Cré
Composting & Anaerobic Digestion Association of Ireland

CLIMATE CHANGE MITIGATION THROUGH SOIL CARBON SEQUESTRATION: The Contribution of Compost*

COMPOSTING IS A SOLUTION TO CLIMATE CHANGE

This paper highlights the benefits of compost in soil carbon sequestration. It does not account for the additional benefits of compost:

- in avoiding greenhouse gas emissions by diverting organic waste from landfill where it would produce methane, a more potent greenhouse gas (a significant co-benefit given Ireland's COP26 commitment to reducing methane emissions)
- the potential of compost to displace chemical fertilisers.

Cré believes that soil carbon sequestration is one of the critical paths to achieve net-zero. Furthermore, Cré believes that compost plays a leading role in optimising soil carbon sequestration, based on scientific evidence.

The Benefits of Compost

Soil carbon: is the solid carbon stored in soil. Every tonne of carbon fixed in the soil represents 3.67 tonnes CO_2 equivalent.

Soil carbon sequestration: Is the removal of carbon from the atmosphere into the soil where it can be stored long term (decades to centuries) in the soil.

Composting: is the process of controlled biological decomposition of biodegradable materials under managed conditions, predominantly aerobic, that allow the development of thermophilic temperatures due to biologically produced heat that convert the inputs to compost.

** The potential of digestate to sequester carbon was also researched; see section 'Examination of Digestate'.*

Climate Change – Regulatory Backdrop

Recent European Union (EU) circular economy, bioeconomy and Green Deal policies and the new European Fertiliser Regulations promote the recycling of nutrients from organic wastes into products that can be used as soil improvers and fertilisers, thereby reducing the use of chemical fertilisers. The European Commission is expected to present a Communication setting out an Action Plan for the EU Carbon Farming Initiative. The Carbon Farming Initiative would promote a green business model of carbon sequestration in which farming practices that remove CO_2 from the atmosphere and thus contribute to Green Deal objectives would be rewarded.

The EU Farm to Fork Strategy aims to look at how we produce food sustainably and reduce food waste. The potential to reward farmers in the future for storing carbon in soil is currently being examined. Deploying compost as part of a suite of farming techniques to help store carbon in soil merits examination. The composting of organic residues and manures from agriculture (Pattey et al., 2005) also offers significant potential as a method that would allow Ireland to meet its COP26** methane reduction pledge. Similarly, on-farm anaerobic digestion offers a proven method to manage methane associated with agricultural systems.

The European Green Deal and its commitment for a climate-neutral Europe by 2050, at the latest, requires urgent and concrete measures on the ground to reach the intermediate climate goals for 2030 and 2040, to fulfil the legal obligations of the Paris Agreement and to respect the commitments towards the United Nations Sustainable Development Goals (SDGs).

The Climate Action and Low Carbon Development (Amendment) Bill 2021 sets out the legal framework for Ireland's transition to a climate-resilient, biodiversity-rich, environmentally sustainable and climate-neutral economy by no later than 2050.

Key policy instruments, such as the Ag Climatise Roadmap 2020 and the Waste Action Plan for a Circular Economy 2020, include actions and targets to reduce the environmental footprint of specific sectors regarding greenhouse gas emissions to reach climate neutrality by 2050. These instruments set out to halve our food waste by 2030 while providing sustainable food waste management options for all homes and businesses, in turn providing a quality feedstock for composting and anaerobic digestion.

Composting and anaerobic digestion of organic materials (derived from biowaste and many other organic by-products) have a crucial role in preventing carbon release, improving soil organic matter content and improving sequestration capability by providing alternatives to inorganic fertilisers.

The quantity and quality of soil organic matter are positively influenced by management practices that build soil organic matter, such as the use of cover crops and crop rotations, diversification of grassland species, maintenance of good soil structure and porosity, balancing soil fertility, and using organic manures or amendments, such as compost (Teagasc, 2020).

Area-based targets for afforestation are a frequent and prominent component of policy discourses on forestry, land use and climate change emissions abatement (Matthews, 2020). Agricultural soils, grasslands and wetlands are huge potential sinks for carbon if properly managed and this requires policy recognition. Compost has a positive role to play in addressing climate change, as a positive addition to healthy soil.

Government policy has been to achieve carbon sequestration by focusing on planting trees. Carbon sequestration in soil, however, also provides an opportunity and warrants further recognition and support.

The Global Importance of Carbon in Soil

- Soil is a huge sink for carbon, more carbon resides in soil than in the atmosphere and all plant life combined; there are 2500 billion tonnes of carbon in soil, compared with 800 billion tonnes in the atmosphere and 560 billion tonnes in plant and animal life (Schwartz, 2014).
- Soil carbon sequestration is the long-term (decades to centuries) carbon capture in the soil (as opposed to being released to the atmosphere contributing to climate change as carbon dioxide or methane). Soil carbon sequestration offers a tangible way of mitigating climate change
- Carbon in soils exists in both organic or inorganic forms. It makes up approximately 58% of organic

**At COP26 Ireland signed up to 'The Global Methane Pledge', which aims to limit methane emissions by 30% compared with 2020 levels. Methane is one of the most potent greenhouse gases and responsible for one-third of current global warming from human activities. The increase in methane emissions is driven by three anthropogenic sources: (1) leaks from fossil fuel infrastructure – methane is the primary component of natural gas and can leak from natural gas pipelines, drilling operations and coal mines; (2) from agriculture, primarily livestock and rice fields; and (3) from decaying waste in landfills. Composting offers an environmentally superior alternative to sending organic matter to landfill, as composting reduces methane production and provides a series of economic and environmental co-benefits.

matter in the soil. Inorganic carbon exists in carbonate minerals such as calcium carbonate (limestone) and calcium/magnesium carbonate (dolomite).

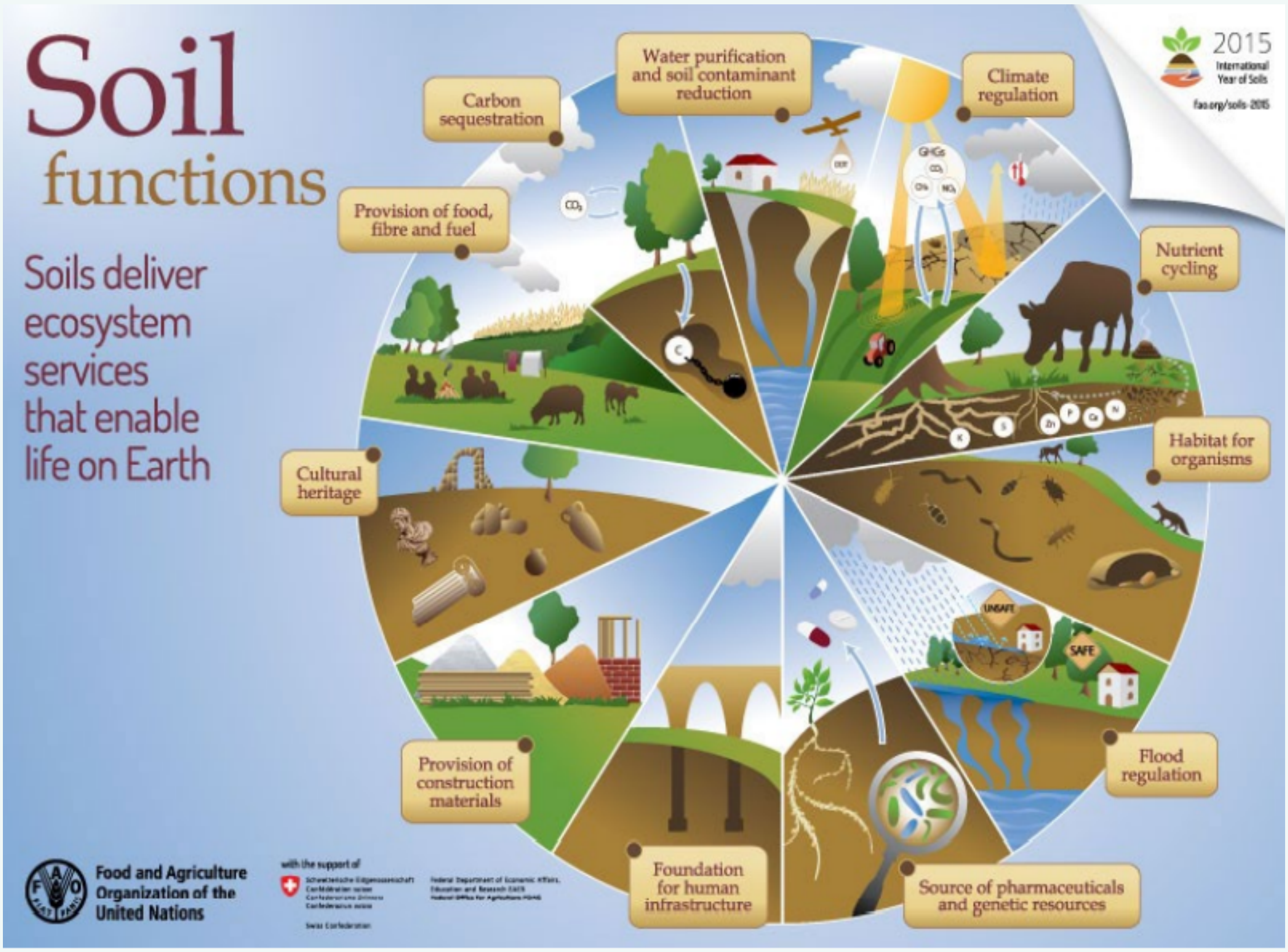
- Traditional thinking on the carbon cycle is that plants die and decay into the soil, and over time the material is transformed into stable organic matter, which is how carbon is sequestered. However, as plants grow, they sequester vast amounts of carbon through photosynthesis. Plants use the sun's energy to remove CO_2 from the atmosphere and convert it into simple sugars. This liquid carbon is exuded through the plant's roots into the soil to feed and stimulate soil microbiology. This carbon is the basis of soil organic carbon (SOC).
- Eventually, the bacteria and the fungi in the soil produce humus, which is the essence of stable soil carbon.
- Soil is part of our planets life support system, providing numerous ecosystem services, healthy soil supports healthy plants that continue to sequester carbon.

Global Challenges

Soil is vulnerable to:

- erosion
- compaction
- pollution
- desertification
- urban development
- intensive agriculture and
- climate change.

The equivalent of 30 football pitches of fertile soil is estimated to be lost globally every minute. Soil organic matter, which is vital to soil health, is decreasing in soils across Europe (Bellamy et al., 2005). A report from Panagos et al. (2017) estimated that European countries are losing up to €1.25 billion annually in agricultural productivity due to soil erosion and loss. In his book, Dirt: The Erosion of Civilisations, Dr David Montgomery explained that the loss of many ancient civilisations was closely linked to the degradation and loss of their soils. The impact of soil loss on civilisations is not just an ancient problem. It is still happening today. The soil must be protected.



Carbon in Soil

All soils contain carbon. Carbon in soils exists in both organic or inorganic forms. It makes up approximately 58% of organic matter in the soil. This organic matter comes from living things or things that once lived. Inorganic carbon exists in carbonate minerals such as calcium carbonate (limestone) and magnesium carbonate (dolomite).

For a long time, soil scientists believed that only the organic pool of carbon in soil was dynamic, but now studies have shown that the inorganic pools also fluctuate (Jorat et al., 2020). However, the pool most improved by compost addition is the soil organic carbon (SOC) pool (as measured by total organic carbon (TOC) in soil analysis).

Plants are made up of 45% carbon (dry weight). Traditional thinking on the carbon cycle is that plants die and decay into the soil, which is how carbon is sequestered. However, it is plants and microbes that make soil what it is. As plants grow, they sequester vast amounts of carbon through photosynthesis. Plants use the sun's energy to remove CO_2 from the atmosphere and convert it into simple sugars. This liquid carbon is exuded through the plant's roots into the soil to feed and stimulate soil microbes. This carbon is the basis of SOC.

Eventually, the bacteria and the fungi in the soil produce humus, which is the holy grail of stable soil carbon. Stable composts contain humic and fulvic acids and contribute to the long-term carbon pool in soil. Compost use creates healthy soils by improving the chemical, physical and biological characteristics of the soil. Healthy soil produces healthy plants, which continue to sequester carbon

Compost has many benefits that contribute to healthy soils, which in turn aids soil sequestration.

Compost Contribution to Soil Health

- Sequesters carbon, increases organic matter and humus content
- Improves soil aggregation, structure & drainage
- Increases plant available water holding capacity and drought resistance
- Increases soil nutrient storage, providing long-term slow-release macro- and micronutrients, displacing chemical fertiliser use
- Improves root development
- Inoculates and stimulates the soil microbiome with beneficial microbes
- Promotes natural plant health

Compost Stores Carbon in Soil

As well as improving overall soil function, compost application adds stable organic carbon to soils. Therefore, compost can be considered as an organic soil improver.

Compost is produced through the composting and biodegradation of organic materials. During the composting process, the easily degradable organic compounds such as sugars, starches, fats and proteins are rapidly broken down. The remaining organic carbon is in cellulose, hemicellulose and lignin compounds which are resistant to further breakdown. Stable composts also contain humic and fulvic acids and contribute to the long-term carbon pool in soil. The stability of commercial composts must be confirmed with stability analysis such as oxygen uptake rate. Therefore, the carbon in compost is stable and leads to a net increase in soil organic carbon levels when applied to the soil. Composts manufactured from different feedstocks materials will sequester different amounts of carbon. Compost made from different feedstocks e.g. woody lignaceous material as well as processing condition which is conducive to humic substance produce compost that will have higher sequestration ability.

Research has demonstrated that 60–150 kg of CO_2 equivalents are sequestered in the soil for every tonne of compost applied (Gilbert, Ricci-Jürgensen & Ramola, 2020b).

Compost use also plays an indirect role is climate change mitigation by by offsetting chemical fertiliser use. There are currently no comprehensive field trials in Ireland using organic ameliorants (e.g. composted green/biowaste) which examine carbon sequestration in soil.

Examination of Digestate

Whole digestate is comprised of approximately 70–95% liquid fraction, the remaining is a solid fraction. When composted, the solid fraction of digestate is made more stable and thus has improved carbon sequestration ability (e.g. Italy & Netherlands).

There is a significant body of peer-reviewed publications on carbon sequestration properties of compost. However, in comparison, there is very little published evidence of digestate sequestering carbon in the soil. One study from France (R. Béghin-Tanneau, 2019) showed the solid fraction of digestate from maize aided carbon sequestration. Further research is required to establish if digestate contributes to significant soil carbon sequestration (Gilbert, Ricci-Jürgensen & Ramola, 2020a).

Sector in Ireland

The chart below outlines the current situation and the potential in Ireland on the amount of biowaste composted and the in turn benefits of carbon sequestered, greenhouse gas emission savings and the equivalent number of cars avoided based on these savings.

The composting and anaerobic digestion sector in Ireland has been developed over the last 20 years. The quantity of organic waste (such as household food waste, commercial food waste, green waste, industrial organic wastes, sewage sludge and manures) accepted for treatment at composting and anaerobic digestion facilities in Ireland was 436,000 tonnes in 2018 (EPA, 2020).

Compost derived from food waste/biowaste represents the compost likely to be available and used on agricultural land. However, not all of this waste can be processed by composting, as an element is processed by anaerobic digestion, and an increasing amount of biowaste is exported to Northern Ireland for processing.

IRELAND CURRENT	IRELAND POTENTIAL
160,000 tonnes a year of biowaste/green waste	**550,000 tonnes** of biowaste & green waste In addition, there is potentially other materials which could also be composted such as chicken manure (60,000t), spent mushroom compost (~80,000t) & farmyard manures.
70,000 tonnes of compost	**240,000 tonnes** of compost
7,700 tonnes a year of CO_2 equivalents	**26,400 tonnes** a year of CO_2 equivalents
59,754 GHG Savings (tonnes CO_2-eq/year)	**224,078 GHG Savings** (tonnes CO_2-eq/year)
12,714 Equivalent number of cars	**43,703** Equivalent number of cars

CASE STUDIES

Farmers should be encouraged to trade carbon credits, and this should be done on a farm-by-farm basis in which soil samples are taken to independently show increases in carbon sequestration in soil.

Austria

The 'Humus Projekt' refers to an Austrian private scheme for soil carbon credits. In this project, participating farmers can sell so-called 'soil carbon credits' equivalent to the amount of additional carbon they have stored in their soil while participating in the project. Companies wishing to reduce their carbon footprint buy the carbon credits. Started as a local initiative in 2007, the scheme now involves more than 100 farmers throughout the country. The Austrian retailer Hofer AG (part of Aldi) is the main buyer of credits. When a farmer starts participating in the project, a baseline measurement is made of the stable organic matter (humus) in their soil. The farmer then starts working on storing additional organic matter, e.g. by applying organic soil improvers, planting green cover, reducing tillage. An initial high-compost dosage of 100–200 tonnes/ha is a vital first step, as it is claimed that this high dose kickstarts/resets the soil microbiology and helps the further rapid build-up of soil organic matter. The farmer then receives a payment of carbon credits equivalent to the amount of CO_2 sequestered.

The carbon credit price is €45/tonne, of which €30 is for the farmer and €15 for the scheme management. The costs of soil sampling and soil analyses, as well as coaching of farmers throughout the project, are included in the scheme management costs. The relatively high carbon credit price is acceptable to buyers because of the credible layout of the scheme and the local context ('carbon in soils of local farmers instead of trees in Brazil').

Australia

In March 2019, Australian farmer Niels Olsen was the first farmer in the world to be paid for sequestering carbon in a regulated government-run carbon credit scheme. Olsen was paid for sequestering 11.2 tonnes CO_2 equivalent/ha in 2019 and he was paid 13.7 tonnes CO_2 equivalent/ha in 2020. The current rate of carbon credit in Australia is around €10/tonne, so sequestering 13.7 tonnes CO_2 equivalent/ha generated an income of €137/ha.

Call to Action

- Cré supports any action that recognises the value of carbon sequestration in mitigating climate change and progress to net-zero.
- In line with scientific evidence, Cré is recommending valorising the role of compost in soil carbon sequestration.
- The Government should incentivise agriculture (livestock, tillage & horticulture) to improve soil carbon sequestration and for farmers to trade carbon credits.
- There is a need to incentivise the quality and quantity of biowaste collected and processed to increase the supply of compost available to the market.
- There are currently no comprehensive field trials in Ireland using organic ameliorant (e.g. composted green/biowaste) which examine carbon sequestration in soil. Fields trials should be established.

ABOUT CRÉ

Established in 2001, Cré is the Composting and Anaerobic Digestion Association of Ireland. Cré (the Irish word for 'soil') is a non-profit association of public and private organisations dedicated to growing the biological treatment sector. Cré supports the production of high-quality outputs, assists the delivery of Government waste diversion and bioenergy targets, and promotes the creation of sustainable indigenous jobs. Cré has a broad membership base ranging from compost and anaerobic digestion facilities, waste companies, local authorities, technology providers, local authorities, consultants and third-level colleges. Cré is recognised by Government and agencies as the voice of the industry in Ireland. It is frequently called on to give the industry view on future policy and legislation. Cré is a member of the European Compost Network, and the European Biogas Association See www.cre.ie

Report prepared by: Cré Carbon Task Group – Dr. Brian Murphy (Enrich), Percy Foster (Cré), Karen Mahon (OCAE) and Julian Beatty (Nova-Q).

APPENDIX: Sources of Some Important Peer-reviewed Publications

Gilbert, J., Ricci-Jürgensen, M. & Ramola, A. (2020). Benefit of Compost and Anaerobic Digestate when Applied to Soil, International Solid Waste Association.

https://www.iswa.org/biological-treatment-of-waste/?v=d2cb7bbc0d23

Summary of C sequestration potential following compost application to soil

Compost Type	Soil Type / Crop System	Time Period	C sequestered	Reference
Green waste derived compost	Four sites in the UK	5 & 8 years	Mean annual increase in SOC of **60 ± 10 kg C ha^{-1} yr^{-1} t^{-1} dry solids** Similar to a rate of 70 kg C ha^{-1} yr^{-1} t^{-1} dry solids by Ros *et al.* 2006 (quoted in Powlson *et al.* 2012) in Austria over 12 years. **23% of the organic C in the compost remained in the soil.** (cf. about half as much carbon was stored when farmyard manures were applied directly to soil)	Powlson *et al.* 2012
Dairy-waste compost	Not stated	5 years	Carbon stored in the soil organic matter accounted for about **11% of the total amount of C applied.**	Quoted in: Diacono & Montemurro 2010
Cattle manure compost	Silty clay loam, Nebraska, USA	4 years	**36% of the organic carbon in compost remained** in the soil at the end of trial (cf. 25% of C applied as manure).	Eghball 2002
Green waste compost	Two experimental sites in the UK: sandy/light and medium (heavy) with a prior history of organic amendment application	9 years	**20-24% of the organic carbon was retained in the soil** (cf. 12% farm-yard manure)	Bhogal *et al.* 2016
Garden & household waste anaerobically digested & post-composted	Sandy loam, Denmark	12 years	**45% of the organic C remained in the plough layer after 12 years** of annual application (cf. 38% of C for sewage sludge and 21% for cattle manure).	Peltre *et al.* 2017
Poultry manure compost	Two soil types: silt loam and silty clay loam	19 years	Increase in SOC of 2.22 tonnes / hectare / year following compost applied at 9 tonnes / hectare (compared to conventional treatment). Difference of 3.5 times the conventional system. Application of 700–800 kg C /ha/ year increased soil C by 12% over 19 years. Rate of increase of 6.6‰ per annum. Increase in SOC levels in the subsoil noted.	Tautges *et al.* 2019

The Benefits of Using Compost for Mitigating Climate Change
The Office of Environment and Heritage (2011)

Full report:
https://www.researchgate.net/publication/292149826_The_benefits_of_using_compost_for_mitigating_climate_change

Short version report:
https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/waste/110171-compost-climate-change.pdf?la=en&hash=7ADC0B32600A8EE49E72187E4A027FA1C809AEAE#:~:text=These%20environmental%20benefits%20include%20improved,change%20by%20%27locking%20up%27%20or

The report summarises the scientific literature reporting on research on the use of compost and related products in mitigating climate change. Compost and related products are processed from recycled organic materials such as garden organics, food organics, crop residues, biosolids and manures. Diverting these materials from landfill reduces methane emissions. Applying the products leads to climate change benefits through carbon sequestration in soil, substitution of nitrogenous and other synthetic fertilisers and the flow-on effects of improved soil health and water-holding capacity following their application.

Based mainly on European and North American data, it is estimated that the use of garden and biowaste compost as a soil conditioner will result in the following carbon sequestration rates:

- 20-year accounting time frame: 40–55% of carbon applied with compost
- 50-year accounting time frame: 30–50% of carbon applied with compost
- 100-year accounting time frame: 0–14% of carbon applied with compost.

The Potential Role of Compost in Reducing Greenhouse Gases
Favoino, E. & Hogg, D. (2008)

https://www.researchgate.net/publication/5513046_The_potential_role_of_compost_in_reducing_greenhouse_gases

E. Favoino, D. Hogg

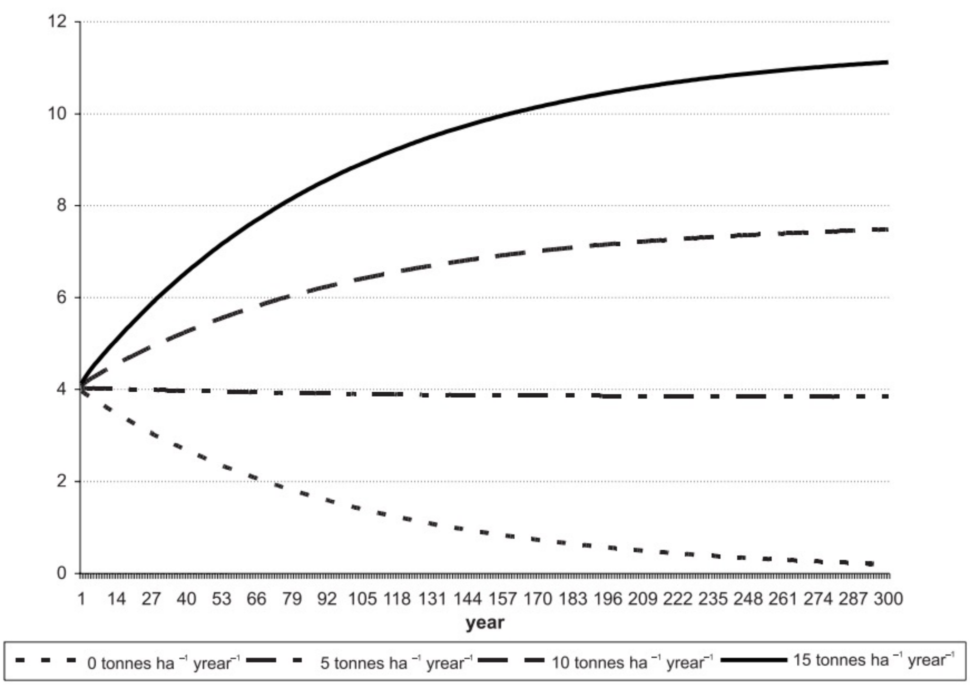


Fig. 1: Effect of different rates of compost application on soil organic matter levels (as a percentage of soil weight) in time.

Summary of Recent Peer-reviewed Publications

Compost Type	Soil Type/ Crop	Years	Carbon Sequestered	Reference
Green Garden Compost				
Green compost	Clay subsoil/willow	10	The average SOC contents after 10 years of 6.44% (750 t ha^{-1}) or 5.70% (500 t ha^{-1}) are, respectively, 1.59% or 0.85% above the 4.85% found in the unamended soils (0 t ha^{-1}), equivalent to relative increases of 32.7% and 17.5% compared with no compost addition or cultivation	Lord & Sakrabani, 2019
Green compost	Four sites in the UK	5 & 8	Mean annual increase in SOC of 60 ± 10 kg C ha^{-1} yr^{-1} t^{-1} dry solids. Similar to a rate of 70 kg C ha^{-1} yr^{-1} t^{-1} dry solids by Ros et al. (2006) (quoted in Powlson *et al.,* 2012) in Austria over 12 years. 23% of the organic C in the compost remained in the soil (cf. about half as much carbon was stored when farmyard manures were applied directly to soil)	Powlson *et al.,* 2012
Green compost	Two sites in the UK. Sandy/light and medium (heavy)	9	20–24% of the organic carbon was retained in the soil. (cf. 12% of farmyard manure)	Bhogal *et al.,* 2016
Biowaste Compost				
Domestic organic wastes mixed with garden waste	Applications of compost at 5 and 10 t ha^{-1} yr^{-1} were compared with control and mineral fertiliser application for 14 years in a nectarine orchard in Italy	14	The rate of compost application of 10 t ha^{-1} yr^{-1} showed a C storage in soils three times higher than the rate of 5 t ha^{-1} yr^{-1}. The rate of C application is crucial, indicated by the fact that compost supplied at the rate of 10 Mg ha^{-1} yr^{-1} was the only fertiliser strategy of the ones tested that resulted in higher C sequestration. Application of compost at the highest rate increased C in the soil; approximately 60% of the amount of C sequestered was from the amendment source and 40% from the net primary production of trees and grasses, with a net increase of C compared with mineral fertiliser application	Baldi *et al.,* 2018
Biowaste compost	5-year trial in the Mediterranean (sandy loam soil) on vegetable crops	5	The study involved four treatments: biowaste compost (COM), mineral NPK fertilisers (MIN), biowaste compost with half-dose N fertiliser (COMN), and unfertilised control (CK). The SOC stocks were increased in COM, COMN, and MIN by 20.2, 14.9 and 2.4 Mg ha^{-1} over CK, respectively	Baiano & Morra, 2017
Biowaste compost in Italy and Belgium and from olive mill waste, sheep manure, olive tree prunings in Spain			Potential bound C after 100 years for compost has been calculated to range from 2% to 14% of C applied (Boldrin *et al.,* 2009), so for this study an average C Stability Factor (CSF) of 8% was assumed C sequestered (kg CO_2 ha^{-1}) = 1760 Spain 3197 Italy/Belgium	Oldfield *et al.,* 2018
Compost made from using a mixture of food residues and ligno-cellulosic wastes in a 3:2 v/v ratio	Compost application at two rates (50 and 85 Mg ha^{-1}) on a field near Milan growing maize	150 days	Results indicated that the compost C that accumulated in the soil after 150 days was 4.24 Mg ha^{-1} and 6.82 Mg C ha^{-1} for 50 and 85 Mg ha^{-1} compost rate, respectively. Compost C was sequestered at the rate of 623 and 617g C kg^{-1} compost TOC for the 50 and 85 Mg ha^{-1} compost doses, respectively. The amount of C sequestered was similar to the total recalcitrant C content of compost, which was 586 g C kg^{-1} compost TOC, indicating that, probably during the short experiment, the labile C pool of compost (414 g C kg^{-1} of compost TOC) was completely degraded	Fabrizio *et al.*, 2009

1. Compost from plant, animal and sewage sludge; 2. Organic fraction of municipal solid waste; 3. Sheep manure; 4. A mineral fertiliser (NPK); and 5. An unaltered control	Soil quality in vineyard in Spain	13	CO_2 equivalents per hectare were 1745 kg for the organic fraction of municipal sludge waste and it was the only significant difference found	Calleja-Cervantes ***et al.***, 2015
Compost from municipal solid waste (MSW)	Field trial with barley in Italy	4	Predictions of the calibrated and validated RothC10N model showed that SOC change in 20 years was negative in the scenario with no Agro-ecological Service Crops ASCs-no compost (No ASC Cp0), where the C inputs were not sufficient to offset C losses, whereas positive values were predicted for all the other scenarios. The average values of predicted C stock change in 20 years were 3.8, 13.3 and 19.8 Mg C ha^{-1} for NoASC, Flattened (FB) and green manure (GMB) respectively and 8.2. 12.2 and 16.5 Mg C ha^{-1} . for Cp0, Cp15 and Cp30. The historical and experimental results were used as input to run a soil C dynamics model (RothC10N) to predict the effect of the factors of different combinations in the medium term (20 years). Compost application represents a valid option in terms of carbon sequestration increase	Farinaa, 2018
A farmyard manure, FYM; a municipal solid waste compost, MSW; a bio-waste compost, BIO; a co-compost of green waste and sewage sludge, GWS			The CERES-EGC mechanistic model was used to simulate the effects of repeated applications of urban waste composts and manure over 13 years on both soil carbon (C) and nitrogen (N) dynamics in the soil–crop–water–air system of the long-term field experiment, QualiAgro The GWS compost generated the highest C storage over the 13-year period and MSW the lowest, with 65% and 36% of the exogenous organic carbon applied incorporated into the soil organic C, respectively	Noirot-Cosson ***et al.***, 2016
Manure Compost				
Composted poultry manure	Field trial in California in maize–tomato and wheat–fallow cropping systems	19	Suggests that compost plays a larger role than once thought in building soil carbon. Ignoring the subsoil carbon dynamics in deeper layers of soil fails to recognise potential opportunities for soil C sequestration, and may lead to false conclusions about the impact of management practices on C sequestration In maize-tomato rotations, SOC increased by 12.6% (21.8 Mg C ha^{-1}) with both winter crop cover and composted poultry manure inputs, across the 2-m profile It also found that carbon levels fluctuate more in deeper soil than most evaluation methodologies tend to account for. In practical terms, the findings could mean compost has been undervalued by agricultural incentive programmes, and that we have been measuring carbon levels in soil incorrectly	Tautges ***et al.***, 2019
Poultry manure compost	Two soil types, silty loam and silty clay loam	19	Increase in SOC of 2.22 t h^{-1} yr^{-1} following compost applied at 9 t h^{-1}. Difference of 2.5 times of the conventional system. Application of 700–800 kg C ha^{-1} yr^{-1} increased soil C by 12% over 19 years, with a rate of increase of 6.6% per annum	Tautges ***et al.***, 2019
Dairy waste compost	5-year trial	5	Carbon stored in the soil organic matter accounted for about 11% of the total amount of carbon applied	Quoted in Diacono & Montemuro, 2010
Cattle manure compost	Silty clay loam, Nebraska, USA, 4-year trial	4	36% of the organic carbon in compost remained in the soil at the end of the trial (cf. 25% of C applied as manure)	Eghball, 2002

Compost from wheat straw, rapeseed cake, and cottonseed cake	Winter wheat and summer maize crops in China		A long-term field experiment established in 1989 was used to monitor the influence of organic and inorganic fertilisers on the SOC stock in a soil depth of 0–60 cm under an intensive wheat–maize cropping system in the North China Plain. The study involved seven treatments with four replicates: CM, compost; HCM, half compost nitrogen (N) plus half fertiliser N; NPK, fertiliser N, phosphorus (P) and potassium (K); NP, fertiliser N and P; NK, fertiliser N and K; PK, fertiliser P and K; and CK, control without fertiliser application The SOC stock in the 0–60 cm depth increased by proportions ranging from 3.7% to 31.1% over 20 years under the addition of compost	Fan *et al.,* 2014
Digestate				
Garden and household waste	Anaerobically digested followed by post composting. Sandy soil in Denmark	12	45% of organic carbon remained in the plough layer after 12 years of annual application (cf. 38% of C for sewage sludge and 21% for cattle manure)	Peltre *et al.,* 2017
Maize digestate	Field in France		Digested effective organic matter (EOM) addition in soil led to C sequestration due to the inherent stability of EOM and to a negative priming effect which decreased native soil organic matter (SOM) respiration. According to the literature, the formation of aliphatics, aromatics and phenol compounds in anaerobic digested amendments could explain the enhancement of SOM and EOM stability. The authors evaluated the C balance of both direct incorporation of maize silage in soil and anaerobic digestion following by digestate incorporation. Their broad estimation shows that the use of digestate amendment not only favours carbon sequestration but also reduces CO_2 emissions by 27% compared with the incorporation of maize silage Digested maize addition to soil increased C sequestration by 67% in comparison with undigested maize throughout the experiment	Béghin-Tanneau *et al.*, 2019

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