ECN
Compost and Digestate for a Circular Bioeconomy

ECN Position Paper

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The importance of recycled organic waste soil improvers in the frame of the upcoming Soil Health Law

Background and summary

In the European Union there is an urgent need to reach healthy soil status in the shortest possible time, since between 60 and 70% of this scarce non-renewable resource is classified as unhealthy. This requires immediate action, with the swift adoption and implementation of an adequate EU regulatory framework.

The regulatory framework for an EU Soil Health Law was established within the EU Biodiversity Strategy for 2030, which was – as part of the EU Green Deal – adopted in 2021. The EU Soil Strategy, issued in November 2021, sets a new vision with the aim of having all European soils in a healthy condition by 2050 and making soil ecosystem more resilient. These goals are closely linked and in synergy with other EU policies and initiatives proposed under the EU Green Deal package: these associated policies include missions focusing on carbon removals through better soil restoration and soil management (EU Carbon farming Initiative), the better closing of sustainable nutrient cycles and the utilization of recycled nutrients (Integrated nutrient management action plan Initiative), and the better management of agricultural soils in order to increase their capability of providing relevant ecosystem services (EU Biodiversity Strategy, CAP Strategic Plans).

An EU Soil Health Law should draw up harmonised common rules and specify concrete measures for the protection, restoration and sustainable use of soils, as well as the options for soil monitoring at EU level. These ambitious objectives can only be achieved by integrated and comprehensive measures which will contribute and lead to achieving good biological, physical and chemical condition of soils. This framework is complemented by the EU Mission 'A Soil Deal for Europe' which provides new tools for research and innovation to lead the transition towards healthy soils.

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OFFICE-ADDRESS Im Dohlenbruch 11 - 44795 Bochum (Germany) **PHONE** +49 234 438 944 7 **FAX** +49 234 438 944 8 **MAIL** info@compostnetwork.info
WEB www.compostnetwork.info / www.ecn-qas.eu **UST-ID-NR.** DE813811932 **TAX-NO.** FA Bochum-Süd: 350/5705/4233 **REGISTERED AT** Amtsgericht Bochum VR 4604
REGISTERED PLACE OF ASSOCIATION European Compost Network ECN e.V., Bochum **TRANSPARENCY REGISTER** 26513411360-51

As already done in the papers recently issued - the last one in March 2022 about the "Impact assessment on a Soil Health Law" - ECN reiterates its support for establishing EU Common indicators and certifications for soil health, always striving for increasing the awareness of the need of creating, in the upcoming policies on soil, the right conditions to encourage the return to the soils of Organic Waste Soil Improvers (OWSIs, in this paper) such as compost and solid digestate.

OWSIs are the products of the strictly regulated industrial processing of organic waste, and they are used mainly in agriculture and horticulture; the contributions of the regular application of OWSIs to soil health, fertility and soil carbon content, that are inseparable from the environmental benefits of separate collection and recycling, have been already pointed out in previous ECN papers.

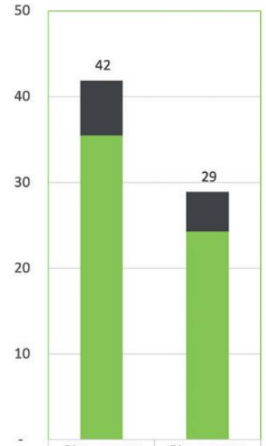
In this position paper ECN evaluates, in particular, the results of several long-time field trials of OWSIs application, in order to demonstrate the announced benefits to soils in real scale conditions. Moreover, the paper provides additional information about the features of these fertilising products which, together with the collected evidence, should remove any residual concern about the possible role of OWSIs as sources of soil contamination and therefore be classified as safe products.

From bio-waste to soil improvers: state and perspectives in the EU

The recycling of organic waste into compost and digestate is one of the key pillars of the circular bioeconomy, that the EU policy is strongly pushing forward, as one can see through the data concerning bio-waste management. As shown in the figures below, ECN[1] estimates that 60 million tonnes per annum of bio-waste (of municipal and commercial/industrial origin) is generated in the EU27 and treated in some 3.800 bio-waste recycling plants in operation in Europe: 59% of that quantity is composted, while 41% is recycled through anaerobic digestion.

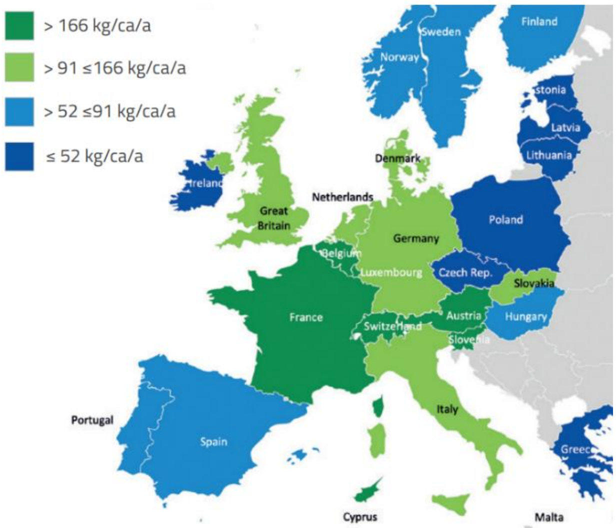
[1] ECN data report 2022 https://www.compostnetwork.info/ecn-data-report/

QUANTITIES OF BIO-WASTE SENT TO COMPOSTING & AD
(tonnes per annum)



	Biowaste to composting	Biowaste to AD
TOTAL	42	29
CH, NO & UK	6	5
EU27	36	24

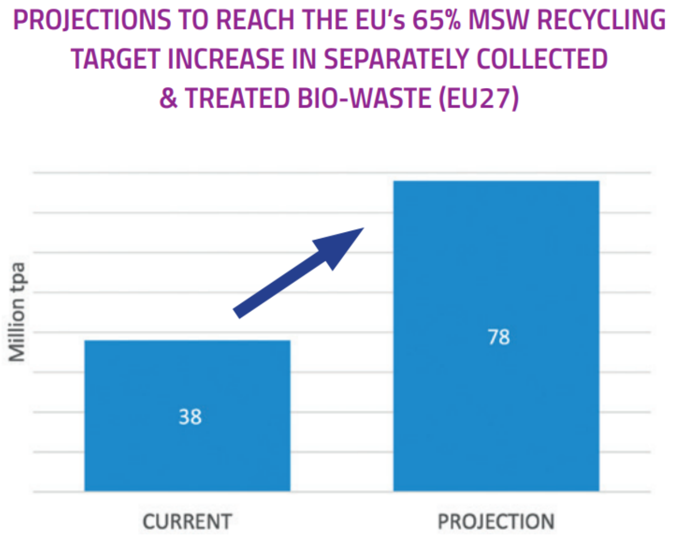
BIO-WASTE COLLECTED PER CAPITA IN SELECTED COUNTRIES GROUPED INTO QUARTILES
(kg/capita/annum)



Sources: ECN & EEA data. Excludes derived estimates

From the recycling process, around 17,6 Mt/year of compost are produced, while limited data are available on the amount of digestate released into consumption. Since quality compost is recognised as an important soil improver, adding organic matter and helping to preserve crop yields, agriculture is the dominant market segment for compost; the agricultural sector even borders to 100% for digestate.

The EU target for reuse and recycling of municipal waste will increase to 65% by 2035. This goal can only realistically be met by increasing bio-waste recycling through separate collection and treatment through both composting and anaerobic digestion, since, as seen in the previous figure, separate collection rates are still quite unevenly distributed throughout the different countries. As the proportion of bio-waste in high and upper-middle income countries ranges between 34% and 46% of the total amount of municipal waste, ECN estimates that 35% of EU’s municipal solid waste would need to be separately collected as bio-waste to meet the 2035 65% recycling target. This means that additional 40 million tonnes per annum of bio-waste need to be separately collected and treated by 2035; with the production of OWSIs to increase accordingly.



High quality soil improvers

The solely separate collection of organic waste is not the target itself, whereas the main goal is to achieve, through a careful attention to the quality of these feedstocks and their proper treatment, high-quality products (compost and digestate) that can be used as organic fertilisers or soil improvers.

Many EU countries have implemented national waste and/or fertilising products legislations, and this has made it possible many years ago - decades in some cases - to introduce and fine tune the best parameters and limits to qualify high quality OWSIs. A step forward for the environmental protection was determined by the implementation of national quality labels[2] and, in parallel, in the first pan-European harmonisation of the criteria for the high-quality production of compost and digestate through the creation by ECN of the voluntary quality certificate "ECN Quality Assurance Scheme" (ECN-QAS).

The certificate of ECN-QAS can be awarded to National Quality Assurance Organisations (NQAO) that have benchmarked their quality assurance scheme with ECN-QAS, allowing it to grant its label to compost and digestate plants operating in their countries. The ECN-QAS Quality Manual[3] provides all information and requirements for both the applicant (compost or digestate producer) and the corresponding body (NQAO).

[2] e.g. Austria (KBVÖ), Belgium (Flanders, Vlaco), Estonia, Finland, Germany (BGK), Hungary (Hungarian Compost Association), Ireland (Cré), Italy (CIC), Netherlands (Keurcompost), UK (PAS 100), Sweden (RISE, SPCR152)

[3] https://www.compostnetwork.info/ecn-qas/quality-mark/

At present, four NQAOs have been awarded with ECN QAS: CIC (Italy), BGK (Germany), KBVÖ (Austria) and Vlaco (Belgium).

The latest step in the direction of qualifying the OWSIs has been carried out with the implementation of the EU Regulation (EU) 2019/1009 (the so called Fertilising Products Regulation, FPR), that lays down rules on the making available on the market of EU fertilising products. This regulation includes common rules on product safety and quality (such as limit values for heavy metals, physical contaminants, pathogens) as well as labelling requirements for fertilising products. Since being a risk-assessment based norm, all the fertilising products complying to the FPR (including those deriving from recycled organic waste) reach the end-of-waste status and can be freely traded in the EU market.

It is also worth mentioning that bio-organic waste compost and digestate are included among the few fertilisers that can be utilized in organic farming; in fact, the recently updated regulation (EU) 2018/848 and its implementing Regulation (EU) 2018/1165 confirm the eligibility of compost and digestate obtained from source separated bio-waste, provided that they comply to more stringent limits for some heavy metals (cadmium, copper, nickel, lead, zinc, mercury, chromium).

Using organic carbon of compost to preserve soil fertility and help Tackle Climate Change

Farmers and growers have spread compost, the best known and most widespread among OWSIs, onto their fields for millennia, safe in the knowledge that it would help their crops grow stronger and make their soils easier to work. Whilst these benefits were localised, there is now better understanding of the ways in which using compost and the other OWSIs can help reduce or counterbalance atmospheric greenhouse gas levels.

OWSIs are derived from decayed plant and animal matter, meaning they are formed from biogenically derived carbon. Whilst some of this carbon is released into the atmosphere during composting and anaerobic digestion (as carbon dioxide), the remaining carbon forms the major component of compost and digestate in the form of ‘organic matter’. This is a poorly understood complex mixture of large molecules, whose structure and components depend upon the original feedstocks and the way in which the fertilising product was formed.

When applied to soil, some of this organic matter is readily degraded by soil microbes and invertebrates. This is called the ‘labile’ fraction and it is an important source of food for the soil biota; this helps to recycle nutrients maintain soil function. The remaining organic fraction is less easily degraded and is termed the ‘stable’ fraction. Some of this is further transformed by soil microbes into more stable molecules where it can remain in the soil for long periods of time (ranging from decades through to centuries). In addition, organic matter can also interact with soil components such as clay, where it can form stable complexes thereby making it further resistant to degradation.

The amount of organic matter that remains in soil depends on the type of soil improver, the soil type, the climate and the way in which the soil is managed. Long-term field trials of compost utilization have suggested that soil organic carbon[4] increases of between 50-70 kg carbon per hectare per year per tonne of compost (measured on a dry matter basis) are possible[5]. As every tonne of soil organic carbon holds the equivalent of about 3.67 tonnes of atmospheric carbon dioxide, this equates to between 110-154 kg of carbon dioxide equivalents (CO_2-eq) per tonne of compost (dry mass). This carbon has therefore been effectively 'removed' from the current atmospheric pool of carbon dioxide and can be considered to be 'sequestered'.

OWSIs can also indirectly reduce greenhouse gas emissions due to the macro plant nutrients it contains. Chemical fertilisers, the source of nutrients used by most European farmers and growers, need to be either mined out of the ground (i.e., phosphorus and potassium) or made through energy intensive industrial processes (i.e., for nitrogen-based compounds). Manufactured chemical fertilisers therefore carry a high environmental impact. The nitrogen, phosphorus and potassium present in OWSIs are effectively recycled as they are derived from plants and animals, so they therefore avoid the emissions associated with their chemical alternatives. Estimates suggest that one dry tonne of compost made out of garden and food waste contains enough nitrogen, phosphorus and potassium (NPK) to avoid 122 kg CO_2-eq of emissions.

Overall, estimates based on the current manufacture of bio-waste compost across Europe, suggest that a total of 1.2 million tonnes of carbon dioxide equivalents are sequestered as soil organic carbon and 1.7 million tonnes of CO_2-eq are offset through nutrient recycling. Overall, this equates to 2.9 million tonnes of carbon dioxide equivalents every year. As Europe has potential to manufacture over twice as much compost every year, these benefits could increase to 6.2 million tonnes of CO_2-eq a year, equivalent to the carbon sequestered by 103 million tree seedlings grown for 10 years (see table).

[4] Soil organic matter is the soil organic carbon plus the hydrogen, oxygen and nitrogen that are part of the organic compounds.
[5] Summarised in: Gilbert, J, Ricci-Jürgensen, M & Ramola, A. (2020) A Summary of the Benefits of Compost and Anaerobic Digestate When Applied to Soil. ISWA, Rotterdam.

Estimates of compost benefits in the EU27, Norway, Switzerland and the UK		
	2022	**POTENTIAL**
Amount of compost (tonnes per annum fresh mass)	21 million	46 million
Sequestered carbon in soil* (tonnes CO_2-eq per annum)	1.2 million	2.5 million
Displaced NPK** (tonnes per annum)	300 thousand	700 thousand
Offset CO_2 emissions due to displacement (tonnes CO_2-eq per annum)	1.7 million	3.7 million
TOTAL CO_2-EQ BENEFITS (tonnes CO_2-eq per annum)	**2.9 million**	**6.2 million**
CARBON SEQUESTERED in tree seedlings grown for 10 years	**48 million**	**103 million**

* This assumes that 49% of the total compost manufactured would be applied directly to soil.
** NPK = Nitrogen, phosphorus & Potassium. Estimates based on 100% of compost manufactured and relate to total concentrations.

Nutrient content of waste derived organic soil improvers and their fertilising capacity

It is widely recognized that OWSIs can be valuable sources of nutrients, mainly nitrogen and phosphorus, potassium, to be successfully used for crop nutrition. However, the different feedstocks (bio-waste, urban and agro-industrial sludge, green waste), can influence their nitrogen and phosphorous content and the following plant availability. This feature is not a constraint, thus representing a chance to be capitalized by matching up different types of OWSI to different soil types and plant nutrient requests (amount and timing), in a more comprehensive view of the latest fertilisation strategy in the light of soil organic matter maintenance and increase.

The adoption of this strategy requires a thorough understanding of the characteristics of the different OWSIs, greatly depending on raw organic waste. Much research is being conducted on nitrogen content and release and recently increasing research is focusing on phosphorus from the different OWSIs. They, however, can be also a valuable source of many other elements (potassium, calcium, magnesium, sulphur), helpful to plant nutrition and partially or totally replacing chemical and mineral fertilisers.

In light of this, their utilization in different soils can be tailored to maximize the plant nutrient efficiency, minimizing over-fertilisation in the frame of the best synchronization with plant requests. In well stabilized OWSIs nitrogen is organic mainly, with their nitrogen fertilising efficiency generally ranging between 5-20% depending on their C:N ratio, but also on the soil type (sandy; clayey; loamy), crop type, climate conditions and application period. Winter cereals suffer some lower nitrogen efficiency, due to the low temperature (and consequently lower mineralisation) generally registered during the critical phases of the maximum nitrogen requests from cultivated plants, when compared with summer crops, where highest mineralisation corresponds to the greatest plant need of nitrogen. On the contrary OWSIs application to spring-summer crops such as maize represents a successful option, since the temperature registered during the crop cycle generally promotes the nitrogen mineralisation if adequate soil moisture is ensured. Furthermore, successive application of OWSIs appeared to promote the whole mineralisation trend, thus representing a potential substitute of chemical nitrogen fertiliser in the medium-long-term, also in winter cereals under this management.

Another important plant nutrient, phosphorous, is generally detected in OWSIs in inorganic forms. Despite the high amount of organic matter, most of phosphorous is generally found as orthophosphate (PO_4^-). Phosphorous suffers poor modification during composting, being the raw organic waste characteristics the main driver of the following phosphorous release in soil. Part of this phosphorous can be easily accessible for plants, while differently bound forms (with organic matter, iron, calcium), can be more often detected in compost. The presence of iron, calcium, and the pH can regulate their accessibility, turning in very different plant nutrient efficiency. Phosphorous fractionation assessment is quite important, and possible fertilisation should target the plant’s directly available free phosphorous and the medium to long-term phosphorous availability. The organic matter from OWSIs can then protect phosphorous from soil absorption/precipitation thus showing a long-lasting effect on the potential availability of this nutrient.

Nutrients in OWSIs are not limited to nitrogen, phosphorous and potassium: these fertilisers can be also sources of calcium and potassium, being the added organic matter also a cation exchange capacity (CEC) promoter, an important feature for the long-term soil fertility. OWSIs are also rich in sulphur, a key nutrient for some cereal crops (wheat), often scarce in soil.

The positive results of long-term field trials

Long trials on the use of WSIs – mostly consisting in bio-waste compost - in full field are essential to show their long-time effect on soil, and to observe their real use, year after year, on crops. To highlight positive effects and assess any possible adverse consequences of WSIs use, the outcomes of several long-term trials carried out in several European countries (Austria, Belgium, Germany, Italy, Spain, United Kingdom) were compared. All the trials considered (11 in total) consist in real-scale and open-field experiments, with only 2 of them lasting less than 6 years, and the longest one being 20 years long. In order to properly compare the studies, eight parameters were selected, among those proposed as soil quality indicators by the report drafted by the European Environment Agency[6] in light of the impact assessment of the upcoming Soil Health Law. Some of them were not considered: "Soil Sealing" because not inherent with the topic, and "Soil Erosion" of which it was not possible to find relevant results. On the other hand, the parameter "Organic Pollutants in Soil" was added, as well as "Crop Yield" which, although not being a soil indicator, is a direct consequence of soil quality in agriculture. The final eight soil indicators chosen were: Organic Carbon (SOC), nutrients status, acidification, Heavy Metals contamination (HM), Organic Pollutants contamination (OP), biodiversity, compaction and crop yield.

In each study few plots of land were fertilised with compost (sometimes compost + chemical fertilisers), while others received the same tillage, same crop, but different fertilisations (or none). Soil samplings and analyses were carried out at least once per year, and the results were compared with:

- analyses results of the same plot, before the start of the trials
- analyses results at the same time, in plots with different treatment (e.g., untreated, chemical fertilisation, digestate, slurry, etc…)

Soil Organic Carbon (SOC). The application of OWSIs had always a positive effect on SOC content when tested; moreover, an accumulation of organic matter was observable since the first application and year after year. SOC keeps increasing even after years of application; for example, one study reported that 13 years of application of compost brought SOC from 0.9 to 1.6 %, the increasing rate of the last two or three years was about as consistent as the one of the first years, suggesting the possibility to keep increasing SOC over the following years. The increased organic matter (i.e., the difference with the SOC value before the start

[6] Soil Monitoring in Europe – Indicators and thresholds for soil quality assessments. Version 24 Sept. 2021 for REVIEW. Authors: Rainer Baritz, Wulf Amelung, Veronique Antoni, John Boardman, Rainer Horn, Gundula Prokop, Jörg Römbke, Paul Romkens, Bastian Steinhoff-Knopp, Frank Swartjes, Marco Trombetti, Wim de Vries.

of the trial) lasted for at least three years after the stop of compost application, showing the high stability of organic matter applied with OWSIs.

Nutrient status. OWSIs contain interesting amounts of nutrients, mainly nitrogen, phosphorous and potassium. Moreover, nitrogen is mostly present in an organic form, which means that it is not as available, in short time, as mineral fertilisers to crops. In all studies where they were tested, OWSIs application showed an increase on nutrients in soil, which implies a higher availability of these fertilising elements year after year, and a lower need of mineral fertilisers.

Soil acidification. WSIs have a very small but consistent effect in contrasting soil acidification. Each study, but one, that tested pH changes found a small increase in soil pH value. This effect is somehow greater when soil pH is lower, so to show a liming effect.

Heavy metals contamination. Most of the studies that tested HMs concentration in soil showed no accumulation, even after years of OWSI application at high rates (up to 45t/ha/y); only two of them found an increase of one or more element among zinc, lead and copper. Despite significant, this increase is very modest: for example, in one study, after six years of 10t/ha/y of compost application, zinc in soil just increased from 56,2 to 67,5 mg/kg.

Organic pollutants. The existence of organic pollutants in soil is a topic whose concern is growing day by day. For this reason, in long-term trials (which necessarily started years ago) this parameter is not commonly found, even due to the unlikely presence of such pollutants in most of the waste feedstocks that are commonly composted or digested. Only one paper studied this issue, reporting no accumulation of polycyclic aromatic hydrocarbons, dioxins, furans, and phthalates.

Soil biodiversity. This indicator is quite complex since it doesn't rely on one or few specific parameters to quantify it. Different approaches were employed in the studies: microbial biomass, earthworm number or biomass, soil respiration (as microbial activity), microbial carbon, composition of microbial community and others. Considering those studies that investigated the topic, only few observed no substantial difference when applying OWSIs, while most reported positive effects after their use, especially those with longer time trials. No paper reported a negative effect, corroborating the favourable outcomes resulting from the application of OWSIs on soil biodiversity.

Soil compaction. Soil compaction is an extremely important issue in modern agriculture and, as for biodiversity, there is not a single value that can express its status. Along the studies different approaches were chosen to assess soil compaction: soil workability, water retention, bulk density, soil macro-porosity. All the studies that considered one of these aspects found a positive effect in the use of OWSIs. This result was expected, due to the increase of SOM, which is well-known to favour a healthy soil structure; nevertheless, it is important to have such positive results, showing that the connection between the two indicators is not just theoretical but can also be detected in practice.

Crop yield. Despite not being a soil indicator, it's an important factor to consider, and most of the papers tested crop yield in their experiment. About half of them reported a positive effect while the other half showed no significant difference, and none reported negative one. These results should encourage farmers to make use of OWSIs, since they often show a positive effect on crop yields and, in the worst-case scenario, the performance will be identical to the one resulting from the use of chemical fertilisation.

Conclusions

There is increasing awareness of the benefits provided by the application of soil improvers produced by the recycling of organic waste through composting and anaerobic digestion; these benefits are associated to several features that characterise these products, the main ones being their organic matter content and the pool of nutrient elements that, even thanks to their chemical forms, assure a medium and long-term availability for soil biota and agricultural crops.

Besides representing a key step for successfully closing the loop of organic waste management and for meeting the circular economy targets set by the EU, the application of organic waste soil improvers to soils is actively connected to the improvement of many functions that are related to soil fertility and soil health addressed by the upcoming regulation, such as carbon sequestration, nutrient cycling, soil biodiversity, water resources preservation. An overall benefit in soil degradation prevention must be considered also, since the application of OWSIs plays a role in preventing soil compaction and desertification.

Several long-term field scale trials performed in different European countries and assessed through the main soil health indicators have clearly shown those benefits. Moreover, the application of OWSIs has turned into comforting results in terms of absence of side effects of soil contamination, an understandable concern in the past, that should be now reconsidered and removed owing to the proven improvement of organic waste separate collection schemes in obtaining high quality feedstocks, the technological developments of composting and anaerobic digestion industrial processes and the increasingly stringent quality standards required for organic waste soil improvers.

ECN once more highlights that high quality OWSIs should be acknowledged as important elements to consider in upcoming Soil Health Law, recognising the crucial climate, resource and environmental benefits that the regular applications of quality compost and solid digestate to soil generate, and encouraging Member States to reward the use of quality compost and digestate as a way to increase soil fertility, to reduce the use of mineral fertilisers and to close the biological cycle in line with circular economy principles.

To this end, ECN reiterates the calls for promoting compost and digestates use within a sustainable farming system, meaning that:

- the application of compost or digestate should follow good agricultural practices, since the main goal of any soil protection policy should be to restore health and fertility. In this respect, the conditions for application (period, doses, farming techniques) should be based on the actual requirements of the specific crops and the benefit to the soil and regional climate. Any practice that only aims at increasing carbon or organic matter levels in soils, disregarding soil use, should be discouraged.
- Incentives should include appropriate training to farmers on the long-term benefits of soil health and the practical ways of assessing its quality. Since soil improvers do not work in the same way of mineral fertilisers, farmers need advice to evaluate their compost requirements, when it should be spread, and how they can forecast the expected results. Many farmers will gain from agronomic training and advice from experts. Appropriate training should improve farmers' contribution to innovation, and protection of soil health and ecosystem biodiversity.

Protecting soil and its fertility requires long-term interventions. Any policy protecting and improving soil and biodiversity should forecast long-term (at least 5 years) programs coupled with appropriate rewards and incentive instruments.

About the ECN

The ECN is the leading European membership organisation promoting sustainable recycling practices by composting and anaerobic digestion of organic resources and guarding over the quality and safe use of the recovered organic fertilisers and soil improvers. With 66 members from 29 European Countries ECN represents more than 4500 experts and plant operators with more than 45 million tonnes of biological waste treatment capacity.