"We know more about the movement of celestial bodies than we do about the soil underfoot"

Leonardo da Vinci

"Look after the soil, and everything else will look after itself"

Farmers' proverb

Earth matters

Tackling the climate crisis from the ground up

GRAIN

Some things have not changed much since da Vinci's time, 500 years ago. For many, soil is a mix of dirt and dust. But in reality soils are one of Earth's most amazing living ecosystems. Millions of plants, bacteria, fungi, insects and other living organisms – most of them invisible to the naked human eye – are in a constantly evolving process of creating, composing and decomposing organic living matter. They are also the unavoidable starting point for anyone who wants to grow food.

Soils also contain enormous amounts of carbon, mostly in the form of organic matter. On a global scale soils hold more than twice as much carbon as is contained in terrestrial vegetation. The rise of industrial agriculture in the past century, however, has provoked, through its reliance on chemical fertilisers, a general disrespect for soil fertility and a massive loss of organic matter from the soil. Much of this lost organic matter has ended up in the atmosphere in the form of carbon dioxide (CO_2) – the most important greenhouse gas.

The way that industrial agriculture has treated soils has been a key factor in provoking the current climate crisis. But soils can also be a part of the solution, to a much greater extent than is commonly acknowledged. According to our calculations, if we could manage to put back into the world's agricultural soils the organic matter that we have been losing because of industrial agriculture, we would capture at least one third of the current excessive CO_2 in the atmosphere. If, once we had done that, we were to continue rebuilding the soils, we would, after about 50 years, have captured about two thirds of the excess CO_2 in the atmosphere. In the process, we would be constructing healthier and more productive soils and we would be able to do away with the use of chemical fertilisers, which are another potent producer of climate change gases.

Via Campesina has argued that agriculture based on small-scale farming, using agro-ecological production methods and oriented towards local markets, can cool the planet and feed the population (*see* Box 1, on p. 10). They are right, and the reasons lie largely in the soil.

Soils as living ecosystems

Soils are a thin layer that covers more than 90 per cent of the land surface of the planet and, contrary

Box 1: Small scale sustainable farmers are cooling down the earth[1]

Current global modes of production, consumption and trade have caused massive environmental destruction, including global warming, which is putting our planet's ecosystems at risk and pushing human communities into disasters. Global warming shows the failure of a development model based on high fossil-energy consumption, overproduction and trade liberalisation.

Via Campesina believes that solutions to the current crisis have to emerge from organised social groups who are developing modes of production, trade and consumption based on justice, solidarity and healthy communities. No technological fix will solve the current global environmental and social disaster. Sustainable small-scale farming is labour-intensive and requires little fuel; it can contribute to cooling down the earth.

All around the world, we practise and defend small-scale sustainable family farming and we demand food sovereignty. Food sovereignty is the right of peoples to healthy, culturally appropriate food produced through ecologically sound, sustainable methods, and their right to define their own food and agriculture systems. It puts the aspirations and needs of those who produce, distribute and consume food at the heart of food systems and policies, rather than the demands of markets and corporations. Food sovereignty prioritises local and national economies and markets, and empowers peasant and family farmer-driven agriculture, artisan-style fishing, pastoralist-led grazing, and food production, distribution and consumption based on environmental, social and economic sustainability.

We urgently demand of local, national and international decision makers:

- The complete dismantling of agribusiness companies: they steal the land of small producers, produce junk food and create environmental disasters.
- The replacement of industrialised agriculture and animal production by small-scale sustainable agriculture supported by genuine agrarian reform programmes.
- The promotion of sane and sustainable energy policies. This includes consuming less energy, and producing solar and biogas energy on farms – instead of heavily promoting agrofuel production, as is currently the case.
- The implementation of agricultural and trade policies at local, national and international levels supporting sustainable agriculture and local food consumption. This includes a ban on subsidies that lead to the dumping of cheap food on markets.

1 Extracted from La Via Campesina's statement on climate change, http://www.viacampesina.org/main_en/index.php?option=com_content&task=view&id=457&Itemid=37

to what many people think, is a living, dynamic ecosystem. Healthy soil teems with microscopic and larger organisms that perform many vital functions, including converting dead and decaying matter (and minerals) into plant nutrients. Different soil organisms feed on different organic substrata. What distinguishes this living system from dust is that it can retain and slowly provide the nutrients needed by plants to grow. It can store water and slowly release it into rivers and lakes or into the microscopic surroundings of plant roots, so that rivers can run and plants can absorb water long after rain has fallen. If soils did not allow these processes to take place, life on earth as we know it simply wouldn't exist.

A key component of what makes soils function is known as soil organic matter (SOM). It is a mixture of substances that originate from the decomposition of plant and animal materials. It includes substances excreted by fungi, bacteria, insects and other organisms. As manure and dead organisms decompose, they gradually liberate nutrients that can be taken up by plants and used in their growth and development. As all these substances get mixed into the soil, they form new molecules that give the soil new characteristics. Molecules of SOM can absorb up to 100 times as much water as those of dust, and they can retain and later release to plants a similar proportion of nutrients.[1] Organic matter also provides binding molecules that keep soil particles together, thus protecting the soil against erosion and rendering it more porous and less compact. These characteristics are what allows soils to absorb rain and slowly release it to lakes, rivers and plants. They also allow plant roots to grow. As plants grow, more stubble reaches or stays in the soil and more organic matter is formed, thus creating a continuous cycle that accumulates organic matter in the soil. This process has taken place for millions of years, and the accumulation of organic matter in soils was a key factor in lowering the amount of

1 C.C. Mitchell and J.W. Everest, "Soil testing and plant analysis", Southern Regional Fact Sheet, Department of Agronomy & Soils, Auburn University, http://tinyurl.com/lbg6st

CO_2 in the atmosphere millions of years ago, thus making possible the emergence of current forms of life on Earth.

Organic matter is mostly found in the top layer of soil, which is the most fertile. Being on the top, it is prone to erosion and needs to be protected by a plant canopy, which is in turn a permanent source of additional organic matter. Plant life and soil fertility have thus been mutually enhancing processes, and organic matter has been the bridge between the two. But organic matter is also the food of bacteria, fungi, small insects and other organisms that live in the soil. They are the ones that turn manure and dead tissue into nutrients and the amazing substances described above, but they are also the ones that decompose organic substances in the soil. So organic matter must be replenished constantly; if it is not, it will slowly disappear from the soil. When micro-organisms and other living beings in the soil decompose organic matter, they produce energy for themselves and release minerals and CO_2 in the process. For each kilogram of organic matter that decomposes, 1.5 kilograms of CO_2 are released into the atmosphere.

Rural peoples around the world have a deep understanding of soils. They learned through experience that soil has to be cared for, nurtured, fed and rested. Many common practices of traditional agriculture reflect this knowledge. The application of manure, crop residues and compost feed the soil and renovate organic matter. Leaving some land unplanted (fallow) in a system of rotation, especially when spontaneous wild vegetation is encouraged (covered fallow), allows the soil to rest, so that the decomposition processes can take place properly. Limits on tilling, terraces, mulching and other conservation practices protect the soil against erosion, so that organic matter is not washed or blown away. Forest cover is often kept intact, altered as little as possible or mimicked, so that trees can protect the soil against erosion and provide additional organic matter. At those times in history when these practices have been forgotten or laid aside, a high price has been paid. This seems to have been one of the main causes of the disappearance of the Maya kingdom in Central America. It may have also been behind a number of crises in the Chinese empire, and it is certainly a central cause of the dust bowl in the United States and Canada.

The industrialisation of agriculture and the loss of soil organic matter.

The industrialisation of agriculture, which started in Europe and North America and was later replicated in the Green Revolution that took place in other parts of the world, was based on the assumption that soil fertility can be maintained and increased through the use of chemical fertilisers. Little attention was paid to the importance of organic matter in the soil. Decades of industrialisation in agriculture and the imposition of industrial technical standards on small farming have weakened the processes that ensure that soils obtain new supplies of organic matter and that protect the organic matter already stored in the soil from being washed or blown away. The effects of not renovating organic matter and applying fertilisers initially went unnoticed because of the large stocks of organic matter within the soils. But over time, as these stocks have been depleted, the effects have become more visible -- with devastating consequences in some parts of the world. From a global point of view, the pre-industrial equilibrium between air and soils was that for every tonne of carbon in the air, approximately 2 tonnes existed in soils. The current ratio is down to approximately 1.7 tonnes in soils for each tonne in the atmosphere.[2]

Photo: Practical Action

Crops destroyed by drought

Soil organic matter is measured in percentages. One per cent means that in every kilogram of soil, 10 grams are organic matter. Depending on soil depth, this is equivalent to 20–80 tonnes per hectare. The amount of organic matter necessary to ensure fertility varies widely, according to how the soil was formed, what other components it has, climatic conditions, and so on. It can be said, however, that generally 5 per cent organic matter is a good minimum for healthy soil, but for some soils the best growing conditions will be reached only when the organic matter content is more than 30 per cent.

2 Y.G. Puzachenko et al., "Assessment of the Reserves of Organic Matter in the World's Soils: Methodology and Results", *Eurasian Soil Science*, Vol. 39, No. 12, 2006, pp. 1284–96, http://tinyurl.com/npd648

Box 2: The growing problem with industrial fertilisers

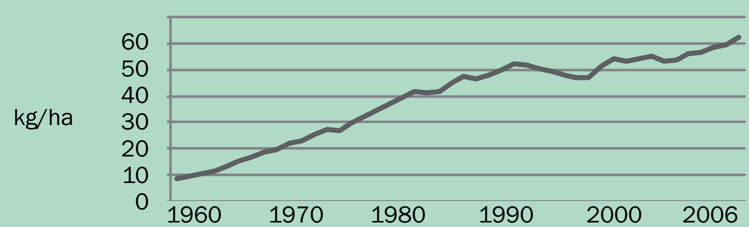
An important factor in the destruction of soil fertility has been the tremendous global increase in the use of chemical fertilisers in farming, with consumption more than quintupling since 1961.[1] Graph 1 tracks the increase of world consumption of nitrogen per hectare, a seven-fold increase since the 1960s.[2] But a lot of this extra nitrogen does not reach the plants, and ends up in groundwater or the air. The more nitrogen fertiliser is applied, the less efficient it becomes. Graph 2 shows the relationship between yields and nitrogen fertiliser consumption for corn (maize), wheat, soya and rice, the four crops that cover almost a third of all cultivated land. For all of them, the yield per kilo of nitrogen applied is today about one third of what it was in 1961, when fertiliser use started to expand worldwide.

The ever decreasing efficiency of industrial fertilisers should come as no surprise. Soil experts and farmers have long known that chemical fertilisers destroy soil fertility by destroying organic matter. When chemical fertilisers are applied, soluble nutrients become immediately available in huge amounts, provoking a surge of microbial activity and multiplication. This increased microbial activity, in turn, speeds up the decomposition of organic matter, as it is consumed at high speed, and CO_2 is released into the atmosphere. When nutrients from fertilisers become scarce, most micro-organisms die, and the soil is left with less organic matter. As this process has been going on for decades, and is reinforced by tilling, soil organic matter is depleted. It is made worse because the same technological approach that promotes chemical fertilisers rules that crop residues should be discarded or burnt, not put back into the soil.

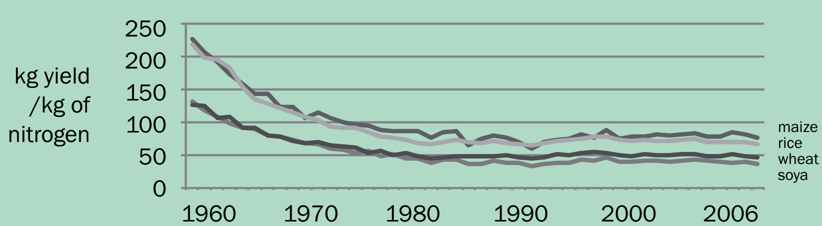
As soils lose organic matter, they become more compact, absorb less water and have a diminished capacity to retain nutrients. Roots grow less and have less capacity to absorb nutrients, nutrients are more easily lost from the soil, and less water in the soil is available for growth. The result is that the use of nutrients from fertilisers becomes less and less efficient, and the only way to overcome such inefficiency is to increase fertiliser doses, as world trends show. But increased application only compounds the problem; inefficiency and soil destruction continue apace. It is not uncommon to hear organic farmers say that they turned organic because their yields collapsed after years of heavy industrial fertiliser use.

Problems with industrial fertilisers do not end there. The forms of nitrogen provided by chemical fertilisers are readily transformed in the soil, so that nitrous oxides are emitted into the air. Nitrous oxides have a greenhouse effect more than two hundred times as strong as that of CO_2,[3] and they are responsible for more than 40 per cent of the greenhouse effect caused by current agricultural practices. Worse, nitrous oxides also destroy the ozone layer.

Graph 1: Increasing nitrogen fertilisation: from a world average of 8.6 kg/ha in 1961 to 62.5 kg/ha in 2006.[4]



Graph 2: For each kg of nitrogen applied, 226 kg of maize were obtained in 1961, but only 76 kg in 2006. The figures were, respectively, 217 and 66 kg for rice, 131 and 36 kg for soya, and 126 and 45 kg for wheat.[5]



1 See website of the International Fertilizer Industry Association (IFA), http://www.fertilizer.org/ifa/Home-Page/STATISTICS
2 Data obtained by GRAIN based on statistics provided by IFA (see note 1), and FAO, http://faostat.fao.org/default.aspx
3 P. Forster *et al.*, "Changes in Atmospheric Constituents and Radiative Forcing", in S. Solomon *et al.* (eds), *Climate Change 2007: The Physical Science Basis*, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, London and New York, Cambridge University Press, 2007, p. 212.
4 Data from IFA website (see note 1)
5 Data obtained by GRAIN based on statistics provided by IFA (see note 1) and FAO (see note 2).

According to a wide range of studies, agricultural soils in Europe and the United States have lost, on average, 1–2 percentage points of organic matter in the top 20–50 cms.[3] This figure may well be an underestimate, as most often the point of comparison is the organic matter level in the early twentieth century, when many soils had already been subjected to industrialised processes, and could have already lost large amounts of organic matter. Some soils in the agricultural mid-west in the USA contained 20 per cent carbon in the 1950s, and are now down to a mere 1–2 per cent.[4] Studies in Chile, Argentina,[5] Brazil,[6] South Africa,[7] and Spain[8] report losses of up to 10 percentage points. Data provided by researchers of the University of Colorado indicate that the world average for organic matter loss in cultivated land is 7 percentage points.[9]

The climate calculation

Let us suppose, as a conservative estimate, that soils around the world have lost, on average, 1–2 percentage points of organic matter in the top 30 cm since the beginning of industrial agriculture. This would amount to some 150,000–205,000 million tonnes of lost organic matter. If we were to manage to put this organic matter back into the soil, we would take 220,000–330,000 million tonnes of CO_2 from the air. This represents a remarkable 30 per cent of the current excess CO_2 in the atmosphere. Table 1 summarises the data.

In other words, actively recovering SOM would effectively cool the planet, and the cooling potential is significantly higher than that presented in these figures, as many soils could store – and benefit from – a larger amount of organic matter than the 1–2 percentage point recuperation rate used in this example.

Can it be done? Bringing organic matter back into the soil

The industrialisation of farming that has destroyed SOM has been going on for more than a century in industrialised countries. The global process, however, really started with the Green Revolution in the 1960s. So the question is: how long would it take to counteract the effects of, say, 50 years of soil deterioration? Recovering one percentage point of SOM means that around 30 tonnes of organic matter per hectare would have to enter the soil and remain there. But, on average, around two thirds of organic matter added to agricultural soils will be decomposed by soil organisms (and the resulting minerals will feed the crops), so in order to add permanently 30 tonnes of SOM, a total of 90 tonnes of organic matter per hectare would be needed. This cannot be done quickly. A gradual process is required.

What is the realistic amount of organic matter that farmers throughout the world could incorporate into the soil? The answer will vary widely from place to place, from cropping system to cropping system, and from one ecosystem to another. A production system that relies exclusively on annual, non-diversified crops can provide 0.5–10 tonnes of organic matter per hectare per year. If the cropping system is diversified, and pastures and green manures are incorporated, that amount can easily be doubled or tripled. If animals are added, the amount of organic matter will not necessarily increase, but it will make the cultivation of pastures and green manures economically feasible and profitable. Moreover, if trees and wild plants are also managed as part of the cropping system, not only will crop production increase but additional organic matter will also be produced. As organic matter increases in the soil, soil fertility will

Table 1: Capturing carbon dioxide by building soil organic matter (SOM)

CO_2 in the atmosphere[1]	2,867,500 million tonnes
Excess CO_2 in the atmosphere[2]	717,800 million tonnes
World's agricultural land[3]	5,000 million hectares
World's cultivated land[4]	1,800 million hectares
Typical reported SOM loss in cultivated land	2 percentage points
Typical reported SOM loss in prairies and non-cultivated land	1 percentage point
Amount of organic matter lost from the soils	150,000–205,000 million tonnes
Amount of CO_2 that would be sequestered if these losses were recuperated	220,000–300,000 million tonnes

1 See Carbon Dioxide Information Analysis Center, http://cdiac.ornl.gov/pns/graphics/c_cycle.htm
2 Calculations based on concentration changes over time.
3 Information from FAOSTAT, http://faostat.fao.org/site/377/default.aspx#ancor
4 Ibid.
Source: GRAIN calculations

3 R. Lal and J.M. Kimble, "Soil C Sink in U.S. Cropland", http://tinyurl.com/muurmc
P.Bellamy. "UK losses of soil carbon – due to climate change?", Natural Resources Department, Cranfield University, http://tinyurl.com/l9zcjx

4 Tim J. LaSalle and Paul Hepperly, "Regenerative Organic Farming: a solution to global warming", Rodale Institute, 2008, http://tinyurl.com/mle5nq

5 I. Gasparri, R. Grau, E. Manghi. "Carbon Pools and Emissions from Deforestation in Extra-Tropical Forests of Northern Argentina Between 1900 and 2005", abstract available at http://tinyurl.com/ljrjyo
J. Galantini. "Materia Orgánica y Nutrientes en Suelos del Sur Bonaerense. Relación con la textura y los sistemas de producción" http://tinyurl.com/nkjhfh

6 Carlos C. Cerri, "Emissions due to land use changes in Brazil", EU Conference on Soil and Climate Change, 12 June 2008, http://tinyurl.com/m3dmyz

7 C. S. Dominy, R. J. Haynes, R. van Antwerpen, "Loss of soil organic matter and related soil properties under long-term sugarcane production on two contrasting soils", *Biology and Fertility of Soils*, Vol. 36, No. 5, November 2002, pp. 350–56, abstract available at http://tinyurl.com/kp9gav

8 E. Noailles and A. de Veiga, "Pérdida de Fertilidad de un Suelo de Uso Agrícola", Instituto de Suelos, Argentina, abstract available at http://tinyurl.com/nc92cl

9 K. Paustian, J. Six, E.T. Elliott and H.W. Hunt, "Management options for reducing CO_2 emissions from agricultural soils", *Biogeochemistry*, Vol. 48, No. 1, January 2000, pp. 147–63, abstract available at http://tinyurl.com/nlzekf

Box 3: The NPK mentality – poor soils, poor food

We now know that plants absorb 70–80 different minerals from a healthy soil, while most chemical fertilisers add no more than a handful. In the mid-nineteenth century, German chemist Justus von Liebig conducted experiments in which he analysed the composition of plants in order to understand which elements were essential for their growth. His primitive equipment identified only three: nitrogen, phosphorus and potassium, known by their chemical symbols as NPK. Although von Liebig later acknowledged that many other minerals are present in plants, his experiments laid the foundations for a lucrative agrochemical industry, which sells NPK fertilisers to farmers with the promise of miraculously increased yields. NPK fertilisers have certainly revolutionised agriculture, but at the cost of a tragic degradation of the quality of the soil and our food.

In 1992, the official report of the Rio Earth Summit concluded "there is deep concern over continuing major declines in the mineral values in farm and range soils throughout the world". This statement is based on data showing that, over the last 100 years, average mineral levels in agricultural soils had fallen worldwide, by 72 per cent in Europe, 76 per cent in Asia and 85 per cent in North America. Most of the blame lies with the massive use of the artificial chemical fertilisers instead of more natural methods of promoting soil fertility. Apart from the direct depletion that the NPK mentality provoked, chemical fertilisers also tend to acidify the soil, thus killing many soil organisms that play a role in converting soil minerals into chemical forms that plants can use. Pesticides and herbicides can also reduce the uptake of minerals by plants, as they kill certain kinds of soil fungi that live in symbiosis with plant roots (called mycorrhiza). The micorrhiza symbiosis give plants access to a vastly greater mineral extraction system than is possible by their roots alone.

The net result of all of this is that most of the food we eat is mineral-deficient. In 1927, researchers at the University of London's King's College started to look into the nutrient content of food. Their analyses have been repeated at regular intervals since, giving us a unique picture of how the composition of our food has changed over the last century. The table summarises their alarming results: our food has lost 20–60 per cent of its minerals.

Reduction in average mineral content of fruit and vegetables in the UK between 1940 and 1991

Mineral	**Vegetables**	**Fruit**
Sodium	−49%	−29%
Potassium	−16%	−19%
Magnesium	−24%	−16%
Calcium	−46%	−16%
Iron	−27%	−24%
Copper	−76%	−20%
Zinc	−59%	−27%

A new study published in 2006 shows that mineral levels in animal products have suffered a similar decline. Comparing levels measured in 2002 with those present in 1940, the iron content of milk was found to have declined by 62 per cent, while calcium and magnesium in Parmesan cheese had each fallen by 70 per cent, and copper in dairy produce had plummeted by a remarkable 90 per cent.

From: Marin Hum, "Soil mineral depletion", in *Optimum nutrition*, Vol. 19, No. 3, Autumn 2006.

improve and more organic matter will become available. When they start converting to organic farming, many farmers incorporate fewer than 10 tonnes per hectare per year, but they may end up after a few years producing and adding up to 30 tonnes of organic matter per hectare.

So, if proactive agricultural policies and programmes were drawn up to promote the widespread incorporation of organic matter into the soil, initial goals might have to be rather modest, but progressively more ambitious goals could be set. Table 2 gives an example of how organic matter could be incorporated into the soil.

The example is completely feasible. Today agriculture around the world produces each year at least two tonnes of usable organic matter per hectare. Annual crops alone produce more than one tonne per hectare,[10] and recycling urban organic waste and waste water could add approximately 0.2 tonnes per hectare.[11] If the recuperation of SOM became a central goal of agricultural policies, it would be perfectly possible and reasonable to set as an initial

10 Calculations by GRAIN based on world production of annual crops. Figures obtained using data provided by J.B. Holm-Nielsen (http://tinyurl.com/l4nqra) and the Oak Ridge National Laboratory of the US Department of Energy (http://tinyurl.com/t4x96) at least double the amount of annual crop residues. The same figures can be arrived at using data provided by the University of Michigan at http://tinyurl.com/38mrkw

goal the incorporation on average throughout the world of 1.5 tonnes per hectare per year. The new scenario would require a change in approach, with the use of techniques such as diversified cropping systems, better integration between crop and animal production, increased incorporation of trees and wild vegetation, and so on. Such an increase in diversity would, in turn, increase the production potential, and the incorporation of organic matter would progressively improve soil fertility, creating virtuous cycles of higher productivity and higher availability of organic matter. The capacity of soil to hold water would increase, which would mean that excessive rainfall would lead to fewer, less intense floods and droughts. Soil erosion would become less of a problem. Soil acidity and alkalinity would fall progressively, reducing or eliminating the toxicity that has become a major problem in tropical and arid soils. Additionally, increased soil biological activity would protect plants against pests and diseases. Each one of these effects implies higher productivity and hence more organic matter available to soils, thus making possible, as the years go by, higher targets for SOM incorporation. More food would be produced in the process.

But even the very modest initial goal would have far-reaching effects. As Table 2 shows, the process would start with the annual incorporation of 1.5 tonnes of organic matter in the first 10 year period, which means that 3,750 million tonnes of CO_2 would be captured each year. This is about 9 per cent of the current total annual human-made emissions.[12] Two other forms of reduction in greenhouse gases (GHGs) would simultaneously take place. First, nutrients equivalent to more than all of current world fertiliser production would be captured in the world's agricultural soils.[13] The elimination of the current production and use of chemical fertilisers would have the potential to reduce yet further GHG emissions by reducing both emissions of nitrous oxide (equivalent to approximately 8 per cent of all GHG emissions and, after deforestation, by far the most important contribution made by agriculture to the greenhouse effect) and the worldwide production and transportation of fertilisers, which is currently responsible for more than 1 per cent of world GHG emissions.[14] Second, if organic waste was returned to agricultural soils, methane and CO_2 emissions from landfills and waste water (equivalent to 3.6 per cent of total current emissions)[15] could be significantly reduced. In sum, even such a modest start would have the potential to reduce global GHG emissions by approximately 20 per cent per year.

And we are talking only about the first ten years. Table 2 shows that, if we were to increase progressively the reincorporation of organic matter into our agricultural soils, within 50 years we would increase the share of organic matter in the soil by two percentage points. This is about the same amount of time that was taken to reduce it. In the process we would have captured 450 billion tonnes of CO_2, more than two thirds of the current excess CO_2 in the atmosphere!

It can be done, but it needs the right policies

The climate crisis requires a political response, with many broad social and economic changes. Even though the recuperation of SOM is a feasible and beneficial way to cool the earth, climate change will continue to accelerate unless we have fundamental changes in our patterns of production and consumption. The process of returning organic matter to the soil will not be possible if current trends towards increased land concentration and

Table 2. Impact of the progressive incorporation of soil organic matter (SOM) into world's agricultural soils

number of years	1–10	11–20	21–30	31–40	41–50
Tonnes of organic matter incorporated (per hectare per year)	1.5	3	4	4.5	5
Total organic matter incorporated in world's agricultural land by the end of the period (cumulative, in million tonnes)	75,000	225,000	425,000	650,000	900,000
Average increase of organic matter in the soil at the end of the period (in percentage points)	0.15	0.50	0.94	1.4	2.0
Total CO_2 captured per year (in million tonnes)	3,750	7,500	10,000	11,250	12,500
Total CO_2 captured across the period (cumulative, in million tonnes)	37,500	112,500	212,500	325,000	450,000

Source: GRAIN calculations

11 Calculations based on figures provided by K.A. Baumert, T. Herzog and J. Pershing, "Navigating the Numbers: Greenhouse Gas Data and International Climate Policy", World Resources Institute, http://tinyurl.com/m5e7kb

12 Calculations based on figures provided by the Greenhouse Gas Bulletin No. 4, http://tinyurl.com/m4apxz

13 Calculations based on the following contents of nutrients in organic matter and efficiency of recovery: nitrogen: 1.2–1.8%, 70% efficiency; phosphorus: 0.5–1.5%, 90% efficiency; potassium: 1.0–2.5%, 90% efficiency.

14 See "Navigating the Numbers: Greenhouse Gas Data and International Climate Policy", World Resources Institute, http://tinyurl.com/m5e7kb

15 *Ibid.* See also http://tinyurl.com/lfrcx4

Box 4: Climate solutions from organic farming

For more than 50 years, the Rodale Institute in Pennsylvania, USA, has been carrying out research into organic farming. Nearly 30 years of Rodale Institute soil carbon data show conclusively that improved global terrestrial stewardship – including regenerative organic agricultural practices – is the most effective available strategy for mitigating CO_2 emissions. Below are some of their impressive conclusions.[1]

> "During the 1990s, results from the Compost Utilisation Trial (CUT) at Rodale Institute – a 10-year study comparing the use of composts, manures and synthetic chemical fertiliser – show that the use of composted manure with crop rotations in organic systems can result in carbon sequestration of up to 2,000 lb/acre/year. By contrast, fields under standard tillage relying on chemical fertilizers, lost almost 300 lb of carbon per acre per year. Storing – or sequestering – up to 2,000 lb/acre/year of carbon means that more than 7,000 lb of carbon dioxide are taken from the air and trapped in that field soil.
>
> In 2006, US carbon dioxide emissions from fossil fuel combustion were estimated at nearly 6.5 billion tons. If 7,000 lb/CO_2/ac/year sequestration rate was achieved on all 434 million acres of cropland in the United States, nearly 1.6 billion tons of carbon dioxide would be sequestered per year, mitigating close to one quarter of the country's total fossil fuel emissions."
>
> "Agricultural carbon sequestration has the potential to substantially mitigate global warming impacts. When using biologically based regenerative practices, this dramatic benefit can be accomplished with no decrease in yields or farmer profits. Even though climate and soil type affect sequestration capacities, these multiple research efforts verify that practical organic agriculture, if practised on the planet's 3.5 billion tillable acres, could sequester nearly 40 per cent of current CO_2 emissions."

1 From: Tim J. LaSalle and Paul Hepperly, *Regenerative Organic Farming: A Solution to Global Warming*, Rodale Institute, 2008, http://www.rodaleinstitute.org/files/Rodale_Research_Paper-07_30_08.pdf

homogenisation of the food system continue. The daunting goal of returning to the soil over 7 billion tonnes of organic matter every year will be feasible only if it is undertaken jointly by millions of farmers and farming communities. This, first and foremost, requires fundamental agrarian reforms that give small farmers – the vast majority of farmers around the world – access to land, and makes it economically and biologically possible for them to make the necessary crop rotations, covered fallow and the formation of pastures. It also requires dismantling current anti-farmer policies that drive farmers off the land, such as laws that foster the monopolisation and privatisation of seeds, and regulations that protect corporations but kill off traditional food systems. The global growth of hyper-concentrated industrial animal production – which creates mountains of manure and lakes of slurry that spew millions of tonnes of methane and nitrous oxide into the air – must be reversed and replaced by decentralised animal husbandry integrated with crop production. As we show in other articles in this issue of *Seedling*, the current international food system, one of the central drivers of climate change, requires nothing short of a complete overhaul. If this is done, then the climate crisis has a possible solution: the soil.

Box 5: Building organic matter: fungi at work

> "Researchers are fleshing out the mechanisms by which soil carbon sequestration takes place. One of the most significant findings is the high correlation between increased soil carbon levels and very high amounts of mycorrhizal fungi. These fungi help to slow down the decay of organic matter. Beginning with our Farming Systems Trial, collaborative studies by the USDA's Agriculture Research Service (ARS), led by Dr David Douds, show that the biological support system of mycorrhizal fungi are more prevalent and diverse in organically managed systems than in soils that depend on synthetic fertilisers and pesticides. These fungi work to conserve organic matter by aggregating organic matter with clay and minerals. In soil aggregates, carbon is more resistant to degradation than in free form, and thus more likely to be conserved. These findings demonstrate that mycorrhizal fungi produce a potent glue-like substance called glomalin that stimulates increased aggregation of soil particles. This results in an increased ability of soil to retain carbon."[1]

1 From: Tim J. LaSalle and Paul Hepperly, *Regenerative Organic Farming: A Solution to Global Warming*, Rodale Institute, 2008, http://www.rodaleinstitute.org/files/Rodale_Research_Paper-07_30_08.pdf