a “loss rate”, which actually increases the displacing potential of organic fertilisers. For

synthetic fertilisers, we assume a loss rate of 23% for nitrogenous fertilisers.⁷ This means that more nutrient has to be applied in a given year in the synthetic form than would be available in mineralised form from the composted materials. For an application of 10 tonnes dry matter per annum in one year, the N displacement would follow the evolution set out in Table 1 below. An equivalent projection of K displacement is given in Table 2; in this case we did not consider any loss factor, as its leaching or runoff might be considered as trivial.

Table 1: evolution in N displacement associated with 10 tonnes dry matter of compost applied to farmland

Year	Displacement potential N (kg)	Cumulative Displacement (kg)
1	58.4	58.4
2	40.9	99.4
3	28.6	128.0
4	20.0	148.0
5	14.0	162.1
6	9.8	171.9
7	6.9	178.8
8	4.8	183.6
9	3.4	186.9
10	2.4	189.3

Table 2: evolution in K₂O displacement associated with 10 tonnes dry matter of compost applied to farmland

Year	Displacement potential K₂O (kg)	Cumulative Displacement (kg)
1	36.0	36.0
2	25.2	61.2
3	17.6	78.8
4	12.3	91.2
5	8.6	99.8
6	6.1	105.9
7	4.2	110.1
8	3.0	113.1
9	2.1	115.2
10	1.5	116.6

⁷ This is the loss rate from Hydro Agri Europe (1995) *Important Questions on Fertilizer and the Environment*, Brussels: Hydro Agri Europe.

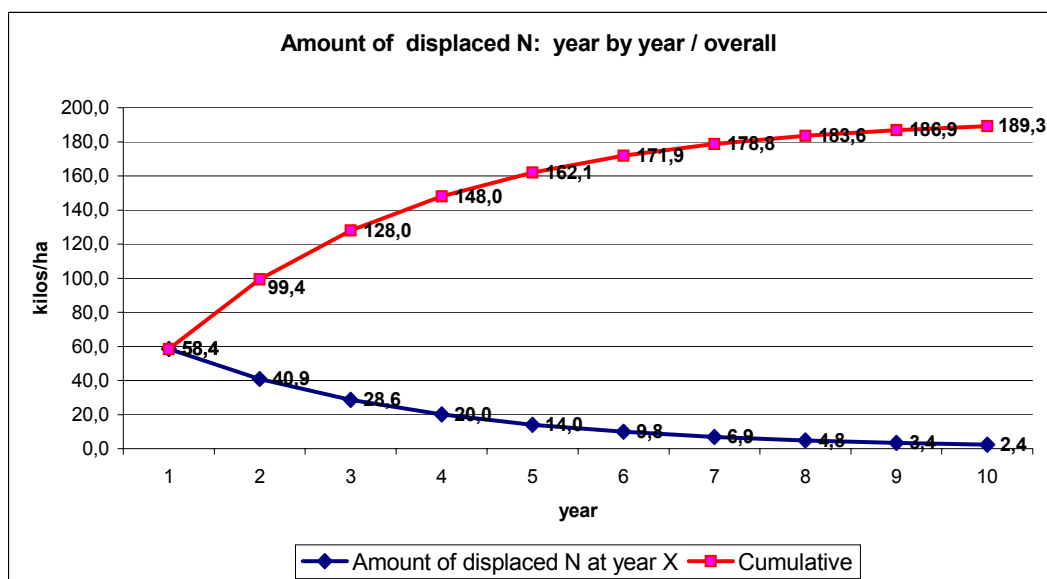


Figure 1: evolution in N displacement associated with 10 tonnes dry matter of compost applied to farmland

Avoided emissions from production of fertilisers

The use of manure and composted manure as a replacement for fertiliser *will thus displace the pollution and other externalities associated with fertiliser production, including the energy uptake*, that is important as to climate change issue. From this standpoint, many further calculations may be developed.

There is substantial evidence that, unlike fertiliser, the application of organic amendments also improves aspects such as soil structure, and that a higher proportion of the nutrients are available for uptake by plants. There is very little quantitative data in this area and therefore it is likely that analyses of this type will underestimate the benefits from application of organic fertilisers.

As to the potential savings for energy and greenhouse gases implied by the displacement of chemical fertilisers, we'd just like to provide some input data and a preliminary assessment. Fertilisers vary a great deal in terms of nutrient content and therefore the externalities will vary also. We considered data for the production of NPK fertiliser because this is one of most widespread in terms of use, and the most readily available from a data perspective. Again because of data availability, we calculated the externalities associated with the production of one tonne of 15:15:15 NPK fertiliser (i.e. 150kg N, 150kg K₂O and 150kg P₂O₅).

We found data based on Best Available Technologies from EMFA (European Fertilisers Manufacturing Association). Most of the data available refers to production via the mixed acid route. There are three further distinctions within this route (granulation with a pipe reactor system, drum granulation with ammoniation and digestion). The data concerning emissions have been taken from those for the 'digestion' process because it is the only process for which this study has obtained data associated with all the required raw materials. The EMFA booklets suggest that these three processes cover the majority of NPK fertiliser production in Europe. The EMFA booklets provide gaseous emissions and energy consumption data associated with sulphuric acid, nitric acid, phosphoric acid and ammonia production, the base acids used in mixed acid production of NPK (15:15:15).

The data also quotes the raw material requirement for the mixed acid route, in terms of sulphuric acid, nitric acid, phosphoric acid, ammonia and phosphate rock. Having derived the emissions and energy requirement associated with the production of each of these materials (e.g. extraction in terms of phosphate rock), these were factored according to the relative proportions used in the NPK (15:15:15) fertiliser. It was then assumed that for each of the nutrient components, one-third of the processing requirement was attributable to the manufacture of 150 kg N, one-third to the manufacture of 150kg K₂O portion and one third to that of 150kg P₂O₅. Hence, through this attribution process, the levels from the mixed acid route itself are apportioned to the different nutrients (for the purpose of displacement calculations).

Unfortunately, we have not been able to obtain quality data for extractive processes. We know anyway that mining phosphate rock is an energy intensive activity and approximately 3.3 tonnes of phosphate rock are required to produce one tonne of phosphorous pentoxide (P₂O₅) (100%)⁸. Energy use for producing phosphate rock has been estimated at 73.5 kWh/tonne⁹. Additional energy consumption for phosphate fertiliser may be attributed on this basis. Because we have no information concerning emissions in potash production, *the emissions data for K₂O are likely to grossly understate the environmental benefits of displacement effects.*

It is important to note that these externalities are associated with Best Available Technologies for both new and existing plants. Therefore the costs in terms of gaseous emissions and energy requirements are likely to be underestimated as not all plants will be using Best Available Technologies. Technological improvements in the future however are likely to mean that these levels will become more similar to emission levels observed in practice.

On the basis of such input numbers, the emissions and energy data have been calculated and are summarised in Table 3. Such unit numbers for emission and energy uptake (which should be turned into CO₂-eq taking also into account the typical energy mix and its average CO₂-eq load in each Country) might be matched with the displacing power of organic matter in terms of lower application of chemical fertilisers, as calculated, for instance, in the previous section.

⁸ Bocoum, B. And Labys, W.C. (1993) Modelling the economic impacts of further mineral processing: the case of Zambia and Morocco. *Resources Policy*, **19**, (4), pp.247-63.

⁹ United Nations Environment Programme And United Nations Industrial Development Organisation (1998). *Mineral Fertilizer Production and the Environment – Part 1: The Fertilizer Industry’s Manufacturing Processes and Environmental Issues*. In collaboration with the International Fertilizer Industry Association. Technical Report Number 26 – Part 1. UNEP and UNIDO, Paris and Vienna. 1998.

Table 3: emissions data for fertiliser manufacture

Emission (tonnes)/kg nutrient And unit E uptake	N		P ₂ O ₅		K ₂ O	
	Low	High	Low	High	Low	High
CO ₂	0.00256567	0.002565667	0	0	0	0
NO _x (as NO ₂)	4.087E-06	2.14273E-05	6.67E-07	6.67E-07	6.67E-07	6.67E-07
N ₂ O	0.00000928	3.51867E-05	0	0	0	0
NH ₃ (as N)	4.4444E-07	4.4444E-07	4.44E-07	4.44E-07	4.44E-07	4.44E-07
Fluoride (as F)	4.4444E-08	4.4444E-08	7.11E-08	2.04E-07	4.44E-08	4.44E-08
Dust/particulates	4.4444E-07	4.4444E-07	7.11E-07	1.24E-06	4.44E-07	4.44E-07
SO ₂	4.3727E-07	1.4406E-06	4.3E-07	1.43E-06	4.3E-07	1.43E-06
SO ₃	2.15E-08	0.000000086	2.15E-08	8.6E-08	2.15E-08	8.6E-08
CO	1.29E-08	1.29E-08	0	0	0	0
Energy Use (drying) (MJ)	0.00057759	0.000577593	0.000578	0.000578	0.000578	0.000578
Elec Use (kWh)	8.3704E-05	8.37037E-05	0.000482	0.000482	8.37E-05	8.37E-05

According to our preliminary calculation, we may for instance briefly highlight that *a single compost application of 10 tonnes d.m./ha, which has a potential displacing power of some 190 kg N, might therefore allow an overall saving of electricity of 160 to 1590 kWh, not to take into account displacement of P and K, nor the CO₂-eq. related to other emissions (e.g. N₂O, see the following section).*

Reduction of N₂O emissions from nitrogenous fertilisers

Fertilisation of crops significantly contributes to the emission of greenhouse gases, especially through the emission of nitrous oxide (N₂O) from soils. This is a result of incomplete transformation of ammonia to nitrate (nitrification) and/or the incomplete turnover of nitrate to nitrogen gas (denitrification). Measures aimed at reducing nitrate content in waters may result in declining nitrous oxide emissions.

It is generally accepted that the application of nitrogenous fertilisers increases fluxes of N₂O. Therefore, the reduced application of N fertilisers once we allow for the N-release by organic materials might influence the release of N₂O. Different fertilisers appear to be more or less susceptible to the loss of nitrogen as nitrous oxide. Ammonia products appear most susceptible, with anhydrous ammonia and aqua ammonia losing between 1 and 5% of nitrogen as nitrous oxide. Other products such as sodium nitrate appear to loose much less nitrogen in this way.¹⁰ The emissions depend upon temperature, soil moisture, fertiliser type, fertiliser amount, the timing and mode of application, and the type of soil and crop cultivated.¹¹

Reduction options for N₂O generally rely on:

- *the reduction of nitrogen inputs to soils through enhanced fertiliser use efficiency and*
- *a better accounting for N in manures and other humified products (including compost) applied to soil, so that N of chemical fertilisers can be displaced by slow-release N, whose kinetics make it much less prone to producing N₂O*

¹⁰ See D. Lashof and D. Tirpak (1990) (eds.) *Policy Options for Stabilising Global Climate*, London: Hemisphere; A. Ehrlich (1990) *Agricultural Contributions to Global Warming*, in J. Leggett (1990) *Global Warming: The Greenpeace Report*, Oxford: Oxford University Press.

¹¹ See, for example, I. P. McTaggart, B. C. Ball, and C. A. Watson (1998) *Influence on Land Use in Scotland on Soil N₂O Emissions and Atmospheric CH₄ Uptake*, British Society of Soil Science Annual Meeting, Queen's University, Belfast, September 1998.

Once it comes to the assessment, one could assume a unit loss as N₂O of 0.05% to 0,5% of nitrogen applied as chemical fertiliser. These assumptions might e.g. be matched with the N replacement figures for the compost as outlined in earlier sections and table 1. This approach implies considering the unit loss as N₂O from N released by compost as trivial; this might be held as (substantially) agreeable, insofar as we assume the release of N has a pattern much more consistent with the uptake by the root, and this might therefore subtract much of the released N to kinetics leading to N₂O, whereas a massive release by chemical N fertilisers likely leads to a higher availability of N for such kinetics.

Potential sinks for carbon in the soil through the use of organic fertilisers

This is probably the field of investigation where the most impressive and promising results are to be found.

In general terms, organic matter is an emerging issue for its connection with soil fertility, stability and structure, water storage capacity, etc. Organic matter's decline in many European soils is threatening their capacity to remain fertile and to keep performing their most essential environmental functions. Organic matter is emerging as one key issue in EU policy terms. Looking at carbon stored in farm soils, it is very easy, indeed, to make a link with the organic fertility.

The Commission has indicated its intention in the sixth Environmental Action Programme (EAP) to develop a thematic strategy on soil protection. The draft Council and Parliament decision on the 6EAP sets the objective of the promotion of a sustainable use of soil, with particular reference to preventing erosion, deterioration, contamination and desertification. The EC communications already noted that soil loss and declining fertility are eroding the viability of agricultural land. Accordingly, *the Communication from the Commission on Soil Protection, issued lately, puts particular emphasis on organic matter and sets the goal to promote the use of high quality composted products for such purposes as fighting desertification and erosion, avoiding floods, promoting the build-up of carbon in the soil..*

Sequestration potential of agricultural soils

The IPCC has clearly identified carbon sequestration in soils as one of carbon mitigation measures for agriculture¹².

The loss of organic carbon in soils has been one of the major environmental consequences of industrial agriculture. Arable top soils in Europe commonly contain 1-3 % of organic carbon. ECAF¹³ suggest that over about 20 years tillage, most agricultural soils will have lost about 50% of their organic carbon. The annual net release of carbon from global agricultural

¹² IPCC (1996) *Climate change 1995. Impacts, adaptations and mitigation of climate change: Scientific and technical analysis*. Intergovernmental Panel on Climate Change, Cambridge University Press, New York.

¹³ ECAF (not dated) *Conservation Agriculture in Europe: Environmental, Economic and EU Policy Perspectives*. European Conservation Agriculture Federation, Brussels.

activities has been estimated at about 800 Mt/year, or about 14% of current fossil fuel burning¹⁴.

The most important result of the Bonn Conference for the agricultural sector is the possible unlimited use of agricultural land as sinks. A calculation made by DG ENV assumed that 20 % of the surface of agricultural land in the EU could be used as a sink. This would result in an absorption potential of 7,8 Mt C, which corresponds to 8,6% of the total EU reduction objective. The EC Communication on Soil Strategy also highlights this potential importance of sequestration; the Communication mentions, for instance, the fact that it has been calculated¹⁵ that an increase of 0.15% of organic carbon in arable soils in a Country like Italy would lock the same amount of carbon in soil that is currently released into the atmosphere in one year by the use of fossil fuels.

This should be compared to the impressive decline of organic matter over past decades, whose magnitude in many areas is very frequently of some points percent and which has led its percentage below 2% in many soils. According to the European Soil Bureau, nearly 75% of the total area analysed in Southern Europe have a low (3.4%) or very low (1.7%) soil organic matter content. The problem is however not restricted to the Mediterranean. Figures for England and Wales show that the percentage of soils with less than 3.6% organic matter rose from 35% to 42% in the period 1980-1995. In the Beauce region south of Paris, soil organic matter has decreased by half in 16 years. Once we look at such figures from the opposite standpoint, *they as a whole represent a huge opportunity to lock-up considerable amounts of carbon while restoring organic fertility.*

Many surveys have lately been focusing on measures regarding the application of composted organic fertilisers, which is noteworthy also for its cross-sectoral nature; as a matter of fact, composting can deeply affect in a positive way also the waste management sector, which under the scope of the EC Directive 99/31 on Landfilling is requested to achieve the tight requirements about the reduction of biodegradable waste to be landfilled; on the other hand, biodegradable waste can be turned by means of composting into a valuable resource to promote at the same time soil fertility and a build-up of carbon into the soil.

“Sequestration” and “build-up”: a matter of methodology

Proper application of organic fertilisers in agriculture, besides the adoption of proper cropping and tilling techniques, can have a positive effect on soil carbon levels.

The IPCC framework for estimating greenhouse gas fluxes is based on a 100-year time horizon. *Organic carbon stored in soil as a result of compost application should therefore only be considered to have been sequestered if it remains locked up in the soil for at least 100 years.*

As it has been correctly stressed by many recent surveys¹⁶, estimating a precise lifetime for soil organic matter derived from compost addition is very difficult, because of the large number of inter-converting pools of carbon involved, each with its own turnover rate, which is in turn determined by local factors such as soil type, temperature and moisture. Although a great deal of valuable information now exists on the turnover of soil organic carbon, the

¹⁴ Schlesinger, WH (1995) *An overview of the carbon cycle. In: Soils and Global Change.* Eds R Lal et al. CRC Lewis Publishers, Boca Raton, Florida, pp9-25

¹⁵ Speech by Prof. P. Sequi at the Compost Symposium, Vienna, 29-30 October 1998

¹⁶ see for instance: Smith, A, Brown, K, et al. AEA Technology (2001) *Waste management options and climate change*, Final Report to the EC, DG ENV, from which many of the references in this section have been taken.

question of assigning a typical average value for the persistence of carbon applied to soils in compost remains somewhat problematical.

Life times of various pools of soil organic carbon ranging from 20 to 2000 years have been proposed for bounding purposes by the US EPA. Isotope studies¹⁷ have shown that turnover times differ widely for different fractions of soil organic matter, ranging from less than a year for microbial biomass to between 5 and 1000 years for organic matter associated with silt and clay particles.

Applying first-order decay kinetics (which are widely used in this field), this global average suggests that only 2% of the carbon applied to soil today would remain in the soil organic matter in 100 years time.

Smith and colleagues¹⁸ have reported summary results from several long-term field experiments in which sewage sludge, animal manure and cereal straw had been incorporated annually into the top layer of soil. They derived linear correlations between the organic matter addition and the annual increase in soil organic carbon, which, if a steady state has been reached between carbon input and soil organic carbon, allows the amount of added carbon surviving in the soil for a given period to be calculated. Using the equations provided by Smith et al and assuming a carbon content for manure and sewage sludge of 20% results in estimates of 9 and 6 % as the proportion of added carbon persisting for over 100 years.

Notwithstanding all the findings listed above, which tend to make the potential contribution of compost (and in broader terms, of organic soil improvers) to sequestration particularly small and somehow negligible, we keep considering the approaches undertaken so far – though perfectly agreeable in their sound scientific background - as coming short of another fundamental assessment. But this is actually a basic problem of the IPCC methodology itself.

Our opinion is that *climate models are sufficiently sensitive to the dynamics of emissions as not to be indifferent to a situation in which every unit of GHG likely to be emitted in the next 100 years is emitted today, and one in which every unit of carbon is emitted after an average time frame of 50 or 99.99 years.* If the models are so insensitive, then they could not refute (in themselves) any argument that runs: "why bother doing anything today when we can do it all in 50-100 years' time?". This would be a poor outlet, though perfectly consistent with the current IPCC approach.

We think the focus ought to shift from whether something simply does or does not act as a 'net sequester of carbon', to how much carbon is emitted (and how much kept in the soil) over time under different practices and scenarios.

Organic fertilisation does not result in the permanent and irreversible locking up of all carbon in compost. What organic fertilisers can do is *reverse the decline in soil organic matter which has occurred in relatively recent decades through contributing to the stable organic fraction in soils (effectively locking-up carbon).* It is also important to realise that whilst the debate concerning 'sequestration' has emerged as a topical one in the wake of the debate on climate change, the role played by soil organic carbon is far more complex, and potentially far more important, than the single role played in terms of carbon sequestration.

¹⁷ Carter MR (1999), *Organic matter and sustainability*, in "Sustainable management of soil organic matter", ed. Rees RM et al, based on papers offered at a meeting in Edinburgh 1999. CABI publishing. ISBN 0 85199 465 2.

¹⁸ Smith, P, Powlson, DS, Glendining, MJ, Smith JU (1997) *Potential for carbon sequestration in European soils: preliminary estimates for five scenarios using long-term experiments.* *Global Change Biology*, **3**, 67-79.

The accumulation of organic matter is a process leading to a steady-state condition in the long run, with the steady-state level – at which mineralisation of organic matter tends to offset the yearly accumulation - depending on such factors as, above all, climatic and cropping conditions, and the yearly load. However, the overall sequestration can be considerable in the short and medium run, when the system is most distant from the steady-state condition, and *this means that soil sequestration can provide a great contribution to the achievement of targets in some years to some decades.*

The simplified modelling shown hereafter, based on dynamics among different pools of organic matter in the soil and the atmosphere, might for instance lead to find out that, depending on starting conditions and climate and cropping situations, the build-up of organic matter during first 50 years may allow a net accumulation of 1 to 3 %, corresponding to 0,58 to 1,74 % organic carbon (which – once compared with the figure given above¹⁹ - is the quantity that could offset 4 to 12 yearly overall emissions of carbon dioxide).

The assessment of potential accumulation may get even more impressive if we make a comparison to a baseline scenario with no application of organic fertilisers, nor any practice to increase or keep the quantity of organic matter in the soil – which has been the case in most farmlands throughout last decades, and might be a scenario driven by the consideration of biomass only as a substitute for fuel. Proper attention therefore ought to be paid to what seems to be a primary tool to tackle greenhouse gases.

A preliminary assessment of lock-up of carbon through a simplified model

Usually dynamics related to carbon lock-up in the soil are neglected in policy making referred to GHG and climate change, notwithstanding a good deal of scientific insight in to this issue has been developed. Actually, long-term trials show a good capability of soil to store organic carbon over long times; though the complexity of related dynamics makes it difficult a quantitative assessment of effects.

However, we think that when an issue is IMPORTANT though controversial, it shouldn't be neglected, It should be further investigated instead.

To stress the high potential contribution of carbon sequestration in soil we would just remind readers that a quick calculation shows that overall yearly CO₂ emissions from a whole nation as Italy (541.542 Gg CO₂ being emitted yearly, roughly 30 millions hectares total land area) can be equalled by a lock-up of just 0,14% organic carbon in soils. The figure is likely to hold dimensionally valid across Europe. This also means that loosing 0,14% SOC would mean a net transfer of a further yearly CO₂ emission pool from the soil into the atmosphere. If we consider that in wide areas losses of OM from the soil in the range of 1-1,5% have been reported during last decades, and that 1% OM means 0,58% SOC, we come to assess the extreme importance of such issues.

Therefore, to provide a first assessment of the potential contribution of sequestration of SOC to management of global climate issues, we have modelled the dynamics of its lock-up – on the one side - and mineralisation – on the other.

In our simplified modelling, three pools of organic carbon are available for microbial utilisation:

¹⁹ i.e. around 0,15% more carbon in soil to offset the yearly CO₂ – eq. yerly emission in Italy.

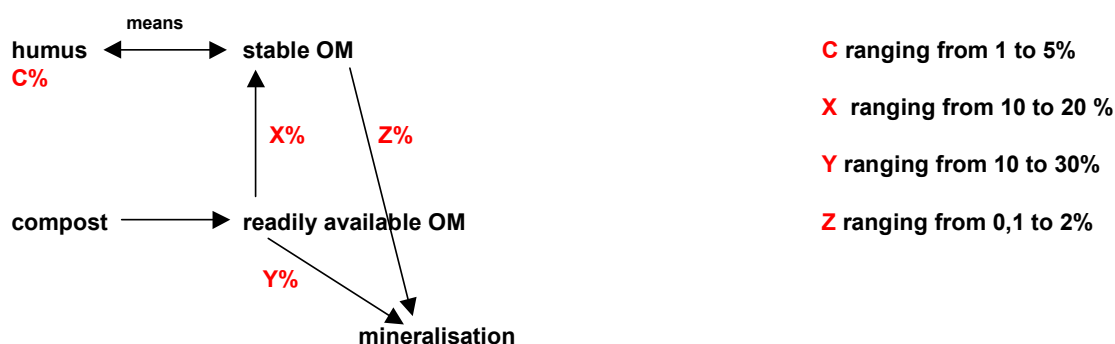
1. The “active” soil fraction (representing short-term sequestration of carbon – provides source of energy for microbes, and soil carbon and nitrogen supply necessary for amino acid synthesis);
2. The “slow” or “decomposable” soil fraction (of great importance to developing good soil structure – disturbed by cultivation and other disturbances – provides a source of carbon for biological digestion by microbes, so linking to the active pool. – can be viewed as mature compost); and
3. The “passive” soil organic fraction. (turnover time of order 100 to 1000 years - resistant to oxidation processes – acts as a ‘cement’ that binds particles).

Only the first two of these pools contain carbon in readily available forms for microbial utilisation. The last pool contains carbon in a highly stable form. Some microbes can utilise this pool so depletion does occur. It can also be replenished from active and slowly decomposable fractions. It is the fact that this passive pool of carbon can be maintained or increased that leads to the idea that the passive pool can act to ‘sequester’ carbon in the soil. Clearly, this long turnover time does appear to imply that, for all intents and purposes, this carbon is not simply released into the atmosphere; *it will be locked up inside the soil for a long lasting time, thus contributing to a build-up of carbon sink in it.*

We have sought to model the dynamics of soil organic carbon e.g. where it is applied in composted form. The pathways modelled are outlined in the figure below.

Figure 2: basic description of modelling of fate of carbon in compost / soil

Description of methabolic / agronomic pathways



The application of compost is assumed to lead to the readily available carbon being mineralised at y% whilst x% of the readily available organic carbon is converted to stable organic matter. Of this stable organic matter, some carbon (z%) is mineralised, but at a much lower rate than that at which the readily available matter is converted to stable organic matter. Consequently, application of organic matter to soil can act to increase soil organic carbon levels (though as we shall see, the degree to which this occurs varies according to the choice of the different parameters chosen, the rate of application of compost and the baseline level of organic matter in the soil).

The model can then be run through the application of values for X, Y, Z as found in literature for mineralisation of both stable and readily available OM, and for humification of readily available organic matter. For instance, referring to Z, one could consider the half-life times of humic carbon reported in literature, ranging between some decades and more than 1000 years. Solving the equation:

$$C * (1-Z)\expHL = 0,5C$$

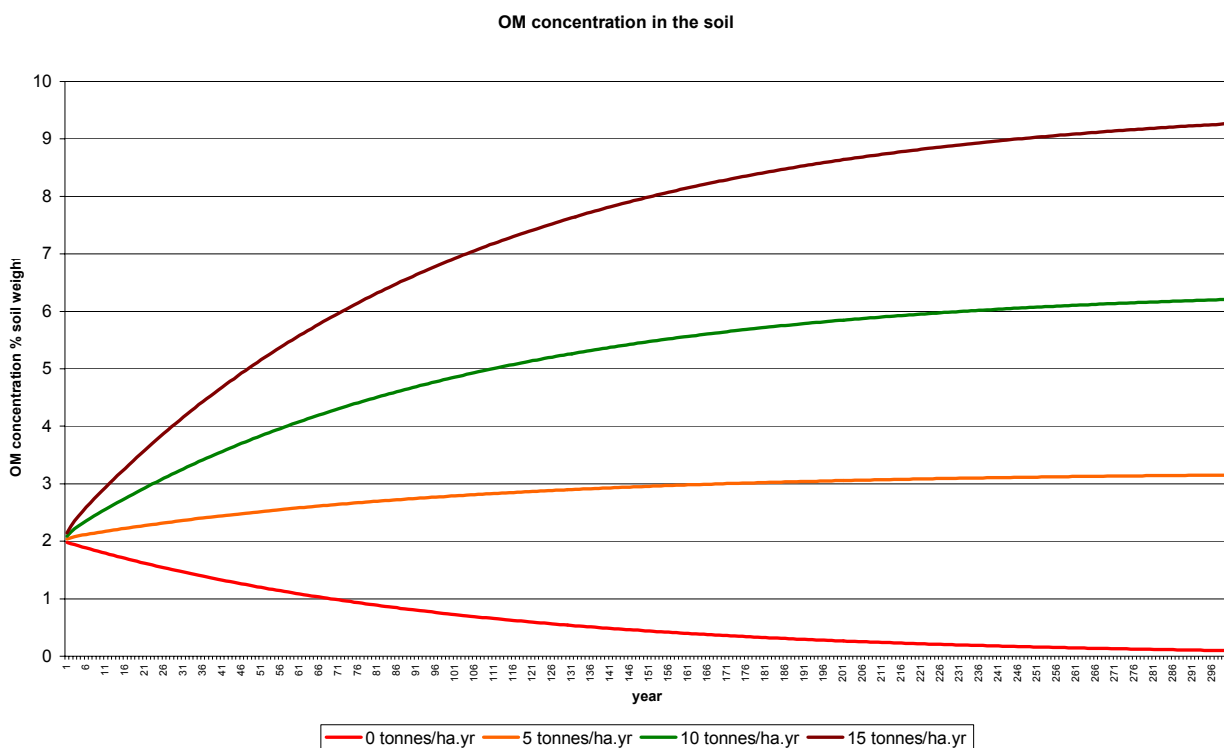
Where: C is the initial concentration of SOC
HL is the assumed half-life time

we can get different typical values of z.

Using the following figures:

X = 25%, Y = 20%, Z = 1% (HL time at some 70 yrs.), and with an initial organic matter concentration of 2%, deemed to be typical of Southern European areas one can understand the effects of different rates of compost application (0, 5, 10 and 15 tonnes/ha d.m. a year) over a 300 yrs. time frame. This is shown in Figure 3.

Figure 3: effect of different rates of compost application on soil organic matter levels : case *Southern Europe*



In figure 4 we have the response curve under following conditions:

X = 30%, Y = 15%, Z = 0,8% (HL time at some 80-90 yrs.), and with an initial organic matter concentration of 4%, deemed to be typical of Northern European areas:

Such outcomes are – on the other hand - highly consistent with long-term field trials which have already been run by the Rothamstead Agricultural Experimental Centre for more than one century, surveying long-term effects of different agronomic practices about the build-up or decrease of organic matter in the soil.

Outcomes in Rothamstead (table 4) clearly show that giving up organic fertilisation determines a big loss of organic matter in the soil, which causes a net transfer of Carbon (as carbon dioxide) to the atmosphere. The application – continued with time - of organic soil improvers (manure in the trial, but outcomes would hold similar with compost) makes it possible to keep concentrations of Carbon at those levels that are typical of natural

background concentration - or to increase the concentration in those soils already depleted. This makes the soil a powerful “sink” for Carbon.

Numbers show a loss of 1-1,5% carbon from the soil in just 50 years (and it must be further noted that cropping conditions weren't yet so intensive as modern ones, this latter leading probably to a even higher and faster mineralisation of organic matter); this is of utmost importance, if we go back to the evaluations reported above, on the relationship between Carbon lost from the soil and the increasing amount of carbon dioxide in the atmosphere.

Figure 4: effect of different rates of compost application on soil organic matter levels : case Northern Europe

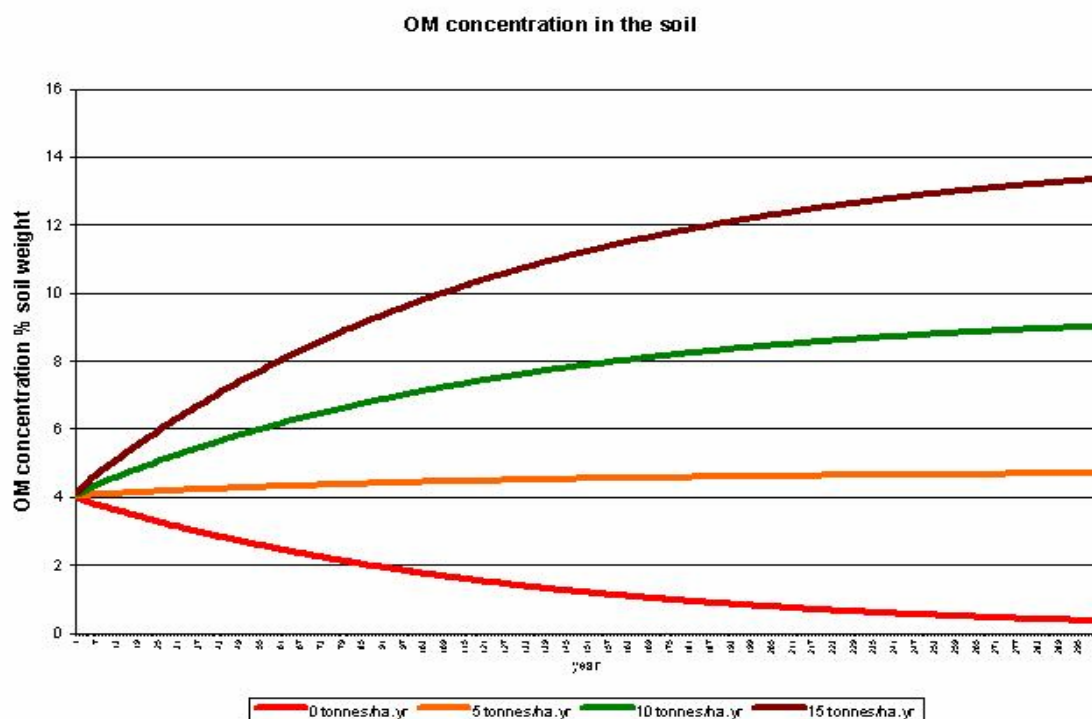


Table 4: findings of long-term field trials in Rothamstead

Type of vegetation or cropping	% C
<i>Pasturelands</i>	<i>1.52</i>
<i>Under a forest</i>	<i>2.38</i>
<i>After cropping wheat continuously for 50 years, 1893</i>	
<i>No manure added since 1839</i>	<i>0.89</i>
<i>Only chemical fertilisation since 1843</i>	<i>1.10</i>
<i>14 tonnes manure yearly since 1843</i>	<i>2.23</i>

Economic drivers and funding programmes

A noteworthy attempt to price up measures which promote accumulation of organic matter in the soil, is the one laid out by some Regions in Italy, where under the scope of Rural Development Plans (2000-06) (Reg. CE 1257, on sustainable agriculture), farmers get subsidised for the application of organic fertilisers and namely composted products:

- Region Emilia Romagna has already been paying since a couple of years 250.000 ITL/ha (some 130 €) to use compost and promote a build-up of soil organic carbon in depleted soils
- Region Piemonte pays 220 €/ha to use up to 25 tonnes d.m. in depleted soils over a 5 years' time frame in order to take into account crop rotation.
- Region Umbria also has issued lately some budgetary provisions, though they show to be somewhat symbolic as the budget so far is fairly limited (50.000 Euro being the overall budget)

Such grants might constitute a precedent, when it comes to environmental policy-making and economic instruments for that, to drive agronomic practices – and the related waste management practices - towards a more sustainable approach under the scope of climate change issues and soil fertility.

Other side effects of compost application on GHGs

Many other side effects of organic fertilisation are likely to affect – besides improved cropping conditions – also the GHGs balance: one should at least mention:

- Disease suppression (less request for energy linked to the production of pesticides)
- Reduced susceptibility to soil erosion (lower loss of soil, therefore lower mineralisation of organic matter)
- Reduced irrigation requirement (less energy inputs)
- Improved tilth (less energy input for ploughing, tilling, seeding, etc.)

Furthermore, another net benefit as to GHGs could stem from the displacement of peat by compost as a growing medium. The use of peat results in the mineralisation of the carbon kept in peat bogs (which might be treated as “fossil carbon” due to its long-term storage), so making a net positive contribution to global warming. It has been calculated²⁰ that, as peat contains around 50% carbon (on a dry weight basis), which at a moisture content of 55% is 23% carbon, and assuming a density of around 300 kg/m³, if all this carbon is released during mineralisation of the peat, this equates to 247 kg CO₂/m³. Each cubic metre of peat replaced by compost might therefore save the emission of about 247 kg of CO₂, equivalent to about 362 kg CO₂ per tonne of compost (considering also its different bulk density and the fact that it usually replaces peat on volume basis).

Closing remarks: a potential role for composting in the context of Emission Trading Schemes

From science-based evidence and related strategic and practical implications, which have been considered through this paper, the following conclusions may be drawn:

- GHG-mitigation measures related to LULUCF (Land Use, Land Use Change and Forestry) may imply cheaper solutions relative to technological ones.

²⁰ Smith, A, Brown, K, et al. AEA Technology (2001) *Waste management options and climate change*, Final Report to the EC, DG ENV.

- Composting and the use of composted products ought to be considered too, among such measures, since they imply reduction of GHGs through various mechanisms (C sink, reduced production of GHGs from both production and application of mineral fertilisers and pesticides, peat replacement, etc.)
- At the reference price of around € 20/tonne CO₂, emission trading may be considered as a comparatively limited source of extra income for farmers, given the levels of reduction achievable per unit area. This “extra income” may anyway start driving farming practices towards patterns of higher sustainability, thereby renewing and enhancing the “environmental role” of the agricultural sector

The following also ought to be remarked:

- Compost can only temporarily store the carbon in soils, which will be released, in the very long run, into the atmosphere. *As already argued, anyway, the effect of “progressive build-up” may have a comparatively important duration, until a steady-state situation is reached where release equals further accumulation; this may help fulfilling reduction targets during the first commitment period; more in general, the effect of “temporary progressive storage” of C is not negligible in the mid-term, and this provides for opportunities to tackle effectively the reduction targets until science and technology help reducing further and sharply emissions from energy, transports, industry.*
- Compost is not covered by the Community emission allowance trading scheme; *this is the key subject worth some consideration for future revision.*
- There is an outstanding opportunity for additional scientific research on carbon dynamic in soil, and on other potential benefits of compost, in order to endorse its potential role further, thereby making our views on achievable/achieved results sharper.