Global Development and Environment Institute
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Hope Below Our Feet

Soil as a Climate Solution

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Can the world meet the ambitious goals necessary to avoid catastrophic climate change? A major reduction in greenhouse gas emissions is clearly needed, but there is increasing scientific consensus that even if achieved, this will not be enough. In addition to a drastic reduction in carbon emissions, carbon must be removed from the atmosphere. An important solution is beneath our feet – the massive capacity of the earth's soils to remove and store carbon from the atmosphere.

Soils hold about three times more carbon than the atmosphere, and an increase in soil carbon content worldwide could close the "emissions gap" between carbon dioxide reductions pledged at the Paris Agreement of 2015 and those deemed necessary to limit warming to 2° C or less by 2100. To meet this challenge, several international efforts to build soil carbon have been launched, with similar measures underway in the United States.

Proposed policies include reforestation and innovative farming, ranching, and land management approaches that will enhance degraded soil and restore its carbon stock. The French-initiated effort, ***4 per 1000: Soils for Food Security and Climate***, introduced to coincide with the Paris Agreement, calls for an annual increase of 0.4% in annual global soil carbon storage which, if achieved, would amount to nearly one third of total anthropogenic emissions. This brief also addresses other international soil carbon enhancement initiatives and legislation considered or enacted in US states.

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The Climate Crisis and the Need for Negative Emissions

The severity of the climate crisis is alarming.[1] The Intergovernmental Panel on Climate Change (IPCC) predicts that without strong mitigation efforts, the likelihood of extreme and irreversible climate impacts is *highly likely*.[2] A 2016 climate paper suggested that ice sheets in Greenland could undergo exponential rather than linear decline, causing abrupt sea level increases of several meters within a few decades.[3] Additionally, it is now certain that even with immediate cuts in fossil fuel use, the warming impacts of CO_2 already in the atmosphere will continue for centuries.[4] The Paris Agreement, although a historic achievement, fails to meet emission reduction goals necessary to meet the target of 2ºC warming or significantly less by the year 2100. The difference between the voluntarily pledged reductions, and those deemed essential to meet even the basic 2ºC target, is called the "emissions gap."[5] To close this gap, and avoid the most extreme consequences there is a need for "negative CO_2 emissions."[6] In 1988, climate scientist James Hansen warned that:

> If humanity wishes to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted, paleoclimate evidence and ongoing climate change suggest that CO_2 will need to be reduced from its current 385 ppm to at most 350 ppm, but likely less than that.[7]

But today atmospheric CO_2 levels exceed 400 ppm and still rising. This level of CO_2 has not occurred since the Pliocene epoch, approximately 3 to 5 million years ago. While emission reduction efforts are essential, they are insufficient to meet climate protection goals, according to the Intergovernmental Panel on Climate Change:

> A large fraction of anthropogenic climate change resulting from CO_2 emissions is irreversible on a multi-century to millennial time scale, except in the case of a large net removal of CO_2 from the atmosphere over a sustained period. [8]

It will be necessary to remove carbon dioxide from the atmosphere and store it long-term. How can this be done?

Soil as a Climate Solution

Soil restoration can play a critical role in reducing atmospheric accumulations of carbon.[9] [10]

> If rapid phasedown of fossil fuel emissions begins soon, most of the necessary CO_2 extraction can take place via improved agricultural and forestry practices, including reforestation and steps to improve soil fertility and increase its carbon content.[11]

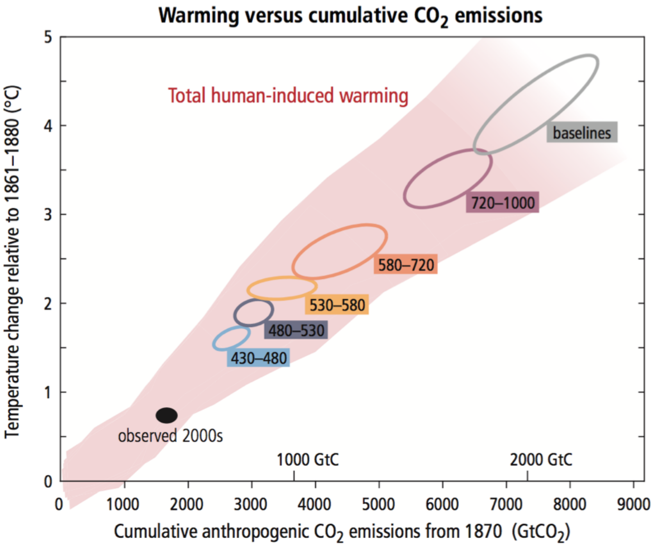

Figure 1: Warming Versus Cumulative CO2 Emissions, Scenarios to 2100

Source: IPCC (2014) Climate Change 2015: Synthesis Report Summary for Policymakers, Page 9.

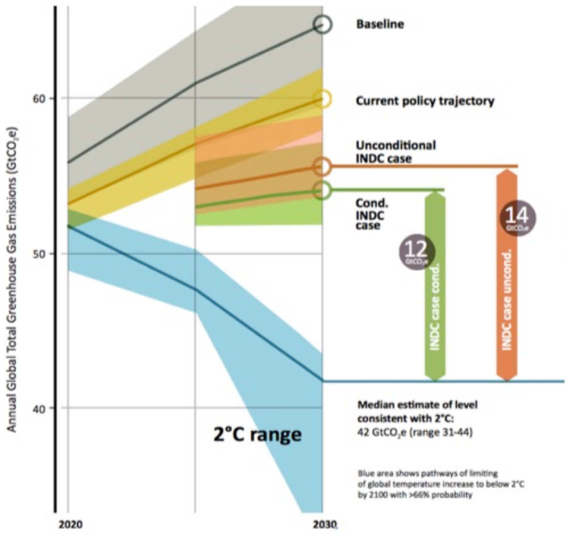

Figure 2: Emissions Gap to 2030 = 3.4 Gt/y

Source: UNEP (2015) Emission Gap Report, p.19.

Figure 1 shows global warming as a function of human-caused carbon dioxide emissions for a range of different emission scenarios going to the year 2100. The 2015 Paris Agreement seeks to keep CO_2 levels to within the first circle range of 430 to 480 ppm, with corresponding temperatures of 1.5 to 2.0° C above pre-industrial levels. **Figure 2** shows the discrepancy between the pledged reductions committed to in Paris and those deemed necessary to meet the goal of 2° C warming by 2100. The gap corresponds to approximately 12 gigatons (billion tons) of CO_2 or 3.3 gigatons of carbon (GtC) per year by 2030 in the best-case scenarios, where conditional Nationally Determined Commitments (NDCs) are included.[12] The goal of the "4 per 1000" proposal discussed in this paper is to remove and store 3.4 GtC per year in world soils, just enough to close this emissions gap.

Soils in the Carbon Cycle

Carbon circulates among terrestrial plants, soils, the oceans, and the atmosphere, as shown in **Figure 3**. (This figure dates from 2004, when atmospheric carbon levels were approximately 800 GtC, as indicated in the graph. As of April 2017, they are approximately 870 GtC.)

Terrestrial and ocean emissions and absorption of CO_2 have been in balance for eons, but human activities have altered the balance, with 9 Gt extra emissions. Some, but not all, of these extra emissions have been absorbed through photosynthesis and by the oceans (numbers in red in Figure 3). The role of oceans as a carbon sink has buffered climate change, but has also has caused an acidification of the oceans, which poses threats to marine ecosystems.

The two major terrestrial carbon sinks are plant biomass, currently a repository of 550 Gt of carbon, and soils, containing 2,300 gigatons. Can we store more carbon in soils, and if so, how?

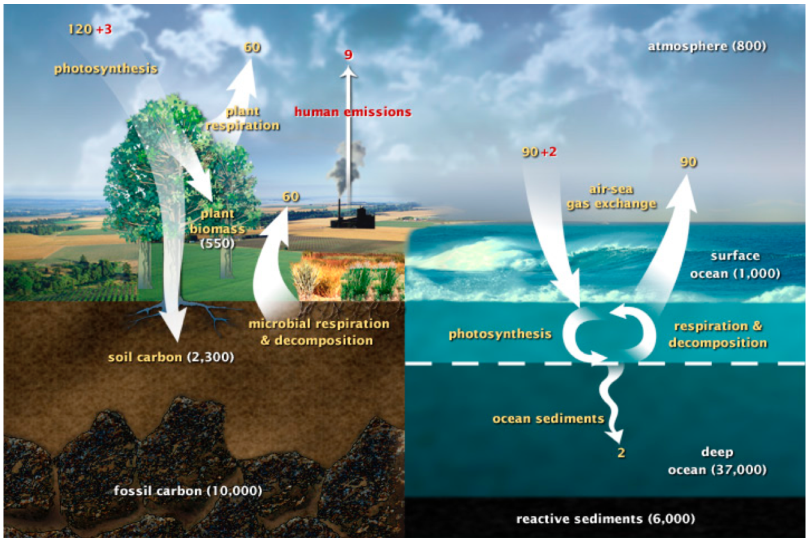

Figure 3: The Carbon Cycle: Soil as the Largest Terrestrial Reservoir
Values are in Gigatonnes C.
Source: http://earthobservatory.nasa.gov/Features/CarbonCycle/

Since the dawn of settled agriculture, the original terrestrial pools of carbon have been drastically altered by human activities including deforestation, biomass burning, soil cultivation, and drainage of wetlands. It is estimated that there has been a global depletion of more than 320 Gt of carbon as a result of global land use change [13] - of which 180 Gt were released into the atmosphere between 1750 and 2000.[14] Today agricultural soils contain 25% to 75% less soil organic carbon than their counterparts in undisturbed or natural ecosystems.[15]

Healthy thriving soils are complex ecosystems, with high carbon content and a great diversity of life. Intensive forms of farming using chemical fertilizers, pesticides, herbicides and fungicides, are a leading cause of degradation of soils worldwide, as are destructive grazing practices in pasturelands. But through appropriate practices that would enhance carbon pools in soils and biota, the potential terrestrial carbon sink capacity could be restored, essentially reversing its historic depletion, in what has been called the "recarbonization" of the biosphere.[16]

Regenerating soils leads to multiple benefits: reducing the concentration of atmospheric CO_2, but also enhancing biomass production, and purifying and storing surface and ground waters. In recent years, thousands of successful local experiments, in the Global South as well as in the Global North, have adapted "pre-modern" methods of sustainable farming and/or introduced innovative soil management forms that mimic and enhance the natural functioning of ecosystems and their rhythms of regeneration.

These approaches include:

- **Cultivated Soils (croplands):** 1) Agroecology and permaculture; 2) No-till methods that leave soils undisturbed; 3) Increased intercropping and use of cover crops; 4) Planting trees and legumes that fix atmospheric nitrogen; 5) Feeding the soil with manure and compost; 6) Reducing erosion and soil loss from sloping soils through terracing; 7) Boosting soil microbiology with root, (mycorrhizal) fungi and other microorganisms; 8) Using biochar (adding charcoal to soils).
- **Pasture Soils:** Promoting best sustainable practices in pasture management and restoring degraded grasslands, notably by regenerative grazing practices.[17]
- **Forested Soils:** Ending deforestation, promoting reforestation, regeneration of degraded forest ecosystems, and agroforestry.
- **Other Soils:** Restoring peatlands and wetlands; restoration of salt-affected soils; reclaiming desertified lands. [18]

The technical potential of carbon sequestration is in the range of 1.8 to 4.4 Gigatons of carbon per year, globally (See Table 1).[19]

Table 1: Technical potential of carbon sequestration in world soils for 50-100 years

Ecosystem Type	Technical Potential Gt C/yr
Croplands	0.6 – 1.2
Grazing lands (grasslands and rangelands)	0.5 – 1.7
Restoration of salt affected soils	0.4 – 1.0
Desertification control	0.3 – 0.5
Total	**1.8 – 4.4**

Source: ww.c2es.org/indc-comparison

The 4 per 1000 Initiative: Climate and Food Security

An international initiative launched by the French Ministry of Agriculture in 2015, to accompany the Paris Agreement, calls for global action to store carbon in soils. A Scientific Committee composed of researchers from leading research institutes in agronomy and soil sciences,[20] reviewed existing research in the field to obtain an estimate of 3.4 gigatons of carbon per year as the maximum "technical potential" for additional carbon storage in soils.

This increase in the carbon composition of soils would take place in topsoil, to a depth of about 40 cm (16 inches). Given that the topsoil layer contains 860 Gt of carbon worldwide, the annual percentage addition of carbon to topsoil would be 3.4/860 = 0.4%. This percentage can also be expressed as **4 per 1000**, which accounts for the name of the program introduced by the French government.

The 4 per 1000 initiative emphasizes the twin benefits of soil enhancement: 1) capturing carbon as a mitigation strategy to climate change; while 2) enhancing the fertility of soils, and their yields to address the problem of world hunger. An independent international initiative, it includes nation-states, regional authorities, non-profit organizations, and businesses.[21] It is an example of *Restorative Development* by which human needs are met in a manner that restores ecosystems instead of degrading them.

As noted above, if implemented fully, the 4 per 1000 initiative would capture an additional 3.4 Gt of carbon in soils per year. The methods needed to accomplish this goal could be closely connected with measures for reforestation and prevention of forest degradation, codified in the United Nations Framework on Climate Change, as the "REDD+" set of measures ("Reducing Emissions from Deforestation and Forest Degradation"). It has been estimated that REDD+ mitigation strategies could sequester at least 1 Gt of carbon per year in biomass by avoiding land use change. In synergy with soils mitigation strategies, it could be over 2 Gt per year if existing secondary forests were allowed to grow to maturity.[22]

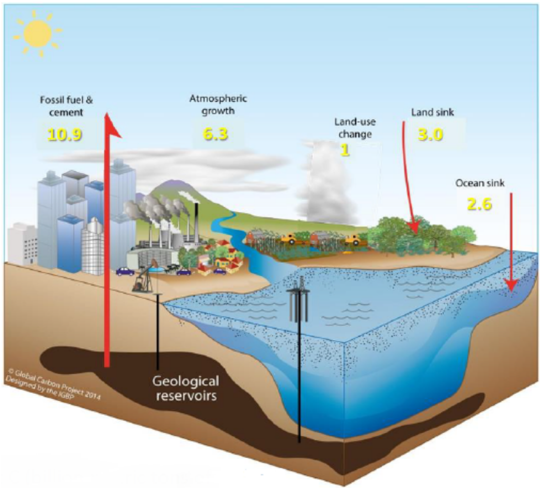

Figure 4: Carbon cycle in 2030-2050, following the Paris Agreement but without any implementation of enhancement of soils and biomass sink

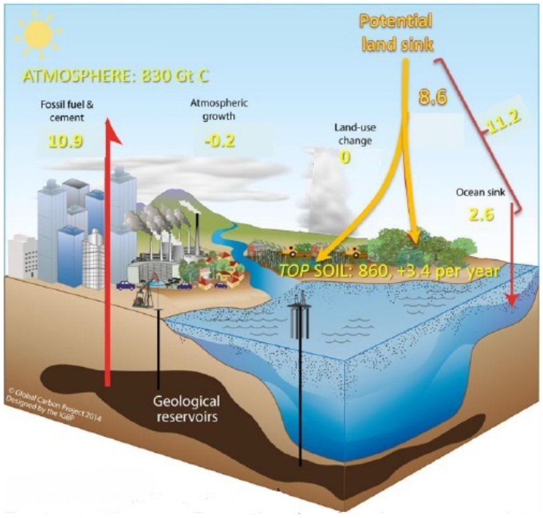

Figure 5: Carbon cycle in 2030-2050, following the Paris Agreement, with the full implementation of 4 per 1000 and REDD+

Figure 4 shows what the carbon budget would look like including the atmosphere, the oceans, terrestrial ecosystems, and soils[23], during the period 2030-2050, assuming that the Paris Agreement has been fully implemented, but without any action on enhancing carbon sinks in soils and forests. 10.9 Gt of carbon would be released every year from fossil fuel and cement usage, up from the about 9.7 Gt in 2015. This figure of 10.9 Gt is significantly lower than it would be in a Business as Usual scenario, as the Paris agreement is assumed to lead countries to adopt more energy savings policies and to switch to non-fossil fuel-based energy.

In this scenario, ocean sinks would absorb 2.6 Gt, land and biomass sinks would absorb 3 Gt (only slightly higher than the current 2.6 Gt), and land-use practices would still be a net contributor of 1 Gt per year (assuming that current agricultural practices continue expanding deforestation and land use changes). That would mean that 6.3 Gt of carbon would be added to the atmosphere each year, adding more than 3 ppm in CO_2 concentration – a path that would launch us on the trajectory of an increase in global temperatures much higher than 2°C, probably close to 3°C.

Figure 5 shows the scenario where the Paris Agreement is complemented by the 4 per 1000 soil initiative and REDD+, implemented to their fullest potential and in synergy with each other. This gives a totally different picture. In 2030-2050, 10.9 Gt of carbon per year is still released into the atmosphere annually, but land use is no longer a contributor to climate change, as land and biomass sinks sequester 8.6 Gt per year, 5.6 Gt more than in the Figure 4 scenario (an extra 3.4 Gt in soils and 2.1 Gt in biomass). Assuming oceans continue to absorb 2.6 Gt of carbon per year, carbon removals would exceed additions by 0.2 Gt/yr. Overall carbon dioxide levels in the atmosphere would thus start to decrease. These soil carbon sinks, however, are not infinite. They will reach their own saturation points. It, therefore, remains imperative to implement deeper cuts in fossil fuel emissions.

Feeding the World

The other potential positive impact of the 4 per 1000 initiative results from the fact that increasing soil carbon at the root zones of crops by one metric ton per hectare increases the yields by 20 to 70 kg per hectare of wheat, 10 to 50 kg per hectare of rice, and 30 to 300 kg per hectare of maize – which would lead to an increase of 24 to 40 million metric tons in grain production at the global level.[24] For the 800 million people who live in extreme poverty with less than $1.90 a day[25], this could mean an additional 30 to 50 kg of grains per person per year.

Three billion people living in rural areas all over the world, including those working in 570 million farms worldwide, could potentially implement the 4 per 1000 initiative, and the restoration methods can be applied in both rich and poor countries.

Equitable Financing & Employment

The cost of sequestering an additional ton of carbon has been estimated at $70 to $140 in croplands soils, per year, and $180 to $280 in grasslands and forests.[26] These are primarily labor costs, as improved practices tend to be labor intensive. Thus, these costs translate into jobs, and this great opportunity to create new jobs in rural areas could reduce the exodus of impoverished rural populations flocking to urban slums worldwide.

The full implementation of the 4 per 1000 initiative, with an additional sequestration of 3.4 Gt of carbon in soils worldwide, would carry an estimated cost of about $500 billion per year, which translates into an extra $160 per year in extra revenue received by each of the 3 billion people living in rural areas and whose incomes are among the lowest. How could this be financed? Interestingly, the projected cost is at the same level of magnitude as current agricultural subsidies worldwide, about $500 billion. Those subsidies favor large-scale farms and agribusinesses, heavily relying on mechanization and chemical inputs, the kind of agriculture primarily responsible for negative externalities in terms of soil loss and biodiversity impoverishment.[27] A re-direction of these "negative" subsidies to the regenerative 4 per 1000 initiative could be a key policy for achieving the goals of carbon reduction and improved food security.

Other International Efforts

In addition to the 4 per 1000 initiative analyzed above, other programs are bringing regenerative agriculture and restorative soil development into the forefront of political, economic, and environmental planning. Three such programs are *Regenerative Development to Reverse Climate Change*, the *Land Degradation Neutrality Fund (LDNF), and Climate Smart Agriculture.* (See Table 2)

Table 2: International Soil Carbon Initiatives

Policy Title	Focus	Agency(ies)
4 per 1000: Soils for Food Security and Climate[28]	Efforts and commitments to increase soil organic carbon by four parts per thousand (0.4%) per year	French Ministry of Agriculture and other international partners
Regenerative Development to Reverse Climate Change[29]	Funding to support regenerative agriculture programs in 52 member nations in The Commonwealth of Nations (the former British Empire)	The Commonwealth of Nations
Land Degradation Neutrality Fund (LDNF)[30]	Innovative financial market for investing in profit-generating sustainable land management and restoration projects globally in support of the UN Sustainable Development Goal 15.3 for assuring land degradation neutrality.	UNCCD, UNEP, Mirova
Climate Smart Agriculture (CSA)[31]	Goal of food security and development, by enhancing agricultural productivity, and climate adaptation, and mitigation	FAO, World Bank, Dutch Government

Commencing in 2021, the European Union will accept land use change, including carbon storage in soils and forests, in calculations toward meeting its commitment of 40% reductions in greenhouse gases (GHG) by 2030 compared to 1990 levels.[32] This broader inclusion of carbon sources and sinks in GHS accounting will inspire further interest in regenerative agriculture efforts.[33]

US Legislation

In addition to 4 per 1000 and other international initiatives mentioned above, state-level legislative initiatives in the United States are addressing the need for regenerative agriculture, restoration of degraded soils, and carbon storage in soils. As with the international efforts, these are being done to mitigate climate change and enhance productivity while improving food and water resilience (Table 3).

Table 3: State Programs on Soil and Carbon

State	Title	Number
California	Healthy Soils Initiative: [34] [35]	S.B. 32
	Water Conservation in Landscaping Act: [36]	S.B. 780
Connecticut	An Act Concerning the Labeling of Topsoil Sold to Customers and the Carbon Content of Soil Sold in the State and Used for Regenerative Farming Purposes [37]	H.B. 6976
Maryland	Maryland Healthy Soils Program [38]	H.B. 1068
New York	Carbon Farming Tax Credit [39]	A3281
Oklahoma	Carbon Sequestration Enhancement Act [40]	*27A-3-4-101*
Utah	Concurrent Resolution on Carbon Sequestration on Rangelands [41]	H.C.R.8
Vermont	Regenerative Soils Program [42]	S.B. 43
	Regenerative Agriculture Program [43]	H.B. 430

Conclusion

Soil carbon restoration is emerging as a potential strategy to mitigate global warming while also enhancing food and water security. The Paris Agreement, although a laudable achievement for the international community, is insufficient to meet its basic goal of 2° C warming by 2100, while scientists have warned that, in fact, 1.5° C is the maximum that should be permitted to avoid catastrophic impacts.[44] In order to close the emissions gap between nationally determined contributions under the Paris agreement and necessary carbon reductions to avoid the most extreme climate disruptions, extensive sequestration of carbon dioxide from the atmosphere is required. Globally, soils have the potential to sequester up to 3.4 GtC per year, just enough to close the "emissions gap." If combined with other atmospheric CO_2 removal efforts, such as reforestation, yearly additional carbon capture in soils and forests could be as high as 5 GtC per year. When combined with deep cuts in fossil fuel emissions, this could lead to a substantial overall reduction in atmospheric carbon dioxide.

The Tufts University Global Development and Environment Institute (GDAE), in conjunction with Soil4Climate, is initiating an effort to research and publicize the significant potential of natural systems to store carbon through improved restorative management.
GDAE's past climate policy briefs discuss the Paris agreement, the role of forests and soils, and current policies on biomass and forests. Look for future policy briefs with more information on forests, soils, and biomass.

Endnotes

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