

Biotic Soil Organic Carbon (SOC) Stock: What We Had & What We Lost

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Abstract

Land's basic biota metric is soil organic carbon (SOC) yet global estimates range 1,417–15,000 Gt C. Erosion of ancient topsoil and loss of vital soil taxa are most urgent – and most ignored – of all context-triaged concerns. Albeit topographical terrain increases most soil calculations and inventories on a non-flat Earth, re-evaluation shows the major contribution to unrelenting atmospheric CO₂ increase more from topsoil loss than fossil fuels. Although increased CO₂ has resulted in a global greening effect with NPP productivity now ~220 Gt C/yr, this is arguably outweighed by more rapid erosion of topsoil and expansion of desertification at 2-15 Gt SOC/yr volatilized due to excessive meat eating with unsupportable soil extractive, toxic farm management. In particular excess synthetic Nitrogen acidifies topsoil and depletes the organic SOC biotic-dynamics. Carbon credits of our disappearing soil biotic stocks are enumerated for plant roots (916 Gt C), litter (600 Gt C), microbes (200 Gt C), fungi (30 Gt C), biocrust (10-20 Gt C), earthworms (2.3-3.6 Gt C), termites (0.15 Gt C), nematodes (0.06 Gt C), ants (0.024 Gt C), and soil viruses (0.02–4.0 Gt C). Consideration of soil microbes and review of global SOC inventories reveal critical topsoil loss up to 20,000 tonnes per second with species extinction as high as 23 taxa each second. Sustainable Development Goals (SDGs) fail without a solid soil foundation. However, heritage soil data points to remedy in modern organic farm restoration. Safe solution is via natural vermi-composting, 100% organic farming, and Permaculture under a simple logical premise that the Problem (i.e., SOC loss) is the Solution (viz., SOC restoration).

Keywords: Humus, soil biota, organic soil carbon, atmospheric CO₂, carbon credits and deficits.

INTRODUCTION

Soil erosion and degradation, melting of boreal Permafrost and peat loss are critical issues that are mostly downplayed or quite ignored in discussions of Ecological Sustainability or Climate Change. The introduction and expansion of intensive agriculture and overgrazing pastoralism have been associated with forest clearance and topsoil erosion since earliest days. An essential

consequence of soil erosion is loss of soil organic carbon (SOC) to waterways or air with biotic declines ultimately leading to desertification. Early realization of the urgency of soil deficits led to organic restoration proposals by Lady Eve Balfour (1943) and Sir Albert Howard (1945).

A 2015 FAO summary report (www.fao.org/3/i5199e/i5199e.pdf) said: *“Today, 33 percent of land is moderately to highly degraded due to the erosion, salinization, compaction, acidification and chemical pollution of soils.”* However, *“FAO TerraSTAT interpretation of GLASOD by Bot et al. (2000), on the other hand, finds that over 6 billion ha, or 66 percent of the world’s land, has been affected by degradation, leaving roughly only a third of the world’s surface in good condition”* (Gibbs et al. 2015). In data presented below, depletion of arable soils is by >50% since expansion of agriculture in prehistoric times and loss rate is rapidly accelerating daily.

UK’s recent Dasgupta Review ([2021](#)) summarizes: *“Collating data on soil erosion, WWF (2017) reported that some half of all top soils have eroded in the past 150 years. A typical estimate is that 75 billion tonnes of soil erode annually at a rate 13 to 40 times the background rates of erosion that prevailed before the acceleration caused by human dominance of the biosphere (Pimentel and Kounang, 1998). The rate of soil erosion accompanying land-use change is judged to be the highest in the past 500 million years (Wilkinson and McElroy, 2007), and some regard it to be the greatest geomorphic agent on the planet today (Hooke, 2000).”*

Major environmental threat to sustainability, productive capacity of agriculture, and species survival is soil degradation. Whereas mountain streams – filtered by forest soils – are crystal clear, agricultural areas mostly have brown rivers (also polluted) and dusty farm air. Farm soils, a travesty if exposed, are mostly depauperate and undarkened by carbon. That requires fixing.

Why Are Soils So Important and Yet So Poorly Known?

Nature and humanity depend upon soils for survival. Despite being eroded (exploited?) at a massive scale, soils yet provide all our fibre/shelter materials, 99.7% human food, filter and store most of our freshwater supplies, many of our medicines (such as Penicillin, Streptomycin, Ivermectin, etc.), and support >99.9% of biodiversity and biomass although know only a tiny fraction of the soil biota. UK’s Dasgupta Review ([2021](#)) provides: *“The soils also supply most of the water needed by plants and for terrestrial biodiversity. Soil water makes up 65% of the world’s fresh water, is the source of 90% of global farm output and provides over 99% of our food calories.. we obtain more than 99% of our food calories from land-based products”*. This

concur with Pimentel & Burgess (2013 from “FAO, 2004” data): “humans worldwide obtain more than 99.7% of their food (calories) from the land and less than 0.3% from the oceans and aquatic ecosystems”. However, until recently, global soil metrics were based upon an unrealistic flat-Earth basis and most research concentrates, illogically, on Oceans or Space.

Soil ecological data are surprisingly so poorly known that values may differ by an order or two of magnitude, often revised upwards. For example, soil SOC stocks range 1,417-15,000 GtC due to a statement by Hiederer & Kochy (2012) that: “the global SOC stock to 100cm soil depth is estimated at 1,417 Pg C” compared to current best estimates for total global SOC of >10,000–15,000 Gt (Blakemore 2018b, 2020b - <https://veop.files.wordpress.com/2020/06/veop-4-5.pdf>) that is seemingly endorsed by Lal (2019a, 2019b, 2020). Without terrain, errors were manifest in mineral soils underestimated by up to seven times (Harper & Tibbett, 2013), Permafrost by 200% or three times (Shelef et al. 2017) – these base values since doubled by Blakemore (2018b, 2020b) – and total Peat SOC is further doubled (Loisel et al. 2021; Nichols & Peteet, 2019, 2021). Winkler et al. (2021b) posited global land use change are 4 x greater than previously estimated. Koren et al. (2019) say soil<->air flux varies widely from 25–450 PgC/year.

Agricultural land use accelerates erosion with rate of loss: “unsustainable at 10–1000 times higher than the rate at which soils form” (Kopittke et al. 2019). Preindustrial SOC emission estimates range from 69-357 Gt C (e.g. van Oost et al. 2012). Postindustrial estimations since 1850s are also variable with conversion of natural ecosystems to agricultural resulting in supposed depletion of SOC releasing between 50–200 Gt C into the atmosphere (cf. Lal 2009).

Roots are underestimated by up to 100% (Robinson, 2004). Mainly terrestrial Bacteria have uncertainty, as with most other soil biota, of up to 10 fold (Bar-On et al. 2018). For Net Primary Productivity (NPP) estimates were 2–5 times higher accounting for belowground dynamics (Scurlock et al. 2002), and Running et al. (2004) discuss wide disparities in both satellite and model assumptions with: “range of two orders of magnitude in field-measured NPP”.

In each case, of the situations given above, subsequent studies tend to support higher values.

Herein allowances wrought for topographical terrain alone double most soil and biotic values, but changes are cardinal numerics rather than exponential. For example, land surface from unrealistic planimetrically flat 15 Gha upps to topographical 30-64 Gha; earthworm numbers and biomass at least double and scurrying ant abundance goes from 2×10^{16} to $>4 \times 10^{16}$ ants.

A major reason for our ignorance of soil basics is lack of a single dedicated “**SOIL ECOLOGY INSTITUTE**” compared to myriad Marine facilities (even in unlikely Las Vegas e.g., UNLV GEOG-116 Oceanography, eeb.arizona.edu/search/node?keys=marine); or landlocked Switzerland (www.switzerlandfortheoceans.org/). This soil research/education deficit is addressed below.

Prehistoric and Historic Rates of SOC Losses

Since prehistoric times humans have unwittingly caused a critical loss of organic matter from soil above natural recycling levels due to “fire-stick farming” and clearing of forests for grassland or cropland. Organic carbon derived from living organisms is stored in soils to depth and Buringh (1984) estimated total 537 Gt SOC loss: from an initial 2,014 (“*prior to the spread of civilizations in the last two millennia*”) to 1,477 Gt SOC. This is 60 Gt more than Hiederer’s 1,417 Gt SOC, although neither guesstimate considers deeper soils nor Permafrost cryosols. Buringh (1984: tab. 3.5 and text) had forest to cropland conversion depleting $(208 - 95) = 113$ t/ha but forest to grassland was less at $(208 - 116) = 92$ t/ha. Percentage losses approximate as forest to cropland as -54%, slightly less for forest to grassland as -44% with a 10% difference.

This approximate halving of global SOC could presumably be reversed via forest restoration. However, human population since has doubled from 4 billion (1980s), to 8 billion today (2020s). Decisions to clear more forest for pasture or cropland requires an informed and balanced view.

Elhacham et al. (2020) also claim humanity has roughly halved the mass of plants since the Neolithic agricultural revolution, from about 2,000 Gt (on a dry-mass basis) down to the current value they say of ~1,000 Gt (or from about 1,000 to just ~500 Gt C). Furthermore, in the last 8,000 years or so conversion of natural vegetation into agriculture has resulted in an accumulated erosion of around $27,187 \pm 9,030$ Gt of topsoil worldwide according to Wang & Van Oost (2019). This they said resulted in an average cumulative sediment mobilization of $1,829 \pm 613$ kg m⁻² for croplands corresponding to an average soil truncation (or loss of depth) of ca. 1.34 ± 0.45 m. These authors also estimate the same depth of cropland soil (“*a mean of ca. 1.3 m*”) remains globally, so about 50% total crop soil loss. If SOC is taken as 2.5%, which may be reasonable for upper layers of topsoil, this gives a SOC carbon displacement of $(27,187 \times 2.5\%) = \sim 680$ Gt C. This is consistent with calculation by IPCC (2013: 484): “*The $\delta^{13}\text{C}$ of atmospheric CO₂ trapped in ice cores can be used to infer changes in terrestrial biospheric carbon pools*”.. “*a modelling study by Kaplan et al. (2011) suggested that more than 350 PgC*

[350 Gt C] could have been released as a result of LULCC [land use/land cover change] between 8 ka and 1850 as a result of a much stronger loss of soil carbon in response to land use change”.

Added to this is erosion at ~75 Gt/yr (Myers 1993, Pimentel et al. [1995](#), Pimentel & Burgess [2013](#): 447) in years since 1850 of ~13,000 Gt (~325 Gt SOC) explaining roughly half topsoil loss.

Cumulative soil carbon losses and emissions over the Holocene, or in the last 10,000 years, as a result of anthropogenic land and soil erosion were realistically estimated to range 456–537 Gt SOC loss (see Appendix A). Most studies however, omit a likely considerable loss of vegetation and soil prehistorically and presently occurring on the Australian continent as is discussed later. Lal (2006: tab. 3.5) has lowest SOC erosion and C emissions from “Oceania” at about half those from Europe albeit both continents are of similar size each being about ~6% of total land area.

As well as a sustainability imperative, SOC loss is a key contributory factor to CO₂ increase. Yet Ussiri & Lal ([2017](#)) misleadingly state: “At the beginning of Industrial Revolution, the emissions of CO₂ were from land use and land use change; now the emissions are largely (~90%) from fossil fuels” whereas, in reality, the reverse is true – soil respiration is 10–20 times (~90–95%) FF emissions. This promotes false ideas that FF are problematic, rather than it being a soil issue.

Latest Soil and Land Use Change (LUC) Contribution with Fossil Fuels (FF) to Atmospheric CO₂

On 11th November, 2022, following latest ESSD (2022; fig. 2) Global Carbon Budget Report (<https://doi.org/10.5194/essd-14-4811-2022>), new compilations by <https://ourworldindata.org/co2-data-update-2022> used data sourced from the Global Carbon Project (www.globalcarbonproject.org/carbonbudget/22/data.htm). New consensus cumulative emission values from 1850 to 2022 (ourworldindata.org/explorers/co2) converge on ~205 ± 60 Gt C due to LUC and ~465 ± 25 Gt C for FF, as shown in table below, with an increase of atmospheric CO₂ from 285 ppm in 1850 to 415 ppm today totalling ~+275 Gt C.

ESSD (2019: tab. 8 <https://essd.copernicus.org/articles/11/1783/2019/>) had shown a budget imbalance of 30 Gt C from the period 1850-2019 such that Gasser et al. (2020) discussed sources of error in LUC models but came to similar cumulative total while estimating LUC also reduced terrestrial sink capacity over the same period (Appendix A). Thus a combined “official” conclusion on human CO₂ emissions from 1850 in Gt C are a third (670/205 = 31.6%) from LUC, two thirds (670/465 = 69.4%) from FF, with almost half (670/276 = 41%) CO₂ accumulated.

However, while total FF values are easily accounted for (~9.6 Gt C/yr), LUC is more complex.

Following Blakemore (2018b), LUC calculations based upon planimetrically flat biomes are at least doubled for terrain. A new LUC value since 1850 is around 410 Gt C that, when added to a corresponding FF estimate of 465 Gt C, is 875 Gt C total emissions (+5Gt C/yr). This value is 31% higher than previous 670 Gt C total emissions (+4 Gt C/yr), yet unchanged atmospheric CO₂ increase of +276 Gt C may be accounted for by an accompanying 31% increase in terrestrial NPP due to a CO₂ fertilizing effect and warmer land (Haverd et al. 2020)*. The many authors on latest ESSD Global Carbon Reports are invited to comment and/or correct Table 1.

Table 1. Summary of Recent Reviews of Carbon Sources and an Atmospheric Sink (in Gt C).

| Carbon Loss/Gain GtC | OurWorldinData (%) | ESSD (2022) (%) | Current study (%) |
|--------------------------------|--------------------|-----------------|-------------------|
| LUC up to 1850 | | | ~350–537? |
| LUC after 1850 | 201* (31%) | 205* (31%) | 410 (47%) |
| FF Emissions >1750 | 459 (69%) | | |
| FF Emissions >1850 | | 465 (69%) | 465 (53%) |
| TOTAL Emissions | 660 (100%) | 670 (100%) | 875 (100%) |
| Increase CO ₂ >1850 | 276 (41%) | 274 (41%) | 276 (32%) |

* Unsurprisingly, Gassser et al. (2020) came up with about the same LUC of 206±57 Gt C in the 1750–2018 period showing how these experts all follow each other's data and vice versa.

[*Note: most Haverd et al. authors are from CSIRO "Oceans & Atmosphere" Business Unit, Canberra or "NIWA", NZ, i.e., as for NOAA, seemingly tasked to study everything except "Soil". The current CSIRO O&A Director is Canadian Dr Ken Lee, not to be confused with my mentor New Zealander Dr Ken Lee, an earthworm authority, who was Chief of CSIRO Division of Soils].

Recent Soil Erosion

Changes of carbon in the Ocean may be largely accounted for by increased soil erosion. Soil erosion has accelerated greatly in recent times yet Lal's (2004) rate of 136 Gt C/yr loss in 150 years or ~1 Gt C/yr is consistent with Lal (2006: fig. 3.2; tabs. 3.4, 3.5) showing current SOC transported by erosion 4.0-6.1 Gt C/yr; most (2.8-4.3 Gt or ~70%) redistributed over the landscape; 0.7-1.2 Gt C/yr (mean ~1 Gt C/yr or 20%) lost to the atmosphere; with 0.4-0.6 Gt C/yr (10%) flowing to the ocean via rivers (or coastal erosion?) (Figure 1). Reduced productivity in eroded soils may be exacerbated by translocations burying productive layers in alluvium.

Comparatively, Buringh (1984) had annual loss of soil organic carbon – mainly from clearing of forests – estimation range of 2.5–7.4 Gt C/yr with 4.6 Gt C/yr he considered a realistic mean.

INFLUENCE OF SOIL EROSION ON CARBON DYNAMICS IN THE WORLD

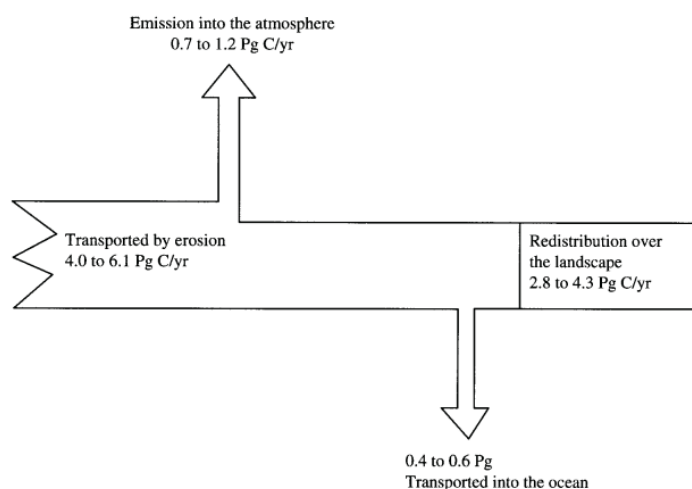


Figure 1. After Lal (2006: fig. 3.2) showing annual SOC loss mechanisms due to global erosion (from agriculture and natural processes) (Pg = Gt). Values mostly require doubling for terrain.

Annual amount of carbon naturally respired or decayed from soils is ~ 40 x erosion values. Lal & Pimentel (2008) argue for higher SOC loss values saying: “soil erosion is a strong source rather than sink of atmospheric CO_2 , and it also exacerbates the problem of nonpoint source pollution and hypoxia in coastal zones”. Data presented herein tend to support this conclusion.

Early on, Hutchinson (1954) suggested terrestrial biota appeared as a net source of CO_2 for the atmosphere, apparently he gained some ideas from V.I. Vernadsky’s concepts of the biosphere. Woodwell et al. (1978) agreed saying: “analysis shows through convergent lines of evidence that the biota is not a sink and may be a source of CO_2 as large as or larger than the fossil fuel source.” These authors said: “Because of the paucity and uncertainty of data the actual rate of release is elusive; under extreme conditions it could be as high as 18×10^{15} grams of carbon [18 Gt C] per year, or more than three times the annual release of carbon through combustion of fossil fuels, currently estimated as about 5×10^{15} g.” This is similar to SOC loss estimates herein.

Conversely, conserving earthworms reduces soil erosion considerably, not least their burrows allowing better drainage and moisture holding capacity; optimally they construct $\sim 9,000$ km/ha increasing soil porosity, infiltration and stimulating plant growth (Gaupp et al., 2015). Pimental & Kounang (1998) quote 220 earthworm burrows per m^2 (3–5 mm diameter) which is 2.2 million drainage points per hectare some of that may extend for several metres depth.

NPP Builds SOC

As already well known, terrestrial GPP/NPP is the most significant carbon cycle on Earth. ESDD (2022: fig. 2) now shows FF +9.5 Gt C/yr (big arrow!), GPP terrestrial exchange of ± 130 Gt C/yr (small arrows!), with similar amount of respiration, presumably half (~ 65 Gt?) from soil gives NPP ~ 65 Gt C/yr. Obvious underestimations, reviewed by Gerke (2022) show what Hayes & Clapp (2001) stated 20 years ago is realistic, namely: worldwide net release of CO_2 from soils is higher by a factor >10 than CO_2 released from fossil fuels. Annual CO_2 net emissions from soils Gerke has at 350 Gt CO_2e (≈ 94.5 Gt C) compared to CO_2 from FF combustion of ~ 9 Gt C/yr. Soil respiration at ~ 100 Gt CO_2 C/yr is >10 x FF emissions (Bahn et al. 2010, Blakemore 2020b).

Soil respiration (SR) at ~ 100 Gt C/yr implies Plant Respiration (PR) about the same to total ~ 200 Gt C/yr balancing GPP from formula $\text{NPP} = \text{GPP} - (\text{PR} + \text{SR})$ (Figure 2). Yet these NPP values are also likely underestimates requiring updates as NPP is now ~ 220 Gt C/yr (Blakemore 2018b).

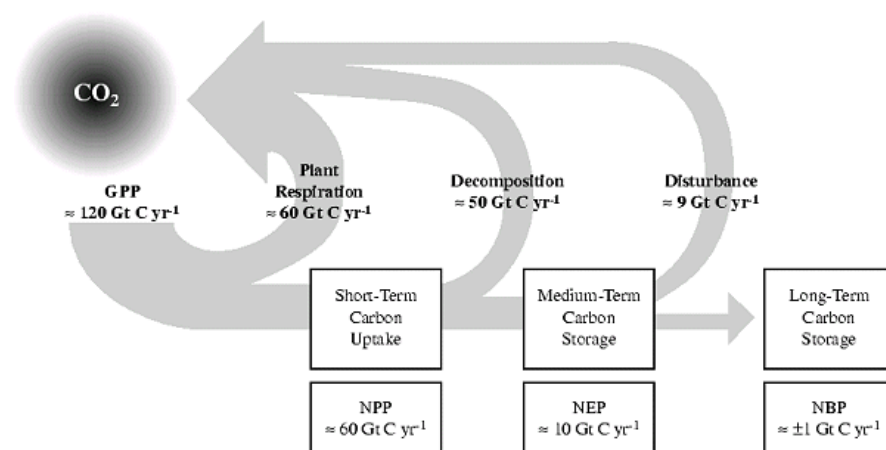


Figure 2. Carbon Cycle from IPCC (2000: fig.1.2 Special Reports LUC - https://archive.ipcc.ch/ipccreports/sres/land_use). “Disturbance” is from “both from natural and anthropogenic sources (e.g., harvest)”. Net Ecosystem Production (NEP) adds to SOC organic matter often as NBP or Net Biome Production. Terrain at least doubles all these values.

In the figure above, if “Disturbance” is doubled for terrain to 18 Gt C/yr and half is due to humans, then 9 Gt C/yr is about the same as FF emissions (see “HANPP” below of ~ 15 Gt C/yr). General considerations are that, rather than admitting 10 times FF emissions, the latest report (ESDD 2022: fig. SPM1) shows net LUC (including soil) CO_2e at just 11% of total. Hence all calculations that ignore terrain are underestimated by two to four times as is discussed below.

True Land Surface Area

Remarkably, all terrestrial calculations of global metrics assume a planimetrically flat Earth of just 15 Gha, ignoring the reality that land is hilly and soil is bumpy. As neither NASA nor NOAA provide a global topography area total, it was beholden upon individual researcher to provide data as compiled by Blakemore (2018b) that effectively doubled land area at coarse metre scale and quadrupled it at superimposed finer cm-mm scale. Whereas terrain increases most actual land values, relative proportions remain roughly the same except for aquatics (e.g. mangroves, despite much hype, a trivial 0.1%; or inland water bodies also promoted at 2.6% - both now likely halved to 0.05% and 1.3%). Figure 3 summarizes initial land proportions and use.

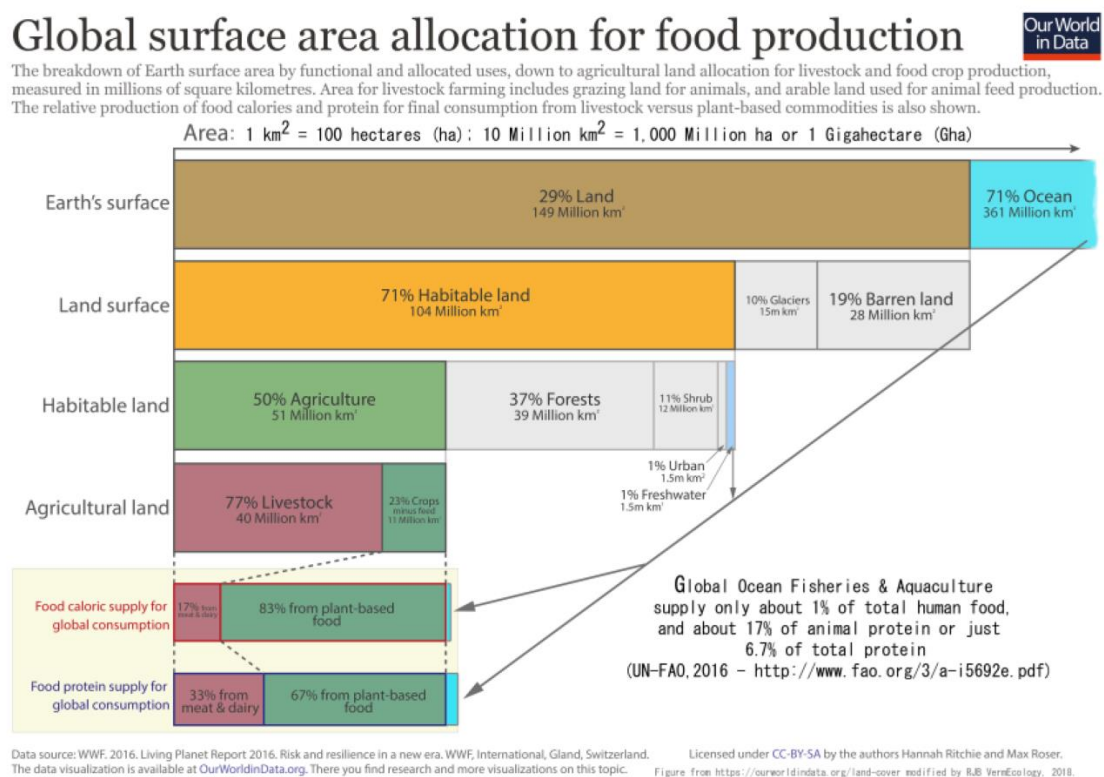


Figure 3. Areas (after Blakemore 2018b: fig. 4). Note: Aquaculture feedstock is often from land. Most ice-core or atmospheric data (and some soil samples?) are reliably inviolate whereas all flat biome extrapolations almost certainly underestimate totals due to neglect of terrain factor. Greater soil surface areas naturally accommodates more plants and has more exposure to the basic elements thereby validating productivity (NPP) and soil organic matter (SOC) increases.

Three main questions to be answered are: What is the total soil organic carbon (SOC) stock? What is the historic and current soil erosion rate and how much does this contribute to CO₂

accumulation. What is the total above and below ground biomass/necromass stock? Can SOC lost from agriculture be reclaimed via organic restoration management to help offset CO₂ rise?

Context of Global Carbon Budgets

Carbon (C) is the fourth most abundant element in the universe by mass after hydrogen, helium, and oxygen (O). On Earth's crust carbon is the 15th most abundant element forming a unique diversity of organic compound at prevailing temperatures and pressures and is a clear indication of living matter. The UNEP Cambridge (2002: tab. 2.1) "*World Atlas of Biodiversity*" has total carbon content of Earth as >81,000,000 Gt, allocated as in the revised Table 2.

Table 2. Earth's Global Carbon Budget.

| CARBON STORE | Inactive & Active C Gt (%) | Active C at Surface Gt (%) |
|---------------------------------------|----------------------------|----------------------------|
| Sedimentary rock (carbonate) | 65,000,000 (80.20%) | |
| Sedimentary rock (organic) | 16,000,000 (19.74%) | |
| Dissolved inorganic (sea) | 38,000 (0.05%) | |
| Active carbon at Surface | Median ~22,000 (0.03%) | |
| Organic carbon (soil)* | | 10,000-15,000 (60%) |
| Dissolved inorganic (soil)* | | 3,000-6,000 (20%) |
| Biomass Soil (+ litter, roots)* | | 2,000 (8%) |
| Biomass on Land* | | 1,100 (2%) |
| Atmospheric carbon (CO ₂) | | 875 (4%) |
| Organic carbon (fossil fuels) | | 805 (4%) |
| Organic carbon (sea) | | 700 (2%) |
| Biomass in Sea** | | ~5.0 (0.02%) |
| Biomass in Freshwater*** | | <1.0 (0.005%) |
| Biomass in Air**** | | <0.5 (0.002%) |
| TOTAL (%) | 81,060,000 (100%) | 18,000-26,000 (100%) |

* Terrain at least doubles values (above-ground biomass ~1,100 Gt C is 99.6% cf. 0.4% oceanic).

** Most authors have total biomass in all of Earth's oceans at ~3–6 Gt C total (0.4% cf. on land).

*** Grosberg et al. (2012) show aquatic systems have less than a third as many biota as ocean.

**** Air biota is 2×10^6 /m² cells + pollen; half insect mass (<0.5 Gt C) and wild birds/bats, etc.

Context of Abundance, Biodiversity and Biomass

Most biodiversity and biomass – excluding phytomass – on Earth is microbial (Prokaryota mainly Bacteria, Archaea, etc.) with immense numbers compared to the Eukaryota numbering only in the millions or billions. (Whether distinct mitochondria found inside nearly all Eukaryota cells – as used for mtDNA barcode identification – also represent separate species is outside of the scope of the present work). For Prokaryote biomass, a much-cited study (Whitman *et al.* 1998 [Ref](#): tab. 5) of estimated total global cellular carbon biomass at 353–546 Pg (median ~450 Gt), they claimed almost equalled the carbon storage in land plants (~560 Gt).

Their allocation of prokaryotic cells was approximately 367×10^{28} in oceans or 276×10^{28} on land (with 305.2 Gt C in ocean and 241 Gt C on land). These totals were revised by several subsequent researchers, not least Bar-On et al. (2018) who have just 77 Gt C microbe biomass, and biodiversity by Louca et al. (2019). A summary by Blakemore (2022) is revised in Table 3.

Table 3. Number and Biomass of Prokaryotes in the World's Severn Ecological Realms

| Ecological Realm | Cells/CFUs $\times 10^{28}$ (%) | Species or OTUs (%) | Biomass Gt C (%) |
|----------------------|---------------------------------|---------------------------------|-----------------------------|
| 1. Soils | 210 * (65%) | 2.1×10^{24} * (99.99%) | ~200* (66%) |
| 2. Land superficial | ? | ? | ? |
| 3. Land subsurface | Median ~100? (31%) | ? | ~100? (33%?) |
| 4. Ocean | 12 (4%) | $>10^{12}$ | 0.6-2.2 ** (0.3%) |
| 5. Marine subsurface | 2.9 *** (1%) | ? | 4.1 *** (1.3%?) |
| 6. Aquatic on Land | 0.02 ** | $<10^{12}$? | 0.3? ** (0.1%) |
| 7. Atmosphere | $(10^{24} ?)$ **** | $(>10^{10} ?)$ | $(100,000 \text{ t?})$ **** |
| *Totals recalculated | $>324 \times 10^{28}$ (100%)? | $\sim 2 \times 10^{24}$ (100%)? | >305 (100%)? |

* From Blakemore (2022) (greatly modified after Whitman et al. [1998](#): tab. 5).

** Whitman et al. [1998](#) aquatic habitats, mainly ocean, are 0.6-2.2. Gt C (or just 0.15-0.55%); Grosberg et al. (2012) estimate that aquatic habitats on land have a third biodiversity of sea.

*** Global ocean sediment carbon was potentially reduced to 90 Gt for Archaea in a 2008 study (Lipp et al. 2008), then Kallmeyer *et al.* ([2012](#)) reduced both this and the original 303 Gt C to just 4.1 Gt C. Carbon ratio from latter figure gives $(2.2 + 4.1 =) 6.3$ Gt ocean to 48-241 Gt land; thus the ocean contribution [6 in $(48 + 6 = 54)$] is at best 11% or, at worst, 6 in $247 = 2.4\%$ and a reasonable median ratio for microbial life in sea to soil is just 6 : 144 or 4%. [Summary: [https://en.wikipedia.org/wiki/Biomass_\(ecology\)](https://en.wikipedia.org/wiki/Biomass_(ecology))].

**** At 10^6 cells/m² to 1 km (<https://en.wikipedia.org/wiki/Aeroplankton>) is 10^{24} ($>10^{10}$ spp?). Whitman et al. (1998) state: "By volume, the atmosphere represents the largest compartment of the biosphere, and prokaryotes have been detected at altitudes as high as 57–77 km".

McMahon & Parnell (2013: tab. 3) reassessed Whitman et al.'s (1998: tab; 5) estimated continental subsurface biomass of 22-215 Gt C in the light of more recent data and refined it to 14–135 Gt C in the top 2 km of continental crust. Moreover, Whitman et al.'s Ocean subsurface sediment of 303 Gt C, was potentially reduced to 90 Gt for Archaea in a 2008 study (Lipp et al. 2008), then Kallmeyer *et al.* ([2012](#)) reduced both this and the original 303 Gt C to just 4.1 Gt C. Bar-On et al. (2018) appear to confirm approximate ratios. These deep carbon data are of less concern to the current study on soils and land's carbon cycles, although they again highlight deficiency of ocean's excessively claimed biota at all scales and all depths.

Whitman *et al.* (1998 [Ref](#): tab. 2) have land estimates for flat-earth areas (total 12.3 Gha) multiplied by numbers of microbe cells sampled from each biome. Terrain will at least double the land count and thus the total biomass by at least one third. Thus land's allocation is yet again greatly increased proportional to that of the ocean for Earth's biota. Many taxa move

variously between the seven main Realms of Life, Grosberg et al. (2012) said their main habitat distinction maybe defined along the lines of where they breed or spend the majority of their time (living, dormant or deceased?). Condensing to super-realms we may refer to those species that breed in or on soils (the “Soliota”?) and a few mainly aquatic species (“Aquaota”?).

With this proper context, issues of preserving biodiversity (including humanity) can be triaged. To clarify, already it is known that soil organic matter loss greatly exceeds fossil fuel emissions.

Soil Respiration (SR) Balances NPP in Habitable Ecosystems

Already more than 40 years ago Schnitzer & Khan (1978) had shown the decay of organic soil matter provides the largest carbon dioxide input into the atmosphere, more so than fossil fuel, etc. emissions. However, the “official” claim of NASA/NOAA/CSIRO/IPCC is of global NPP (and = SR) about 60 Gt C/yr (86%) whilst FF emit about 10 Gt C/yr (ca. 14%). Yet many other reports do have higher estimates: e.g., isotope studies by Welp, Keeling et al. (2011) where: *“Our analysis suggests that current estimates of global gross primary production, of 120 petagrams of carbon per year, may be too low, and that a best guess of 150–175 petagrams of carbon per year better reflects the observed rapid cycling of CO₂”,* i.e., giving approximate NPP, PR & SR rates of >80 Gt C/yr with FF contribution only ~11%. Other “official” counts are also of higher NPP, e.g. IPBES (2018: 245) has *“a total global terrestrial NPP of around 100 PgC yr⁻¹”* trending towards an estimate of 218 Gt C/yr (Blakemore 2018b) reducing FF contribution to just 4–5% of total annual terrestrial carbon output. Ignoring terrain is perhaps a main reason models fail.

METHODS

Contemporary estimates of global soil metrics based upon planimetric land are presented and reviewed to give consensus estimates of their conventional values. Where appropriate these values are doubled to account for neglected topographical terrain after Blakemore (2018b: tab. 5). Rationale is from a “flat” Earth’s surface of 15 Gh total, excluding extreme hot or cold deserts, that Whitman et al. (1998: tab. 2) had with 12.1 Gha or 80% productive land (less 0.2 Swamps or marsh), footnoting that a cubic meter of soil is 1.3 t dry mass. In comparison, Fig. 3 has only 71% habitable land with good soil (ca. 10.4 Gha). Topographical terrain approximately doubles both total land surface area and soil values at the coarsest cm to metre sample scales.

Comparing global SOC loss estimates given in the Introduction, various historical or Long-Term Experimental SOC values are multiplied by true topographic area to give new loss/gain totals.

Gross Primary Productivity (GPP) in Gt C/yr from photosynthesis on land accepts Net Primary Productivity (NPP) as approximately half following Plant and Soil Respiration (PR, SR) from biotic digestion of Soil Organic Matter (SOM). Prior assumption that SOM comprised 58% carbon is simplified with lower van Bemmelen factor: SOC = 50% SOM after Pribyl (2010).

Biotic dry matter is considered ~50% C content too (Whitman et al. 1998, Bar-On et al. 2018). Masses are measured in Gigatonnes (Gt), areas in Gigahectares (Gha) and rates per year (/yr). Atmospheric 1 ppm CO₂ equals 2.124 Gt C, or again about double value; 1 Gt CO₂ has 0.27 Gt C. Conversion of SOC (g C/kg dry soil) to SOC (%) is by dividing by 10, e.g. 15 g C/kg dry soil = 1.5%.

Average SOC content is taken as about 2.5%. This is from “median values for SOC of around 1.3%” (Blakemore, 2018b); from Buringh (1984) with range 1–5% (median ~3%) in the 0 to 25 cm layer that presumably is eroded first; Pimentel & Kounang (1998) who have 4% SOC on average; and from Lal (2006) who takes a mean of 2%. Thus the stated range is 1-5% and for the most eroded upper 1 m topsoil layer a modestly reasonable average SOC may be 2.5%.

Main considerations of this paper are SOC and CO₂ that is 0.04% of atmosphere with an undeniable increase, oxygen O₂ at 21% declining only slightly, and ozone O₃ just 0.00006% that is greatly influenced by intensive agriculture and human activities. Without ozone all Life ends.

Ecological studies interlink, hence prehistoric SOC loss, rates of current loss and soil biota population data, where appropriate, are doubled for terrain with implications discussed below.

RESULTS & DISCUSSION

Historical and Current Topsoil Erosion Rates (as Gt Dry Mass and Gt SOC Stock Loss)

Various “flat” topsoil erosion values presented in Appendix A range -33–200 Gt dry/yr total topsoil erosion with -2.0–4.6 Gt C/yr SOC loss although Gao et al (2017) have river transport erosion alone of -4.0–6.0 Gt C/yr SOC loss. Moreover, Li et al. (2017) say: “As estimated globally, soil erosion redistributes on the order of 75 Gt of soil and 1–5 Gt soil organic carbon (SOC).” Doubled for terrain this is 150 Gt topsoil erosion and 2–10 Gt SOC loss; thus Fig. 4 estimates of 2.2–6.8 Gt C/yr seem reasonably reliable approximations. Moreover, as noted, Buringh (1984: tab. 3.8) had soil loss as 2.5-7.4 Gt C/y that, doubled for terrain is 5-15 Gt C/yr; and Alves et al. (2018: fig. 3) shows “soil degradation” rates of 2-6, doubled as 4-12 Gt C/yr. Thus total range of SOC loss estimates is now ~2-15 Gt SOC/yr loss ($\bar{x} = 8.5 \pm 6.5$ Gt SOC/yr).

How do LUC carbon emissions from 1850 compare or comply with current soil erosion rates?

Current Global SOC Percentage (SOC %) and Total Topsoil Loss

In 2018 an estimate of a true topographical surface area Earth was made (Blakemore, 2018b) as updated by Blakemore (2020b). Prior to this – on the false premise that land topography and soil rugosity are irrelevant compared to the large size of the Earth – all calculations assumed a planimetrically flat-Earth. One consequence was a substantial increase in the total global soil organic carbon (SOC) value. Earlier estimates of just 1,417 Gt C (by 4p1000.org from Hiederer & Kochy, 2012: “*Global SOC Stock Pg 1,417*”) as quoted by FAO (e.g. www.fao.org/3/i7268e/i7268e.pdf or www.fao.org/3/i6937e/i6937e.pdf) or of around 5,000 Gt C (by IPCC) that were raised, by new SOC calculations to 15,000 Gt C (Blakemore, 2019a: <https://vermecology.wordpress.com/2019/09/20/soc-upped-after-uninvited-comment-on-soil-syst-2018-2-64/>). Higher SOC values are seemingly supported by Lal (2019a, 2019b, 2020).

Compare this to Lal (2006: tab. 3.2) showing global Sediment and SOC erosion as 200 Gt/yr and 1.4 Gt SOC/yr (doubled to 400 and 2.8, respectively) thus having unrealistic SOC of just 0.7%. Lal (2020) estimates current water erosion of soil (dry topsoil) at 36.6 Gt/yr (from “Walling, 2008”), but Pimentel & Burgess (2013) had total soil erosion as 75 Gt/yr and Blakemore (2020b) had higher figures based upon the reported loss of SOC and an average soil SOC%. Lal said: “*The GCB [Global Carbon Budget ESSD] is strongly affected by accelerated erosion by water and reportedly emits ~1.1 Pg C/yr. [2]. However, the C emitted by erosion is not accounted for in the GCB.*” Nevertheless, soil carbon losses are undoubtedly much higher than these estimates.

A backcheck is 2-15 Gt C in 150-400 Gt topsoil loss = 1.3-3.75% with median 2.5% SOC. Q.E.D.

Loss range of 2-15 Gt C/yr if comprising 2.5% as mean topsoil SOC rather implies 80-600 Gt/yr loss compared to “official” erosion ranges 75-200 Gt, doubled for terrain to 150-400 Gt dry/yr.

Whereas 75 Gt/yr topsoil loss is about 2,000 dry tonnes per second (t/s). If 2-15 Gt C is lost with mean 2.5% SOC representing 80-600 Gt/yr, an equivalent topsoil loss is ~2,500-20,000 t/s.

Indications are clear that loss of SOC stock and terrestrial carbon cycles are as important, or more so, as contributory factors to atmospheric CO₂ accumulation than fossil fuel emissions.

Land Use Change [LUC] Emission Since Industrial Age

Land use change is often attributed to clearing of forests with erosion of soils. FAO (2015a: 1-1 <http://www.fao.org/3/a-i5199e.pdf>: 2015b: <http://www.fao.org/news/story/en/item/357059/icode/>) had global topsoil erosion ranges from 20 to 200 Gt/yr but argue that reasonable figures are ~25 Gt/yr by water, another 5 Gt/yr for tillage and 2–3 Gt for aeolian dust to total ~33 Gt/yr. Lal (2020, 2022) said erosion of 36.6 Gt/yr at present in the absence of reservoir trapping by water reportedly emits ~1.1 Gt C/yr. He estimated total amount of SOC displaced by sheet erosion from its source was 1.32 ± 0.20 Gt C/yr. Earlier, Lal (2020) had: “*The global magnitude of SOC erosion may be 1.3 Pg C/yr. by water and 1.0 Pg C/yr. by wind erosion..*” (total 2.3 Gt SOC/yr) and that ESSD Global Carbon Budget “*is incomplete and uncertain because SOC erosion is not accounted for.*” The total is 1–2.3 Gt/yr SOC loss that may be doubled for neglected terrain to 2–4.6 Gt/yr SOC erosion. Yet higher values are likely but are not particularly well studied due to lack of general soil research.

Purview of USA Department of Commerce’s National Ocean & Atmospheric Admin (NOAA) is everything except soil (!), while only one of the ~100 authors of the latest ESSD (2022) is from a soil facility (viz. “*Institute of Soil and Water Conservation*”). Their report mentions “soil” 28 times, “erosion” once, zero for “soil organic matter” or “humus”, while “ocean/marine” have >500 hits. Yet they admit: “*Uncertainties in current and historical carbon stocks in soils and vegetation also add uncertainty in the ELUC estimates. Unless a major effort to resolve these issues is made, little progress is expected in the resolution of ELUC.*” They fail to say by whom.

The ESSD (2022: tab. 4 and https://meta.icos-cp.eu/objects/luLZ5Dkg7UoiSt_ZLskXbwGw) LUC budgets are on a planimetrically flat area basis as their sources, e.g. Hansis et al. (2015) say: “*the net LULCC flux can be simply derived from information on carbon stocks of each land use state and the change in area*”. Areas such as, for example, Li et al. (2018) having: “*global areas of forest, cropland and grassland PFTs from ESA as 30.4, 19.3 and 35.7 million km²*” similar to the unrealistic flat areas shown in Blakemore (2018b: fig. 4) https://www.mdpi.com/soilsystems/soilsystems-02-00064/article_deploy/html/images/soilsystems-02-00064-g004.png.

Table 1 in the Introduction has anthropogenic LUC emissions from 1850 at 205 Ct C and 465 Gt C from FFs giving cumulative total 670 Gt with about half ($670/276 = 41\%$) CO₂ accumulated.

However, if terrain doubles values of soil/land losses, total emissions would be raised and losses from soil SOC and fossil fuels become comparable. Arguments that fossil fuels alone are sufficiently old to account for depleted in C isotopes are debunked when soils are also ancient.

Buringh (1984 total LUC loss was 537 Gt SOC, doubled for terrain this is 1,074 Gt C which may be reasonable given that up to one metre of the most fertile topsoil has been lost (Wang & Van Oost, 2019). When based upon ice-core atmospheric data these may be acceptable, but contemporary LUC loss since 1850 calculated per flat area are likely not so reliable. Adding modest Preindustrial LUC of 350 plus Postindustrial LUC of 410 gives combined total of 750 Gt C that is nearly three times the total fossil fuel emissions since 1850 of around 276 Gt C.

How much of the excess ~276 Gt C CO₂ can be restored or sequestered via organic farming and pasture regrowth? If soil erosion is reduced to offset annual atmospheric accumulation (of +5 Gt C/yr) then with modest 2 Gt SOC/yr restored on farmland and forests, total drawdown of ~300 Gt C would take ~150 years. Such SOC loss/restoration rates are further assessed below.

Atmospheric drawdown of 300 Gt C is equivalent to ~1 ppm/yr consistent with Lal's (2009) argument for 106 Gt C soil sequestration reduction rate of 50 ppm in 50 years (also ~1 ppm/yr).

Reconciling Current SOC Stock and the Global Carbon Cycle

Soil offers hope and solace: The present report demonstrates that topsoil is *the* major source of annual carbon emissions and Earth's greatest carbon storage with at least 10,000 Gt total C in soil organic carbon (SOC) alone. A starting point for review of SOC total is IPCC (WG1-TAR1 [2001](#): fig. 3.1) with 1,200 Gt plus 300 Gt leaf litter "detritus" that were almost immediately contradicted by their table 3.2 data showing SOC between 1,567–2,011 Gt to 1 m depth and a statement that peatlands contain an extra 455 Gt SOC, both easily doubled for greater depth to give 4,000–5,000 Gt, most now also doubled for terrain to total 8,000–10,000 Gt SOC (Blakemore, 2019b, 2020). IPCC (WG1-TAR1 [2001](#): tab. 3.2) shows that their calculations are based upon a "*flat-Earth*" model with just 15 Gha land surface, rather than the new estimate for terrain of at least 30 Gha (Blakemore [2018b](#)). Thus all past and current IPCC land estimates may be doubled, including their estimate from "*combustion*" burning of vegetation & detritus of 4 Gt C/yr, now presumed at around 8 Gt C/yr. The data values in IPCC (WG1-TAR1 [2001](#): fig. 3.1) as presented by Houghton ([2007](#): fig. 1) are updated in the following figures (Figs. 4–5).

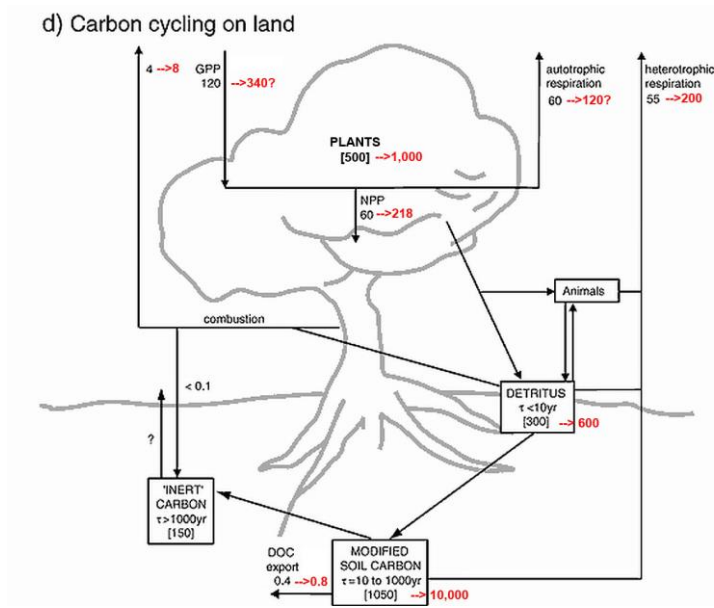


Figure 4. Annual organic carbon cycle on land IPCC WGI-TAR1 (2001: fig. 3–1) updated from Blakemore (2018b) in red (“t” are estimated turnover times in years); as well as a lesser “inert” C may include calcium carbonates of biotic origin (e.g. earthworm calciferous glands or mollusc shells) and a small amount of charcoal. Rather than 150 Gt, soil inorganic carbon (SIC) totals from 695-1,738 Gt C in Naorem et al. (2022: fig. 1); doubled for terrain these values now increase to 1,390-2,476 Gt SIC. Volatile Organic Compounds (VOC), mainly released by plants, are not included but may release 1.2 Gt C/yr (Guenther et al. 1995).

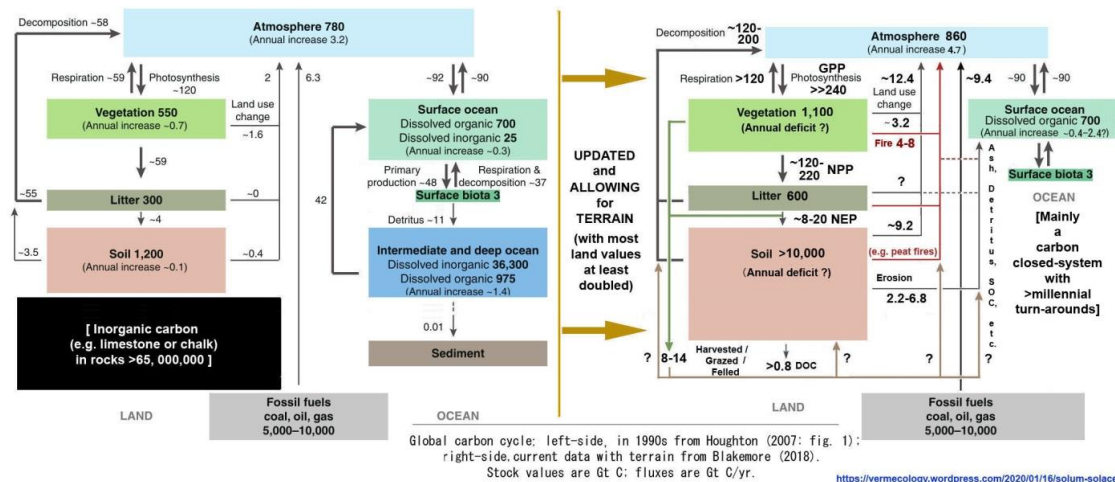


Figure 5. Organic carbon cycle relevant to climate modified from Houghton (2007: fig 1) updated as detailed herein (omitted is relatively minor proportion of C converted to methane as emitted mainly by cattle and other agriculture – IPCC 2001 <https://www.ipcc.ch/report/ar5/wg1/carbon-and-other-biogeochemical-cycles/methane-test-3/feed/>). Mostly natural soil respiration and decomposition (SR) of 200 Gt C/yr is

>20 x anthropogenic FF emissions of 9.4 Gt C/yr matched by up to 9.2 Gt C/yr SOC loss to the atmosphere largely from (bad) farming methods.

Justification and sources for the revised (red) values in Figure 4 are from Blakemore (2020) - <https://vermecology.wordpress.com/2020/01/16/solum-solace/> as discussed in text below.

Compare data in Figure 5 left-side to Canadell et al. (2021: fig. 5.12) having Permafrost (1,200 Gt, actually 1,700-4,000 Gt SOC with some a part of the 1,000+ Gt SOC in peats), Soils (1,700 Gt, actually closer to 10,000 Gt) to give their total of just 2,900 Gt SOC plus Vegetation (450 Gt, truly closer to 1,000 Gt) with an export of 2.5 Gt C/yr to rivers and 0.8 Gt C/yr from rivers to the sea. They also have Gross photosynthesis on land of 142 Gt C/yr (implying NPP = 71 Gt C/yr while it is truly closer to 218 Gt C/yr) with total plant/soil respiration & fire of 136.7 Gt C/yr.

The above two figures may be compared to an isotope analysis (Alves et al. 2018: fig. 3 from Bolin & Fung, 1990: fig. 1) that, although failing to mention 'soil' and having land flux values likely wide underestimations with soil/litter/plant/peat inventories & rates considerably lower than current estimates (Blakemore 2018b, 2020b), yet presents similar soil gain/loss pathways. Viz.: 2-6 Gt C/yr lost to ocean from soil/litter degradation and net 0.4-2.6 Gt C/yr CO₂ emission.

Regarding Soil Inorganic Carbon (SIC) and Dissolved Organic Carbon (DIC) these add to soil carbon tally and often have biotic origin, especially calcium carbonate (CaCO₃). To just 1 m soil depth Monger et al. (2015) have "*inorganic carbon as soil carbonate (~940 PgC) and as bicarbonate in groundwater (~1404 PgC)*" and Lal (2019: tab. 1; 2020) has: "*global SIC (primary and secondary carbonates) stock is estimated at 1237 Pg to 2-m depth [plus tab. 1 an extra 321 Gt in humic soils] and an additional 1404 Pg as bicarbonates stored in ground water*". These figures of ~2,962 Gt, if doubled for terrain totals >5,924 Gt total SIC/DIC to SOC values.

Research show considerable CaCO₃ on Land derived from earthworm calciferous glands with carbon extracted partly from the atmosphere as a valid form of "CCS" (Blakemore 2019c - <https://vermecology.wordpress.com/2019/11/11/earthworm-cast-carbon-storage-eccs/>).

It is important to realize that terrain consideration is not the only justification to revise global SOC/SIC/DIC totals. Current estimates have been based only on superficial soil layers, often ignore litter, logs and/or peat and underplay (or totally ignore!) permafrost soils, also glomalin is almost never considered that alone may increase many values by ~30%. Moreover, other authors quote higher initial SOC values with starting values >1500 Gt C (as per Fig. 4 remarks).

Superficial soil samples (most to 0.3 m) greatly undervalue SOC: Jobbagy & Jackson (2000) reported 56% more SOC at 3 m compared to 1 m and D'Elia et al. (2017) found “SOC in soils quantified from 0–3 m were on average more than double the SOC from 0–1 m”. For mineral soils, Harper & Tibbett (2013) further found two to five times greater SOC (average ~3.5 times) at depth to bedrock (>5–38 m) with “major implications for estimates of global carbon storage and modelling of the potential global impacts of climate change and land-use change on carbon cycles”. Permafrosts may extend to 1.5 km depth and Peats are recorded up to ~200 m. Notwithstanding Permafrost SOC estimates may increase >200% (Shelef et al. 2017) and Peat SOC is doubled (Loisel et al. 2021; Nichols & Peteet, 2019, 2021). So all values at least double.

Where soil-bearing land is the main consideration, Earth's total flat, ice-free area of 12–13 Gha is now doubled (“× 2”) for terrain to about 25–26 Gha as a justification for all current revisions.

These revisions showed that, despite what IPCC and others claim, the increase in atmospheric carbon is mainly from the land use change, fire, and soil erosion (net +~20 Gt/yr?) not from fossil fuel (+~10 Gt/yr) (as in the right-hand side of Fig. 3 above). This is consistent with IPCC (2000) report of “a global net terrestrial source” to excess CO₂. As Lal (2001: 533) stated: “**The atmospheric C pool is increasing at the rate of 3.3 PgCyr⁻¹ [now >4.7 Gt C/yr] primarily at the expense of the soil and the [land] biotic pools**” (my bolding). Using depletion of carbon or oxygen isotopes as evidence that atmospheric carbon is from fossil fuel sources is negated by the antiquity of soils lost (as already remarked upon above and commented on further below).

As well as SOC, complete soil carbon stock inventory broadly includes root/mycorrhizae mass, logs/leaf-litter, biocrusts, and various other soil biota as discussed below that add considerably.

Current total terrestrial carbon of at least 2,000 Gt in above and below vegetation plus many soil organisms mostly intermixed with the 10–15,000 Gt SOC in or humus as active carbon stored and recycled on land (Blakemore, 2018b). This compares with latest ESSD (2022: fig. 2) values of just 450 Gt C in Vegetation, 1,400 in Permafrost and 1,700 in Soils (total 3,100) (cf. just 3 GtC in Marine biota and 700 GtC in Marine Organic carbon to total 703 Gt C ocean total organic carbon). Note however that now they at least accept an active terrestrial GPP of 130 Gt C/yr (= ~65 GtC/yr NPP?) versus an alleged, mostly passive 80 GtC/yr ocean to air exchange.

Permafrosts and the Boreal North

SOC stocks may be sub-divided into soils, peats and permafrost. Permafrost is the most massive soil carbon store that can reach depths of 1.5 km and extends under the ocean. Permafrost soils “officially” contain just ~1,700 Gt SOC comprising 1,330–1,580 Gt C in surface 0-3 m as well as deep carbon in the yedoma region and river deltas, with potential for ~400 Gt carbon in other deep terrestrial permafrost sediments that, along with an additional quantity of subsea permafrost carbon, still remains largely unquantified (Shuur et al. 2015).

Raupach & Canadell (2010) quote frozen soils permafrost with an estimated 1,700 Gt C of which around 100 Gt C (= ~50 ppm CO₂) may be vulnerable to release by thawing over the next century. Melting of permafrost soils with predicted warming trends within the circumpolar region could result in release of 30–60 Gt C by the year 2040 according to Deluca & Boisvenue (2012). Trubl et al. (2018) have permafrost thawing at a rate of ≥1 cm of depth per year also releasing many microbes. Soils and peats are thousands or millions of years old with Permafrosts extending up to 1.5 km deep containing substantially more carbon that may date to >2.6 million years according to a recent *Nature* paper on 1.6 million year old preserved mammoth DNA (Callaway 2021). With half-life of ¹⁴C of 5,568 years (Alves et al., 2018: fig. 2) such old organic soil has its ¹⁴C decayed by 280-450 half-lives thus its loss to the atmosphere would have the same isotope effect as do fossil fuels. Shi et al. (2020) summarized that: *“Integrated to a depth of 1 m, global soil carbon has a mean age of 4,830 ± 1,730 yr, with older carbon in deeper layers and permafrost regions. In contrast, vertically resolved land models simulate Δ¹⁴C values that imply younger carbon ages and a more rapid carbon turnover”*.

Notwithstanding general terrain considerations, Permafrost SOC tally yet has large uncertainties and is widely underestimated in its neglected hill-slope bases (hill toes) by >200% having mean extra values of ~550 and ~720 Gt SOC, with a maximal uncertainty possibly adding >2,000 Gt SOC to the circumpolar Permafrost totals (Shelef et al. 2017). At most, this may represent 1,700 + 2,000 = 3,700 Gt SOC (to 3 m depth?) or 1,700 x >200% = >4,100 Gt C?

Therefore, permafrosts and boreal forests “official” holding are ~1,700-4,100 Gt of SOC while circumpolar forest biomass accounts for approximately 60–80 Gt of total C and boreal peatlands hold an additional 260–600 Gt C (soil/peat total 1,700 -4,100 + 260-600 = 1,960-4,900 Gt C, doubled for depth and terrain these Permafrost values may add to 3,920-9,800 Gt SOC plus plants also doubled at 120-160 Gt C). Deluca & Boisvenue (2012) also said: *“The expansion of temperate and boreal forest ecosystems back into glaciated landscapes resulted*

in the net accumulation of 500–1350 Pg of C on the Earth's surface"; presumably part of this included permafrost soil and peat carbon? These large carbon stores are likely both expanding and simultaneously melting as temperatures rise disproportionately rapidly in the far North.

It is important to note that global average temperature rises are about twice as high on land as in the oceans and about doubled again in the boreal North with the tangible risk of self-fueling Permafrost melting and/or peat fires causing cascading (snowballing?) climate warming effects.

Recently, in June, 2020 in the midst of uncontrollable peat fires, the boreal North experienced record air temperatures of 38°C that were +18°C above their average and the Arctic has already warmed to more than 2 °C above the preindustrial level with this rapid warming expected to double by midcentury and potentially emit up to about 150 Gt C by 2100 (Natali et al. 2021). Thus a 1.5°C global rise may be more than twice this on land and higher yet for soil, more so northerly. Globally: *"mean annual soil temperature differs markedly from the corresponding gridded air temperature, by up to 10°C (mean = 3.0 ± 2.1°C), with substantial variation across biomes and seasons"* (Lembrechts et al. 2021). Thus, if air temp increases +2°C, soil may go up +5°C. Personally having worked in the tropics, sometimes in 40+°C air temperatures while the soil is 60+°C just as most people will have burned their feet on the summer beach while the coastal water is much cooler. Water is a poor conductor of heat and thus the deep ocean remains about the same temperature all year around. (Summaries are found: <https://earthobservatory.nasa.gov/images/146879/heat-and-fire-scorches-siberia>; <https://vermecology.wordpress.com/2020/08/31/barrow/>; <https://vermecology.wordpress.com/2022/05/25/2022-year-of-the-taiga-barrow-2/>).

Missed Peats

Peatland ecosystems are still omitted from the main Earth system models that are used for future climate change projections nor mitigation models (Loisel et al. 2021) these authors (tabs. S4-5) show peat stocks of 808 + 315 = 1,123 Gt C and predict 100 Gt C could be lost by 2100 although uncertainties remain large (www.exeter.ac.uk/news/research/title_829842_en.html). Sometimes included in soil SOC inventories sometimes not, carbon-rich peatlands cover ~3% of land area yet contain >550-1,123 Gt C with degradation from drainage, fires or exploitation of at least 3 Gt CO₂ a year, equivalent to ~0.81 Gt C/yr or ~10% of the global fossil fuel emissions according to Parish et al. (2008: tab. 9.1). This peat total was recently doubled from 545 Gt to

1,055 Gt by an extra 510 Gt overlooked in northern peatlands (Nichols & Peteet, 2019; 2021). So peat loss may now be doubled to ~1.62 Gt C/y? Rather obviously, waterlogged peat does not gain much from terrain, however these peat values are seemingly only for a depth of 1 m and Parish et al. admit peats can extend to great depth (*"The deepest peat/lignite layer in the world is probably the Phillipi peatland in Greece, reputed to be 190 m deep.. and dating largely from the Pleistocene"*), thus the values may also be increased two or more times for deeper peat. Moreover, peats can also be ancient (*"peatlands have certainly existed for hundreds of millions of years"*), yet again diminishing arguments for isotopic C contribution solely from the burning of fossil fuels (e.g., coal, oil, gas).

Global Vegetation Adds to Soil Organic Carbon Stocks

Soil carbon samples taken perpendicular to the centre of the Earth typically use fixed volume cores that are dried and sieved to remove stones, roots and megafauna (such as earthworms). Surface litter is often treated separately, or sometimes included; roots rarely are. Microbes – living, dead or dormant – are typically treated as an integral part of the SOC or humic biomass.

Crowther et al. (2019) stated: *"Soil is the largest repository of organic matter on land, storing ~1500 Gt carbon, which is at least as much as the vegetation (~560 Gt) and atmosphere (~750 Gt) combined"*; all three values are wrong since soil (as calculated herein) is up to 15,000 Gt C, vegetation is >1,100 Gt C and, according to IPCC and the ESSD (2019: fig. 2) the atmosphere had 860 Gt C (now 875 from ESS [2022](https://www.essd.isac.es/eprints/38139/1/Veop-4.pdf): fig. 2). Moreover, Blakemore (2020b: fig. 1 <https://orgprints.org/id/eprint/38139/1/Veop-4.pdf>) (Figure 6 below) showed Crowther et al. (2019: fig. 2C) topsoil figures from SoilGrids to 2 m depth total 4,595 Gt C. Doubled for terrain this is 9,190 Gt which matches 8,580 Gt C (Blakemore, 2018b) plus 510 (= 9,090 Gt C) from the latest studies on northern peatlands. Their *"aboveground plant biomass (green)"* and *"Soil microbial biomass"* values add up to 595 and 23 Gt C, respectively, both also presumably doubled to allow for terrain to ~1,191 and 46 Gt C, respectively (much as was already detailed by Blakemore 2019d Science eLetter commentary - <https://www.science.org/doi/pdf/10.1126/science.aav0550>).

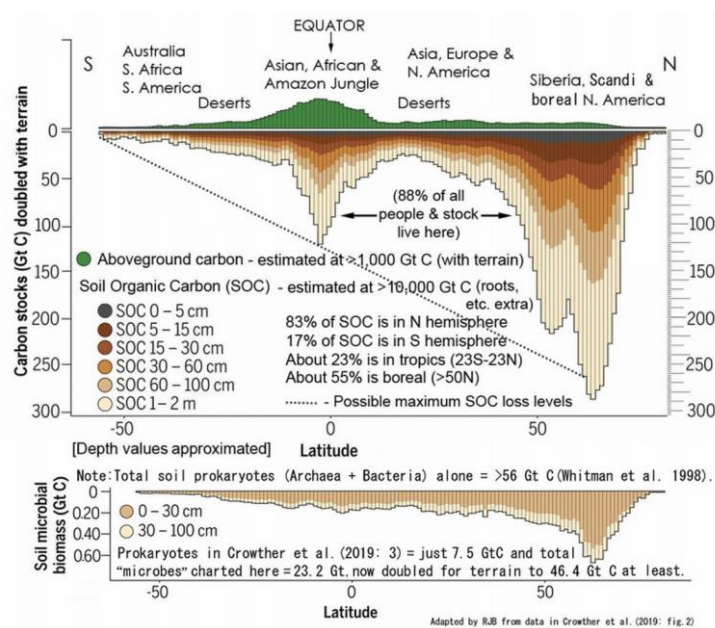


Figure 6. Vegetation, soil carbon and soil microbes (adapted from Crowther et al. fig. 2).

Whereas, ESSD (2019: fig. 2) had Permafrost with 1,700 Gt C and Soils ranging from 1,500–2,400 to total up to 4,100 Gt SOC which was about the same as maximum ranges of all their Fossil Fuel reserves, Atmospheric carbon, Ocean organic carbon plus Vegetation combined (at ~4,150 Gt C). Their “Vegetation” estimate range was 450–650 Gt C (mean 550 Gt?). Strangely, ESSD (2022: fig. 2) now has Permafrost as 1,400 Gt C, Soils with 1,700 Gt C (total 3,100 Gt) and Vegetation just 450 Gt C.

A further remarkable summary recently put out by Wuepper et al. (including T. Crowther) at Wuepper et al. (2021) had: “The above-ground biomass would naturally be 871 Gt C, but currently, it is only 601 Gt C. This means our global above-ground carbon debt is 270 Gt C. Below-ground, naturally, there would be 899 Gt C, but currently, there are only 863 Gt C, which means our global below-ground carbon debt is 36 Gt C.” Above ground refers mainly to trees, and below ground loss is only of soil organic carbon (SOC) stocks (for the upper 30 cm) based upon data from Sandeman et al. (2017) rather than proper inclusion of roots or other biota. These losses they attributed to soil erosion and a “Land degradation debt” (<https://esdac.jrc.ec.europa.eu/content/land-degradation-debt>). They add: “In addition, our analysis suggests that global land use has so far decreased global tree cover by 30%, carbon stored in biomass by 20% (average for above- and below-ground carbon), and increased soil erosion almost fourfold, suggesting that our global soil erosion debt is especially large and

deserving of special attention.” Yet their soil erosion debt of just 36 Gt C is obviously an underestimation when the annual global SOC erosion rate is in the order of 1-6 Gt C/yr, probably for the last few centuries. All these and ESDD values and rates need stark revision.

Regarding carbon “debt”, Elhacham et al. (2020) estimated since a Neolithic agricultural revolution, humanity roughly halved plants, from approximately 2,000 Gt (estimated on a dry-mass basis) down to the current value of 1,000 Gt (or from about 1,000 to just 500 Gt C with a “debt” of about -500 Gt C). Biomass of (mainly soil) Bacteria and Archaea they claim decreased from 80 Gt C to 30 Gt C just from 1900-1990 or a “debt” of -50 Gt C. Falsely claiming “*soil carbon is not living biomass and thus is not included in this study*” (!) they surprisingly excluded SOC entirely from their report. Yet combining their data sets, their “carbon debts” above and below ground total -586 Gt C that doubled for terrain are -1,172 Gt C as a mostly non-SOC loss.

Should current SOC losses be added to this total then our carbon debt becomes truly massive.

Litter and Log “Detritus”

IPCC (2001: fig. 3.1d) and Houghton (2007: fig. 1) had about 550 Gt C in “Vegetation” and 300 Gt C of “DETRITUS” as part of their 1,500 Gt C total soil organic matter (cf. just 3 Gt C in Oceanic “Surface biota”) (see <https://vermecology.wordpress.com/2022/07/04/ip-bees/>). Houghton’s 300 Gt C in soil litter & fallen logs was possibly derived from Matthews (1997) litter report of 160 + 150 = 310 Gt “dm = dry matter”, that should be approximately halved for carbon to 150 Gt C. Compare to Reiners (1973 from Bolin 1970) that has humus, mulch etc. “detritus” at ~700 Gt C!]. Yet, modestly assuming Houghton’s 300 Gt C value was correct, as herein, the total was updated and doubled for terrain to 600 Gt C by Blakemore (2020b: fig. 3).

Contributions of Soil Biotic Totals (Biodiversity, Biomass & Necromass) to Total SOC

Vermeij & Grosberg (2010) estimated between 85% and 95% of all living macroscopic species are found “*on land*” while Locey & Lennon (2016: fig. 3) showed Earth with $\sim 10^{12}$ microbial original taxonomic units (OTUs) with just 10^{10} or $\sim 1\%$ in global Ocean. When microbes are fully accounted for, soil alone supports >99.9% biodiversity of taxa (Blakemore 2022). This is consistent with UNEP (2002: 10) finding that probably over 80% of total plant production enters the soil system either through plant roots or as leaf-litter and perhaps 50% of below-ground allocation is released as extra-root carbon exudates, some being ‘traded’ with microbes for Nitrogen fixation or other growth factors. Intricate soil biotic pathways include

microbial necromass and products making up as much as 80% of global SOC according to Gross & Harrison (2019: fig. 1). Bar-On et al. (2018: tabs. 1) have 70 Gt C Bacteria, mainly terrestrial, with a 10 fold uncertainty, presumably giving a biomass range of 7–700 Gt C. They claim an aboveground plant biomass (≈ 320 Gt C) represents $\approx 60\%$ of global total, with belowground biomass composed mainly of plant roots (≈ 130 Gt C) to total 450 Gt C in Plants; total microbes residing in soil and deep subsurface they give as ≈ 100 Gt C. Terrestrial Arthropods, Annelids and Molluscs they have at just 0.2 Gt C for each while total soil Protists are 4 Gt C (to give total soil organisms just 4.6 Gt C?). (For all marine biota they have ≈ 6 Gt C). All these values may be revised and at least doubled for neglected terrain considerations. The next three figures summarize revision of global biomass and biodiversity (Figures 7–9).

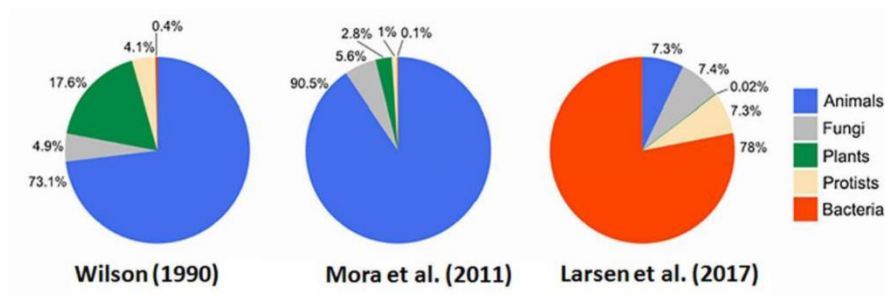


Figure 7. Rapid advancements in concepts of global biodiversity following PCR and genetic sequencing advances. Sources: Blakemore, 2018b: fig. 15 & <https://vermecology.wordpress.com/2021/06/20/tol/>; <https://vermecology.wordpress.com/2022/08/04/different-f3/>.

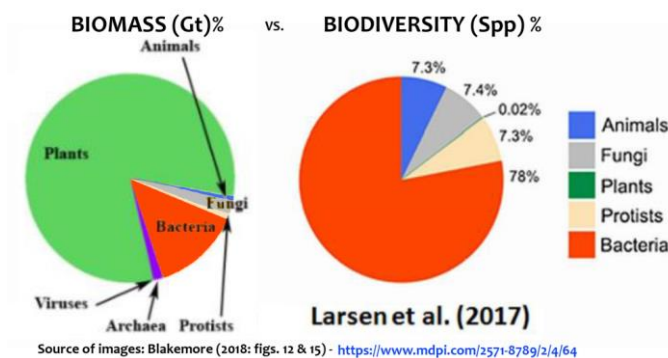


Figure 8. Biomass and Biodiversity allocations. Sourced from Blakemore (2018b: figs. 12 & 15).

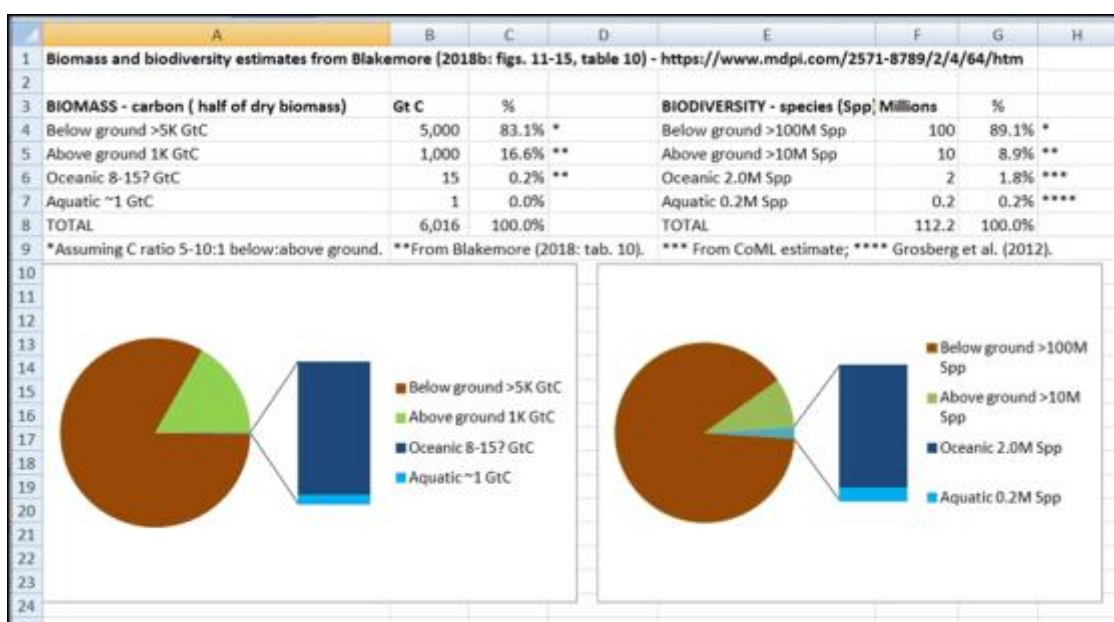


Figure 9. Disparity in global Biomass and Biodiversity allocations to the Realms of Life (excluding the atmospheric “Aeolian biota” or Aeliota that likely supports as much life at any time as the Oceans & Aquatics combined). Source: <https://vermecology.wordpress.com/2022/03/29/eco-taxo-bio/>; <https://vermecology.wordpress.com/2022/07/04/ip-bees/>. Estimates are soils support >83% of biomass (arguably 99.7% with above-ground biota) and now >99.9% biodiversity (<https://vermecology.wordpress.com/2022/08/04/different-f3/>).

Soil Biodiversity and Biomass Soar (Ocean’s Sink)

From divers sources listed therein, Blakemore (2012: tab. 1 ; <https://vermecology.files.wordpress.com/2017/04/blakemore-2012-census-of-soil-invertebrates-cosi.pdf>; 2016a: tab. 3 Blakemore 2022: tab. 5) listed up to 315,500 prospective soil species with biomass ~1,500 Gt C. Logically, this should include all plants that root or seed in soils as factually included soil component adding ~500,000 taxa (Corlett 2016) and another ~1,000 Gt C. This 815,500 species total was recently revised by Blakemore (2022) to update biodiversity with latest genomic and other “Omics” estimations of microbial taxa showing soil houses $\sim 2.1 \times 10^{24}$ taxa representing >99.9% of global biodiversity, mostly Bacteria or other microbes. Justification for revision is based upon $10^2 - 10^6$ unique species (spp) per gram of dry soil (or $10^8 - 10^{12}$ spp/t), and Earth supporting $\sim 2.1 \times 10^{14}$ t of habitable soil, to give a reasonable range of $2.1 \times 10^{22} - 10^{26}$ spp with median value $\sim 2.1 \times 10^{24}$ soil spp.

Root Biomass

A summary for plant roots by Blakemore (2018b) reported an initial 146 Gt C in a dry biomass of 292 Gt from Jackson et al. (1997: tab. 2) that was allocated about 175 or 80% for forests and about 42 or 20% in other biomes. They found fine roots alone (also about 20% of their total) representing 33% of total annual net primary productivity (NPP). Roots were updated by Mokany et al. (2005: 95) to total 241 Gt C which is less than an earlier figure of 267 Gt C by Robinson (2004: fig. 2) he said comprised about half of the 492 Gt C estimated for the planet's above-ground vegetation at that time, but his initial value seems mainly for tree roots not grass, scrub, tundra, etc. that (Jackson et al., 1997: tab. 2) show may be substantial (~20%).

Robinson (2004) not only found that true below-ground biomass of tree roots are generally underestimated by about 60%, but also that losses as large as 20-40% of root samples can occur after recovery from soil due to subsequent handling, washing and storage; i.e, errors may amount to 100%. Instead of an initial 160 Gt C as then estimated in (tree?) root systems globally, he said true amount could be about 267 Gt C. If 20% of this value is added for other than forest biomes from Jackson et al. (1997: tab. 2) a new total is about $(267 + 53 =) 320$ Gt C.

Alternatively, a new total for Mokany et al. (2005) 241 Gt C with 60% added for missed tree roots plus mean 30% added for Robinson's sampling error, is $(241 + 217) 458$ Gt C. Doubled for terrain this then is 916 Gt C or roughly the same as above ground plant values (~1,100 Gt C).

Mokany et al. (2005) had already found a 50% increase in root carbon, and a 12% increase in total carbon of the world's vegetation (from 652 to 733) compared to others' around 450 Gt C. Also: *"More than half (46 Pg) of this estimated increase in carbon stock was for the 'tropical grasslands and savannas' biome. The arctic tundra, temperate grassland and desert biomes had relatively large increases in estimated root biomass (of 123%, 79%, and 79%, respectively). These latter systems all have characteristically low biomass C density, but cover large areas"*.

Soil Biota [Earthworms, Bacteria & Archaea (+other microbes), Fungi, Termites, Ants]

| Taxon | | Mass [Gt C = 10 ¹⁵ g C] | | Abundance | |
|----------|-----------------------------|------------------------------------|------------|------------------|------------------|
| Plants | Trees | 450 | | 10 ¹³ | |
| | | | | | |
| Bacteria | Terrestrial deep subsurface | 60 | | 10 ³⁰ | |
| | Marine deep subsurface | 7 | | 10 ²⁹ | |
| | Soil | 7 | | 10 ²⁹ | |
| | Marine | 1.3 | | 10 ²⁹ | |
| | Total | | 70 | 10 ³⁰ | |
| Fungi | | | 12 | 10 ²⁷ | |
| Archaea | Terrestrial deep subsurface | 4 | | 10 ²⁹ | |
| | Marine deep subsurface | 3 | | 10 ²⁹ | |
| | Soil | 0.5 | | 10 ²⁸ | |
| | Marine | 0.3 | | 10 ²⁸ | |
| | Total | | 7 | 10 ²⁹ | |
| Protists | | | 4 | 10 ²⁷ | |
| Animals | Chordates | Fish | 0.7 (0.5) | 10 ¹³ | |
| | | Livestock | 0.1 | 10 ¹⁰ | |
| | | Humans | 0.06 | 10 ¹⁰ | |
| | | Wild mammals | 0.007 | | |
| | | Wild birds | 0.002 | | |
| | Arthropods | Terrestrial | 0.2 | 10 ¹⁸ | |
| | | Marine | 1 | 10 ²⁰ | |
| | Annelids | | 0.2 (0.82) | 10 ¹⁸ | |
| | Molluscs | | 0.2 | 10 ¹⁸ | |
| | Cnidarians | | 0.1 | 10 ¹⁶ | |
| | Nematodes | | 0.02 | 10 ²¹ | |
| | Total | | 2 (2.42) | 10 ²¹ | |
| | Viruses | | | 0.2 | 10 ³¹ |

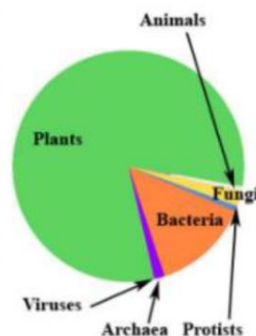


Figure 10. From Bar-On *et al.* (2018: tab. S1 - http://rpdata.caltech.edu/publications/Bar-On_2018_SI.pdf); updated in Blakemore (2018b: fig. 12, tab. 10). Note “Trees” just 450 Gt C.

Please note in Figure 10 how for Soil biota, Bar-On *et al.* (2018: tab. S1) have about 24 Gt C (92%) including Fungi and Protists while Ocean is only about 2 Gt C (8%), before terrain adjustment at least doubles soil value to >50 Gt C and also the Plant biomass (e.g. roots, litter, logs, etc.) to probably total >1,000 Gt C (>99.9%) with Ocean reduced to just <0.01% biomass.

Larsen *et al.* (2017) concluded: “Our estimates suggest that there are likely to be at least 1 to 6 billion species on Earth. Furthermore, in contrast to previous estimates, the new Pie of Life is dominated by bacteria (approximately 70–90% of species)”. If this massive microbial diversity were to have the same proportionate rates of extinction as the current 2 million described species (200 lost per day or 0.01% but just large charismatic taxa not >9% of invertebrates, so rate may be 100 x higher at about 20,000 per day), if increased 100 x again for bacteria, it is 2 million species per day or 23 taxa per second (<https://vermecology.wordpress.com/2021/06/20/tol/>). Using data on terrestrial invertebrates, Regnier *et al.* (2015) estimated 7% species loss and that the biodiversity crisis is real. Cowie *et al.* (2022) had between 7.5–13% of taxa already extinct, status of most is unclear/unknown.

Microbial Biomass

Bar-On et al. (2018 Supplement: tab. S1 www.pnas.org/action/downloadSupplement?doi=10.1073%2Fpnas.1711842115&file=1711842115.sapp.pdf) showed to a depth of 1 m a total biomass of soil microbes as ≈ 20 Gt C which includes soil Bacteria and Archaea of about ≈ 8 Gt C and a total soil fungi value of ≈ 12 Gt C. Their soil microbial error margin is also about ten-fold (i.e., a possible range 2-200 Gt C?).

A recent review by Blakemore (2022) summarized $10^8 - 10^{12}$ microbial cells/g or $10^{14} - 10^{18}$ cells/t, there being 10^6 grams in a tonne soil. With terrain, there is 208,000 Gt or $\sim 2.1 \times 10^{14}$ t global topsoil a new soil microbe total is $2.1 \times 10^{28} - 10^{32}$ cells (median value about $\sim 2.1 \times 10^{30}$).

Soil cell biomass carbon Whitman et al. (1998) took as half mean dry wt./cell (C : N = 1 : 0.24), so if 2×10^{-13} g/cell for all 2.1×10^{30} cells this is $\sim 4 \times 10^{17}$ g or 400 Gt (200 Gt carbon C : 48 Gt N).

Biota is dominated by Bacteria and then Archaea with minor contributions (perhaps less than 1% from other microbes) with this new biomass estimate exactly at Bar-On et al.'s. upper range. In their Supplement Bar-On et al. (2018) state: "*~98% of the total microbial biomass is found in the top 1 meter of soil*" further supporting my microbial estimates to 1 m depth of global soils.

Fungi

Fungi from Bar-On et al. (2018: fig. 5) are 12 Gt C and 10^{27} cells, mainly in soils and herein at least doubled for terrain to 24 Gt C and 2×10^{27} cells. Contributions of Ectomycorrhizal fungi biomass they estimated as "*roughly ≈ 0.2 Gt C*" and for Arbuscular mycorrhiza AM as " *≈ 2 Gt C*".

However, rather than total fungi of 12 Gt C as Bar-On et al. claim, 15 Gt C is found in mycorrhizal hyphae alone (Robinson 2004), doubled for terrain gives soil fungi at least 30 Gt C.

Phytomenon and Biocrust

Soil phytomenon, surface biocrust or autotrophic biofilm and some epiphytes (e.g., bryophytic liverworts, hornworts, epiphytic mosses plus microfungi/yeasts, photosynthetic green algae, lichens, and Cyanobacteria or Cyanophyta) coat the convoluted superficial and interstitial surface rocks, topsoil, and sands. According to Elbert et al. (2012) these 'cryptogamic covers' or biocrust total about 5 Gt C taking up about 4 Gt C per year in NPP, but terrain doubles these values at finer scale to 10-20 Gt C and $\sim 8-16$ Gt C/yr. (See Blakemore 2018b; also -

<https://vermecology.wordpress.com/2022/08/04/different-f3/>). Elbert et al. (2012) further derived a nitrogen uptake by cryptogamic covers of around 49 Tg per year (now >100 Tg N/yr), they say suggests that cryptogamic covers account for nearly half of biological nitrogen fixation. At 100 Tg N this value is approximately the same as annual oversupply of synthetic N fertilizer.

NPP of soil's phytomenon is also about the same, or maybe more, than oceans' phytoplankton.

Earthworm Abundances & Biomass

Earthworms (Annelida: Oligochaeta: Megadrilacea) are the major component of healthy soils. Earthworms, plants soils and microorganisms are co-evolved and interdependent, their interactions regulate terrestrial soils Ecology. Megadrile earthworms comprise 20 families, approximately 600 genera (several un-necessary sub-genera) and ~7,000 described species or sub-species with an expected total of over 35,000 species (Blakemore, [2012](#), 2016a). They represent up to 90% of invertebrate biomass present in soil. Moreover, microbes increase during digestion and after gut passage in their fresh castings up to x 1,000 (Lee, 1985: 27, 206).

Darwin ([1881](#): 158) calculated from Hensen ([1877](#): 360) that there must exist 133,000 living worms in a hectare of productive land (ca. 13.3 m⁻²) with 3 g per worm (Darwin mistakes this for 1 g) (= 40 g m⁻²). In previous reports these were multiplied by "flat" habitable land areas of ~10 Gha to give totals of about 1.3 x 10¹⁵ or 1.3 quadrillion, with 4.0 Gt live biomass.

From a wider range of habitats, including alpine, taiga and dry sclerophyll scrub, an average 273 worms/m² (= 2.73 x 10⁶ ha⁻¹) and a fresh wt biomass of 63 g/m² (= 0.63 t ha⁻¹) were derived from Lee (1985: tab. 7) and multiplied by realistic land area (Whitman et al., 1998: tab. 2) including scrub, Tundra, alpine, etc., of 12.1 Gha by Blakemore (2000, 2016a, 2018b) to give 32.8 x 10¹⁵ and 7.6 Gt live weight – almost double Darwin's figure. (For full calculations - <https://vermecology.wordpress.com/2017/02/12/nature-article-to-commemorate-charles-darwins-birthday-on-12th-feb/>). Doubled for terrain these are 65.6 x 10¹⁵ and 15.2 Gt wet mass. Lee ([1985](#): 33) has ~30% moisture, thus dry mass is 4.5 Gt with half carbon at ~2.3 Gt C.

For Annelida (Oligochaeta, i.e., megadriles + microdriles as they explicitly exclude marine Polychaeta) Bar-On *et al.* ([2018](#): Supplement: 31-32) estimate "300 individual earthworms per m²", 5 mg C per worm and 1.5 g C m⁻² (i.e., about 3 g dry, 10 g wet m⁻²) approximately supporting abundance numbers of 273 m⁻² and fresh weight 63 g m⁻². However, their 0.2 Gt C

total earthworm biomass is now raised to ~2.3 Gt C (Blakemore, 2022). (A ratio C : N of 1 : 0.24, gives about 0.54 Gt N or 540 Tg N, five times the annual synthetic Nitrogen added per year).

Bar-On *et al.* (2018: tab. S1) have “Annelida” abundance as 10^{18} yet on page 61 say: “we use our biomass estimates and divide them by the mean individual body mass”; i.e., 0.2 Gt C or 2×10^{14} g / 5 mg C per worm = 4×10^{16} or 40 quadrillion, not 1,000 quadrillion as they calculated.

In wet organic soils microdrile Enchytraeidae range 10^3 - 10^5 per m^2 (Adl, 2006) two to three times that of megadrile 10^{15} - 10^{16} totals, so total Oligochaeta may be 10^{17} - 10^{19} or median 10^{18} . Annelids (megadriles + microdriles) from Bar-On *et al.* (2018: tab. S1) total 10^{18} is thus feasible.

One of the highest megadrile records is of *Pontodrilus litoralis* (Grube, 1855) that Coupland & McDonald (2008) reported with populations of 750-4,875 m^{-2} under wrack weed on arid beaches in WA they calculated consumed 19-31 $kg\ m^{-2}\ yr^{-1}$ organic material. Highest earthworms in Lee (1985: tab. 7) were in NZ pastures (2,020 m^{-2} with 305 g/m^2 from McColl & Lautour, 1978). Another example, in a 1,000 year-old permanent pasture in the UK, six lumbricid species attained 456 m^{-2} and 153 g/m^2 (Blakemore 1981, 1994, 2000, 2016a, 2018a). Blakemore (2011) found a NZ pasture population equivalent to 716 worm m^{-2} (160 g/m^2) extrapolating to a field population of 7.16 million worms ha^{-1} and 1.6 t/ha. Such biomass levels exceeds all other soil fauna and match stocking rates above ground of either cattle or sheep.

Exceptionally high Enchytraeid population maxima are 290,000 m^{-2} (3×10^5 and 53 g/m^2 live weight) on bare peat at Moor House Nature Reserve in England (Gragg 1963: tab. 2, Springett 1967: fig. 24) (cf. limestone grassland plots had 389 earthworms m^{-2} with 110 g/m^2 live weight).

Eve Balfour (1943) gave Rothamsted earthworm counts of: 123 m^{-2} in unmanured plots (about the same as for N-P-K); 680 m^{-2} in FYM plots; and 2,125 m^{-2} on grassland (cf. Blakemore 2018a: tabs. 1-7). (She also pointed out that “*Earthworms render soil permeable to rain thus checking the tendency to erosion by rain and wind. Aeration and nitrification are also stimulated*”).

Overall megadrile means in Lee (1985: tab. 7) of 273 m^{-2} and 63 gm^{-2} give an average mass per worm of 63/273 or about 0.23 g/worm. However these figures are low estimates when earthworms in fertile soils, forests or orchards are more likely in orders of 50-500 m^{-2} and 20-400 g/m^2 (Blakemore 2016a: tab. 2). Thus potential number and biomass ideal maxima of 500 m^{-2} and 400 g/m^2 if in ~10 Gha fertile soils are 50×10^{15} and 40 Gt (12 Gt dry, 6 Gt C). Doubled

for terrain to 24 Gt dry, 12 Gt C is tempered with ~70% earthworm biomass decline under intensive agrichemical regimes (Blakemore 2018a: tab. 11) reducing this down to ~3.6 Gt C.

Worms process their body weight of soil each day, or about ~1,314 Gt dry soil per year. Lee's (1985) figures show they recycle all of the organic Ah soil horizon in 4 years (cf. Darwin, 1881).

Termites and Ants

Soil terrain consideration (Blakemore, 2018b) doubles evenly dispersed earthworm counts, but taxa such as termites or ants in discrete colonies or nests per unit area are not so enhanced.

Fayle & Klimes (2022) discuss the various estimates of these two taxa (Termitidae and Formicidae) apparently endorsing earlier termite values while accepting most recent ant data by Schultheiss et al. (2022) of 2×10^{16} ants with biomass of 0.012 Gt C; these ant values were raised for terrain by Blakemore (2022 <https://veop.files.wordpress.com/2022/09/new-addendum-file.pdf>) to 40×10^{15} (40 quadrillion) and 0.024 Gt C; both much lower than earthworms 65 quadrillions (65×10^{15}) and biomass of >2.25– 3.6Gt C.

For termites, Whitman et al. (1998: tab. 4) have a world population of 2.4×10^{17} – here raised for terrain to 4.8×10^{17} – and an estimate of global termite biomass is 0.445 Gt wet ([https://web.archive.org/web/20220828201550/https://en.wikipedia.org/wiki/Biomass_\(ecology\)](https://web.archive.org/web/20220828201550/https://en.wikipedia.org/wiki/Biomass_(ecology))) and (30%) ~0.13 x Gt dry with a carbon content (50%) of ~0.075 Gt C (reported by Bar-On et al. 2018: 41 as ~0.07 Gt C and by Tuma et al. 2020 as 0.05 Gt C). This value of 0.075 Gt C, doubled for terrain, is here raised to ~0.15 Gt C biomass for termites alone (see <https://veop.files.wordpress.com/2022/09/new-addendum-file.pdf>).

Unlike earthworms or termites that truly inhabit the soil realm, ants are mostly superficial foragers and their alate forms almost resemble soil “tourists”. Tuma et al. (2020: fig. 1) presented a summary of global ant biomass of 0.07 Gt C, subsequently revised downwards by Schultheiss et al. (2022) to just 0.012 Gt C, or by almost by 6 x demonstrating our lack of knowledge of basic soil biotic data.

Meanwhile, the excessive biomass of 0.1 Gt C livestock subsidized for red meat-eaters is certainly detrimental to natural wildlife on land as shown in the following Figures 11–12.

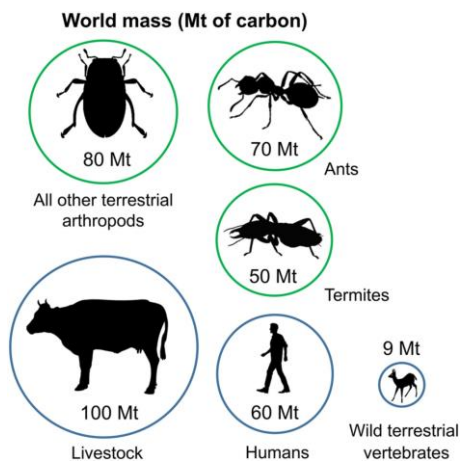


Figure 11. Source Tuma et al. (2009: fig. 1 onlinelibrary.wiley.com/doi/10.1111/brv.12577). Values are mostly doubled by terrain for all groups from (planimetrically flat surface) biome area surveys, except for Livestock (0.1 Gt C) and Humans (0.06 Gt C) based upon audited counts. Notes: reassessment has ants now as 0.024 Gt C, termites 0.15 Gt C; while neglected earthworm biomass at ~2–3.6 Gt C greatly exceeds all other combined taxa total of ~0.5 Gt C.

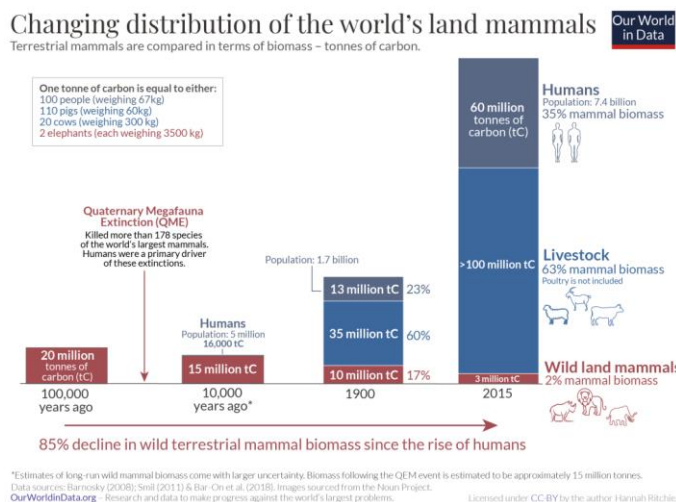


Figure 12. Source OWiD. Associated with a possible increase in plant growth following extinction of quaternary megafauna may be an offset of increased vegetation fires by humans.

Soil Nematodes

Soil nematodes of 4.4×10^{20} expressed either as density per gram of soil or per unit area on a planimetrically flat basis (van den Hoogen et al. 2019) with a total biomass of ~0.3 Gt that translates to ~0.03 Gt of carbon (which the authors claim is three times greater than a previous estimate of soil nematode biomass and represents 82% of total human biomass on Earth) are herein raised, doubled for neglected terrain, to 8.8×10^{20} nematodes with biomass ~0.06 Gt C.

Soil Viruses

Regarding soil viruses especially bacteriophages – aside from questions on whether they are living entities or not – their abundance in soils may be miscalculated by orders of magnitude. In Bar-On et al. (2018: tab. S1) global viruses have of 10^{31} with biomass of 0.2 Gt C and 10^8 - 10^9 phages per gram of soil. Yet a summary paper (Trubl et al. 2018) found: “*While many soils contain large numbers of viral particles (10^7 to 10^9 virus particles per gram of soil.. knowledge of soil viral ecology has come mainly from the fraction that desorbs easily from soils (<10% ..) and the much smaller subset that has been isolated.*” If <10% are detectable a likely range is then $>10^8$ - 10^{10} /g and, as with soil bacteria, their numbers are massive and a reasonable mean estimate is of 10^9 viruses/g that if a similar proportion is isolatable may be closer to 10^{10} (that incidentally is the same value provided by Kuzyakov & Mason-Jones, 2018). Thus Earth’s $\sim 2.1 \times 10^{20}$ g soil to 1 m depth may have $\sim 2.1 \times 10^{30}$ virions and if to 10 m soil depth = $\sim 2.1 \times 10^{31}$. So Bar-On et al.’s 10^{31} and 0.2 Gt C if doubled in soil alone this then equates to ~ 0.4 Gt C. Compare to Bar-On et al.’s (2018: 55): “*assuming a mean soil depth of 10 meters (276), we get to an estimate of $\sim 10^{29}$ - 10^{30} virions in soil globally*” with mean $\approx 6.2 \times 10^{29}$ soil viruses (mainly phages) with 32-fold uncertainty. Terrain allowance doubles this total to $\approx 1.24 \times 10^{30}$ presumably then just 0.02 Gt C. Mushegian (2020) confirms counts over a quadrillion-quadrillion yet, as mentioned, it may be out by orders of magnitude and (as for mitochondria) whether this truly adds living organisms to an ever-evolving soil biota tally is up for debate.

Since compilation, new soil virus data was provided (<https://www.soilviral.com/>) having: “*1 billion viruses g^{-1} , that if calculated over the whole globe amounts to about 4.9×10^{31} soil viruses globally*”. Doubled for terrain this becomes 10×10^{31} and 4 Gt C as a possible new value.

Of especial note to global NPP is whether impact of soil viruses on SOC and nutrient cycling, climate emissions and productivity as they do in marine surface where 20–40% of microbial standing stock are lysed each day to a dissolved nutrient pool (Kuzyakov & Mason-Jones, 2018).

Gross Primary Production (GPP) and its Net (NPP)

GPP – the rate of carbon fixation by photosynthesis – is countered by Plant and Soil respiration.

The most recent Global Carbon Budget (ESSD 2022: fig. 2) has modified several of their soil values slightly and acknowledged an increase in terrestrial GPP to 130 Gt C/yr (to give an NPP rate about half of 65 Gt C/yr?). All their rates and values rates require revisionary review for latest soil and NPP data, not least to include consideration of their errors for terrain omission.

Using C and O isotopes Welp, Keeling et al. (2011), Liang et al. (2017) and Laskar et al. (2019) gave carbon turnover times of 0.9–2.8 yrs (median ~1.8 yrs), mainly due to terrestrial terrain. Welp, Keeling et al. (2011) estimated 475–897 Gt C/yr and atmospheric C turnover time of 0.9–1.7 years with just 80 Gt C/yr from oceans (thus 395–817 Gt C/yr from land!). Since atmospheric CO₂ is ~860 Gt C then, presumably, >430 Gt C is recycled on land each year.

In a summary of the status of global NPP estimations, Chapin & Eviner (2014) said: “NPP includes the new biomass produced by plants, the soluble organic compounds that diffuse or are secreted into the environment (root or phytoplankton exudation), the carbon transfers to microbes that are symbiotically associated with roots (e.g., mycorrhizae and nitrogen-fixing bacteria), and the volatile emissions that are lost from leaves to the atmosphere (Clark et al., 2001). Most field measurements of NPP document only the new plant biomass produced and therefore probably underestimate the true NPP by at least 30% (Table 1).” Their table 1 showed only 30-70% of NPP in new plant biomass (median about 50%). Also, all surveys are based upon planimetrically flat biomes and thus fail to account for terrain. This may also at least double the NPP estimates. Moreover, Chapin & Eviner (2014) found boreal NPP to be especially underestimated; they say: “boreal forests, where NPP estimates are 75% greater than those of Saugier et al. (2001). Therefore, boreal NPP may be underestimated relative to other biomes.” Taking such factors into account, from a starting NPP of 70 Gt C/y the revised total may well be in the realm of plus 50% for 105 Gt C/yr doubled for terrain to 210 Gt C/yr.

NOAA’s undeniable CO₂ summer flux at Point Barrow site is -40 Gt C from its catchment >35°N; Riach et al. (2002: figs. 2,4) show counter SR summer flux >30°N of (+80.3 / 4 for half year & half hemisphere =) ~+20.1 Gt C to total -60.1 Gt C real summer NPP drawdown, as supported by Bartsev et al. (2012: figs. 1-3) by Basile et al. (2020: tab. 1; fig. 4). And, as Haverd et al. (2020) state: “land north of 35°N contributes less than 25% to global GPP”, if so then total global NPP may be (>60.1 x 4 =) >240.4 Gt C/yr or tolerably above ~218 Gt C/yr NPP estimate (Blakemore 2018b, 2020b) that itself is 4 x prior guesstimates of just 55 Gt C/yr terrestrial NPP.

Koren et al. (2019: fig. 1) model 400-514 Gt C/yr leaf<->air flux; 111 Gt C/yr for soil respiration. They have a soil<->air flux of just 30 Gt C/yr while admitting: “global soil invasion flux cover a wide range: from 30 PgC/year (Stern et al., 2001) to 450 PgC/year (Wingate et al., 2009)”. Their figure 4 (Figure 13) has a large leaf<->air flux annual variation from 400 to 750 GtC/yr.

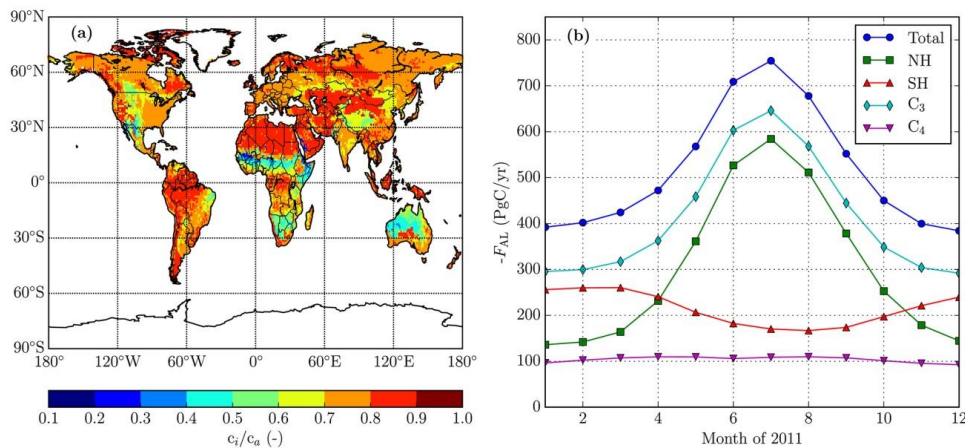


Figure 13. After Koren et al. (2019: fig. 4). F_{AL} = Flux air \leftrightarrow leaf in North and South with C_3/C_4 .

Remarkably, without giving explicit estimates of total global GPP or NPP, Haverd et al. (2020: fig. 2a) yet claimed their GPP “historic value is nearly twice as high as current estimates”, and their graph seemingly shows 2020 GPP model of $\sim 143 \text{ GtC/yr}$ (= NPP $> 71 \text{ GtC/yr}$). Canadell et al. (2021: fig. 5.12) also show “Gross photosynthesis” or GPP of 142 Gt C/yr to give NPP about half this at $\sim 71 \text{ Gt C/yr}$. Their study supports Campbell et al. (2017) who already showed a “large GPP growth during the twentieth century (31%)” with “measurement-based estimates of GPP are as large as 175 Pg C yr^{-1} ” with NPP 87 Gt/yr ?. Moreover, since Koren et al.’s (2019) paper is quoted, presumably some authors accept their current GPP may be as high as 350 Gt C/yr giving $\sim 175 \text{ Gt C/yr}$ NPP? Some prior NPP/GPP guesses are more or less wrong than others as Raich et al. (2002) noted that a study by Keeling et al. had variabilities about twice theirs revealing a large uncertainties in SOC and NPP, so much that Scurlock et al. (2002) have NPP estimates 2-5 times higher than previously. Their median error of 3.5 times current “ 60 Gt C/yr ” = 210 Gt C/yr in the realms of my estimate of 218 Gt C/yr NPP in Blakemore (2018). Q.E.D.

NPP Net Assimilation is Balanced by Soil Respiration and/or Decomposition (SR)

Total Soil Respiration CO_2 release estimates of $88\text{-}108 \text{ Pg C/yr}$ (Warner et al., 2019: tab. 1; Zhao et al., 2017; Hursh et al., 2017) all based upon planimetrically flat land surfaces, when doubled for terrain are up to about 216 Gt C/yr balancing approximately 218 Gt C/yr NPP (Blakemore, 2018b). Thus soils emit twenty times more carbon than burning of fossil fuels does. Hashimoto et al. (2015) had global soil respiration 91 Gt C/yr increasing at a rate $\sim 0.1 \text{ Gt C/yr}$. Allocation was about 51 Gt C/yr from boreal zone and 40 Gt C/yr from temperate or tropics. From their

soil respiration total of about 88 Gt C/yr about 22 Pg C/y or almost a quarter was emitted from Asian region soils (Sha et al. 2021). All these latter values are also to be doubled for terrain.

Greening Effect of Excess CO₂

Further proof of neglected land NPP is from a report by Graven, Keeling et al. (2013) of northern flux increase of 32–59% in just 50 years they thought implied “*growing season uptake increased by 40 to 60%, whereas dormant season release increased by only 20 to 50%*”, this due almost entirely to land change as they said: “*fossil fuel and biomass burning emissions make only minor contributions to the overall cycle*” [just 1-6%]. The ocean did not have any appreciable effect on carbon cycle fluxes [just -3-4%] as shown in their table [S4](#) at neither Barrow nor Moana Loa sites. Moreover, their figs. 4 & S9 show none of the models matched nor could explain observed data (due to ignored terrain?). Thus, CO₂ as a limiting plant growth factor and topographic soil loss as espoused herein may adequately account for such changes.

Similarly, Haverd et al. (2020) found a 30-47% increase in plant growth from 40-50% increase in CO₂ with GPP estimated to have risen by +30% since 1900 or by +47% from pre-industrial levels with rising atmospheric CO₂ concentration as the dominant driver. CO₂ increased ~50% from ~278 ppm in 1750 and 40% from 295.8 ppm in 1900 up to ~415 ppm today or by +119.5 ppm x 2.124 = +254 Gt C implying 30% or a 76.2 Gt C plant/soil carbon sink since 1900. Their fig. 2a gives terrestrial NPP at ~70 Gt C/yr. Increased land temperatures with upped soil activity must surely also plays a part while water or nutrients may be limiting brakes. But that vegetation NPP increase lags behind that of CO₂ may surely be in a large part due to the clearing of forests and erosion of topsoil ensuring it cannot keep pace with CO₂ fertilization.

A study paper by Keenan et al. (2021) with 12% increase for 17% extra CO₂ from 1984–2020 was subsequently retracted seemingly due to critical uncertainties in their figure 1. And Piao et al. (2020) concluded that CO₂ fertilization is the main driver of global vegetation greening although warming is the major cause of greening in boreal and Arctic biomes, having negative effects on greening in the tropics. Zhu et al. (2016) showed warming affecting from 25-50% of vegetated lands from the period including 1982 up to 2009 or 2014 and only 4% “browning”. Their global ecosystem models suggested that CO₂ fertilization effects explained 70% of the observed greening trend, followed by nitrogen deposition (9%), climate change (8%) and land cover change (LCC) (4%). However, a more extensive study from 1982-2017 reported only 40%

greening and 14% browning indicating an intensification of leaf area loss in recent years (Winkler et al. 2021a).

Nevertheless, that the CO₂ continues to rise above plant drawdown indicates photosynthesis is unable to adequately recycle extra CO₂ the reasons for which may include limitations of other resources such as water, loss of vegetation cover especially deforestation and loss of topsoil that also inhibits plants thriving while also releasing yet more CO₂ exacerbating the problem. Figure 14 shows a graphical summary of NPP and Global Carbon Cycle from CO₂ emissions data.

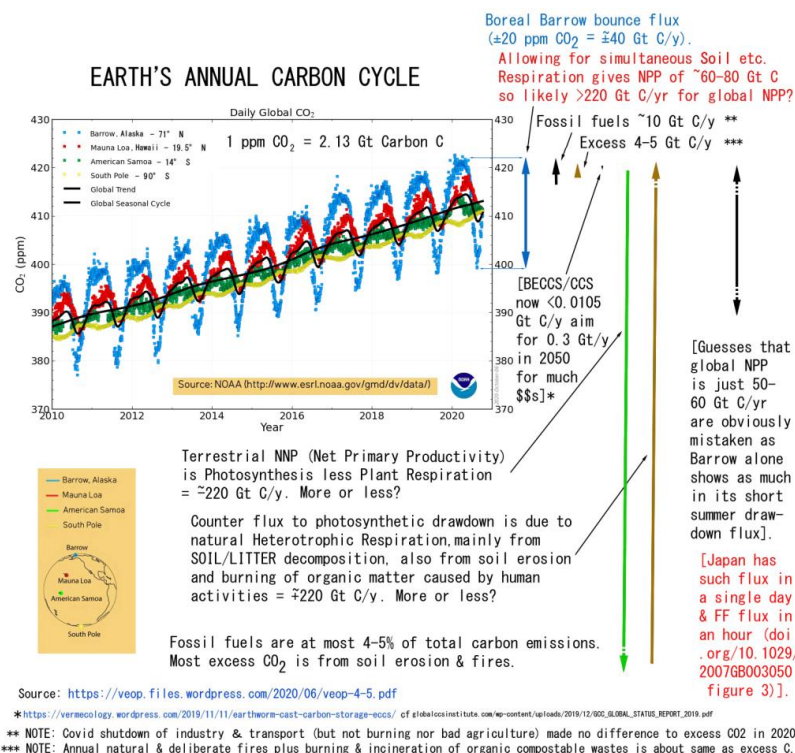


Figure 14. Source: <https://vermecology.files.wordpress.com/2020/10/image-4.png>. Summary of NPP and Global Carbon Cycle from CO₂ emissions data based upon Barrow CO₂ “bounce”.

Leaf-Area-Indices (LAIs) as Backcheck on NPP

As a backcheck a bio-mechanism to explain reasonableness of upping NPP values is Leaf-Area-Index (LAI) which Asner et al. (2003) had a mean of as 4.5 m²/m² Thus on a productive “flat” land basis of 12 Gha, a total leaf area is 54 Gha. Doubled for coarse terrain is 108 Gha. However, as average leaf area is cm² scale, terrain may require doubling again to 216 Gha. Values are variable: Whitman et al. (1998) assumed LAI of 10, Fang et al. (2019) imply about 2.

Ocean Biodiversity, NPP, Carbon and Oxygen Cycles Compared – See Appendix C.

Ferrer *et al.* (2019) categorically claim: “It is estimated that the ocean.. hosts the largest population of microbes on Earth. More than 2 million eukaryotic and prokaryotic species are thought to thrive both in the ocean and on its surface.” This is <0.01% of soil biodiversity.

For NPP, seemingly all ocean estimates (e.g. IPCC, ESSD, etc.) track back to Revelle & Suess (1957: tab. 2) based “in part after HUTCHINSON (1954)” that was “too uncertain to allow any definite conclusions”. Hutchinson (1954: 380) had NPP on land just 20 ± 5 Gt C/yr saying these figures were too low as he failed to account for tropical rainforests (!). His Ocean NPP was five times greater at 126 ± 82 Gt C/yr he said was likely “an order of magnitude too high”. Indeed.

Woodwell *et al.* (1978: tab. 1) marine NPP was 24.8 Gt C/yr and land just 52.8 Gt C/yr whereas Siegenthaler & Sarmiento (1993) gave new marine biological production of 10 Gt C/yr compared to terrestrial NPP of 50 Gt C/yr, or five times greater with land yet much higher now.

Compared to the current terrestrial NPP of ~ 220 Gt C/yr, there is little evidence for ocean NPP much above 10-20 Gt C/y supporting its total biomass of just $\sim 3-6$ Gt C. Of this, less than 100 million tonnes wet weight is captured or extracted each year (www.fao.org/3/cc0461en/online/sofia/2022/world-fisheries-aquaculture-production.html).

Much supporting data is presented here - <https://ourworldindata.org/fish-and-overfishing>. Nevertheless, 100 million tonnes wet catch is about 30 million tonnes dry or 15 million tonnes of carbon, or 0.015 Gt C/yr that is <0.5% of oceans’ total biotic stock or about 0.1% of its NPP.

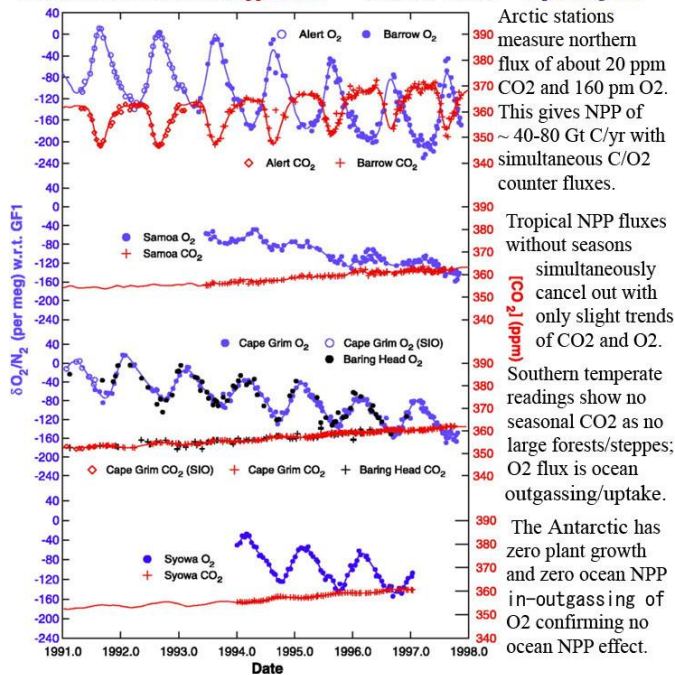
Comparative human appropriation of NPP (HANPP) on land is 1,000 times greater at ~ 15 Gt C/yr (Krausmann *et al.* 2013) including fire and LUC compared to Alexander *et al.* (2017) who have ~ 13.9 for food alone with 8.0 and 5.9 Gt C/yr for croplands and grassland, respectively, representing $\sim 23\%$ of total NPP when taken as just 60 Gt C/yr, or now about 6% for 218 Gt C/yr.

Moreover, gas exchanges with the Atmosphere are passive and instantaneous, as governed by Henry’s Law. Ocean’s overstated importance to global and CO_2 or O_2 cycles is relatively minor.

Koren *et al.* (2019) say: “the gross ocean fluxes largely cancel out” (just ~ 3 GtC/yr globally).

Piao *et al.* (2019: fig. 9) show negligible, or negative, seasonal/annual contribution from the Ocean compared to Land on the total global carbon flux. The following Figure 15 supports this.

Photosynthesis/respiration/fire stoichiometry is 1 mol CO₂ ↔ 1 mol O₂.
 1 ppm CO₂ = 7.8 Gt CO₂ comprising 2.13 Gt C & ~5.7 Gt O₂ or ratio 1:2.7.
 Conversion from per meg to ppm to Gt is 1 per meg = 0.21 ppm = 1.12 Gt O₂.
 Stoichiometric ratio is then 1ppm CO₂ ↔ (5.7/1.12 Gt O₂) = ~5 per meg O₂.



Boreal north has ~25% total NPP, then global NPP must be ~160-320 Gt C/yr.

[Sources: <https://science.sciencemag.org/content/287/5462/2467/tab-figures-data>; <https://vermecology.wordpress.com/2020/08/31/barrow/>].

Figure 15. Oxygen vs. Carbon fluxes. Source: vermecology.wordpress.com/2021/05/27/h2o/. Cf. Keeling & Manning (2014: fig. 2) and wernerantweiler.ca/blog.php?item=2015-06-01.

False claims ocean supplies 50-90% of oxygen we need to breathe each year is countered as its outgassing flux of just ~0.00015% compares to 0.0014%/yr from land’s NPP (Figure 16). Manning & Keeling (2006) had a lower annual outgassing contribution to the atmosphere’s 21% oxygen (37,000 Pmol O₂ or about 1.18 million Gt) of 0.048 Pmol O₂/yr or just 0.0001%/yr. In reality, there is a small net loss of atmospheric oxygen due mainly to burning and SOC loss.

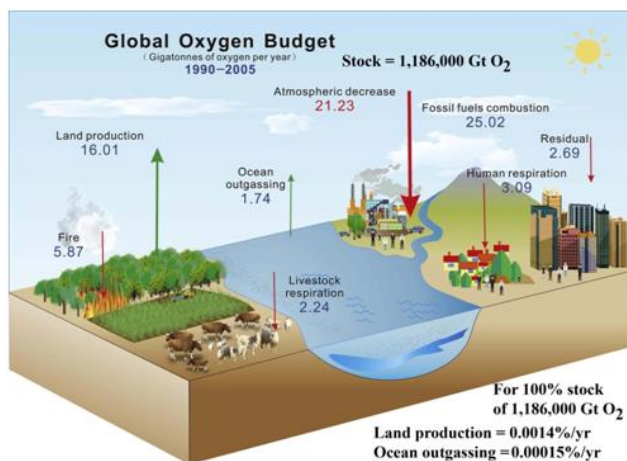


Figure 16. From Huang *et al.* (2018: fig. 4); <https://vermecology.wordpress.com/2021/01/05/pp-bs/>; <https://vermecology.wordpress.com/2021/05/18/o2/> and cf. Keeling & Manning (2014).

Global O₂ level give insight into SOC loss as stoichiometric photosynthetic/decomposition molar ratio on land of O₂:CO₂ (and also O₂:C) is 1:1. Since +1 ppm CO₂ (= ~2 Gt C) then an O₂ decline by -600 meg in 30 years from 1991-2021 (<https://www.oxygenlevels.org/>) implies ~4 Gt C/yr lost both by burning of fossil fuels, which is mostly accounted for, or by loss of SOC, which is not. Comparative CO₂ accumulation in 30 years from 1991-2021 of 335.5 to 416.5 ppm (= +81 ppm or 162 Gt C = +5.4 Gt C/yr) partly from fires and fossil fuels also likely ~8.5 Gt SOC/yr loss.

Soil Acidification and Plastication

NOAA and many other marine institutions distract with claims that ocean “acidification” is a problem as it has basically gone from pH 8.2 to 8.1 (or -0.1) over the last few centuries that they say is 25-30% decrease due to logarithmic scale. However, only ~0.03% of human food comes from the oceans that support less than 0.01% of global biodiversity so it is not so critical. Despite being almost always ignored, soil acidity is a much greater problem at more than a magnitude higher occurring much more rapidly, at a rate 26 times (or 800% more) than in the oceans and only in the last few decades, mainly due to agrichemical intensification. An example, from Tian & Niu (2015): “*We found that N addition significantly reduced soil pH by 0.26 on average globally. However, the responses of soil pH varied with ecosystem types, N addition rate, N fertilization forms, and experimental durations. Soil pH decreased most in grassland, whereas boreal forest was not observed a decrease to N addition in soil acidification*”. Soil acidity disrupts or destroys soil fauna & plants including trees or saplings (https://en.wikipedia.org/wiki/Soil_acidification) and releases toxix Al. Of note is that conifer forests are often associated with more acidic podzols (or podsols) having a compacted humus layer, known as mor, microbially dominated by fungi. Nevertheless, there is a “*need for stringent measures that reduce sulfur and nitrogen emissions so as to maintain ecosystem structure and function*” (Yang et al. 2015). Acid rain, long recognized as a major challenge, is due to many natural or human factors but mainly agrichemicals. As well as Nitrates or Sulphates, the increasing levels of CO₂ form carbonic acid adding to acid rains (https://en.wikipedia.org/wiki/Acid_rain) as does formic acid too (Stavrakou et al. 2011).

Political hype for ocean acidification or plastic pollution as problems are orders of magnitude greater in the soils that we depend upon for 99.7% of human food and >99.9% of biodiversity. For example plastic pollution up to 23 (www.unep.org/news-and-stories/story/plastic-planet-how-tiny-plastic-particles-are-polluting-our-soil) or 32 (<https://ieep.eu/news/isgaper-exploring-plastic-pollution-in-soil>) times greater in soils compared to the oceans. On average soil pH has decreased 0.24–0.26pH points globally (a 100% change) (Tian & Niu 2015, Blakemore 2018a, Meng et al. 2019), more so due to intensive agricultural situations up to two pH units or by 10,000% in just a few decades (Fenn et al. 2006, Gou et al. 2018), thus ocean acidification of 30% in the last two centuries is quite trivially irrelevant (see also - <https://vermecology.wordpress.com/2021/02/02/ocean-acidity/>). Meng et al. (2019: fig. 5) showed acid soils release toxic Al or Fe and decrease roots by 19% soil bacteria by -16.4%. Early reports were of soil fauna (e.g insects, microbes and worms) depletion in acid soils (pH <3.0) at Rothamsted soon after synthetic fertilizers use (Morris 1922, 1927; Blakemore 2018a).

Studies on SOC Loss Over Decades or Centuries Point to Solutions in SOC Restoration

Strzelecki in Australia in 1839-1843

Historically, between 1839 and 1843, soil carbon samples were collected from the colonies of South-East Australia (prior to 1851 the state of Victoria was part of the colony of New South Wales) and Tasmania by Polish explorer and geologist, Sir Paul Edmund [Count] Strzelecki. It is significant that 1839 was also when the longest of long-term experiments (LTEs) commenced at Rothamsted in the UK to determine the effects of different fertilizers on crops and soils, these samples being consistently collected and contentiously stored since that time.

Strzelecki sent soil samples to the UK for analysis. According to Jones (2009), Strzelecki (1845) reported ten farm or paddock soils in a high productivity group with soil organic matter (SOM) levels 11–37.75% (average 20% or 10% SOC) and ten soils in a low productivity group with SOM levels 2.2–5.0% (average 3.72% or 1.85% SOC). Strzelecki's original data are reanalysed and corrected slightly to allow for differing soil moisture contents to now show overall mean SOC for NSW (and partly Victoria) of 4.1% and for Tasmania 4.5%. These are substantially above contemporary values showing SOC decline between 40–50% (cf. Appendix B, Excel file).

SOC decline is consistent with Dr Bill Coching (2018: fig. 3) that shows Tasmanian SOC decline from mean of 5% to 2.5% in about 40 years of cultivation. Compare to Dr C. Jones' summary:

(web.archive.org/web/20200315053953/http://www.farminstitute.org.au/literature_68254/AGE2010_Paper_Dr_Christine_Jones). Jones (2009: appendix C) tabulates range of SOC in Victoria of 0.9–5.8 % with median value ~2.9%. This compares to a range of 2.2–17.2 with median ~9.7% found by Strzelecki for NSW (partly Victoria). As Jones notes: *"On average, 12 tonnes of topsoil are eroded for every tonne of wheat currently produced in Australia. Greater losses are experienced on more fragile soils. For example, over 200 tonnes of topsoil are eroded for each tonne of wheat produced in some parts of the Wimmera region in western Victoria. No civilisation can survive the physical destruction of its primary resource base - the soil."*

Long Term Experimental (LTE) Fertilizer Trial Results for SOC, Yield, Biodiversity, Etc.

A remedy for SOC loss may be found in restoration of 100% organic farming. Therefore, accounts of SOC values of various LTEs are analysed, not just for changes from original starting levels where available, but also comparison of organic treatments, often Farm-Yard Manure (FYM) as a type of coarse compost, taken as preserving the *de facto* starting values since they best represent prevailing management prior to synthetic fertilizer usage (Blakemore, 2018a).

Organic farming is concerned with maintain soil health and so too foundations of Permaculture. Applying the principals and practices of Permaculture (Mollison 1988) allows much flexibility and a transition, where appropriate, from annual high maintenance crops to self-supporting perennials such as fruit and nut trees or vines combined with Yeoman's (1954, https://en.wikipedia.org/wiki/Keyline_design) Key-Line Planning for conservation of water.

A fundamental feature of a healthy soil is its soil organic carbon (SOC) status. Intensive agrichemical farming is known to deplete or "mine" SOC. Three main sets of data are available. Heritage reports from early soil surveyors such as Count von Srzelecki in Australia, data from several plot or field long-term experiments (LTEs) that have preserved samples or recorded changes in SOC with time and contemporary comparative organic farms that act as proxies for original status compared to their conventional chemical neighbours. Reattaining such levels of soil carbon may provide a safe mechanism to reduce harmful effects on soil of bad agriculture.

Several long-term field experiments (LTEs) with a majority in Europe or North America; e.g. at Rothamsted and Woburn (UK), Askov (Denmark), Grignon (France), Bad Lauchstädt (Germany), and the Morrow plots and Sanborn Field (USA), and there have been others for different lengths of time in other regions. An LTE list is to be found online here - <https://glten.org/>.

An assertion often made is that synthetic N fertilization maintains or increases SOC by enhancing production of crop residues. Yet the opposite effect was reported long before (e.g. by Howard, 1945, Balfour, 1943). This is consistent with evidence that mineral N enhances microbial decomposition of plant residues (e.g. Mulvaney et al. 2009) hence loss of SOC.

Blakemore (2018a) found SOC/SOM humus depleted -56.8%, soil moisture -22.3% and earthworms -83.2% on average from their optima in side-by-side organic vs. NPK field trials. Microbes were also significantly depleted by chemical farming in those soils tested. An assumption was that the organically (FYM or compost) managed fields maintain starting levels.

Kahn et al. (2007: tab. 3) tabulated about 50 long-term N fertilization trials from around the world all with rates of carbon loss at the final sample compared to the first reduced by up to -39%. Only three positive increases in carbon sequestration were noted in a report by Buyanovsky & Wagner (1998) from Sanborn Field. Sanborn Field, on the campus of the University of Missouri-Columbia, was established in 1888 with rotation and manure treatments on 39 plots. After over a century of data, Buyanovsky & Wagner (1998: tab. 4, fig. 2) show continuous manure treatments conserved SOC nearer original levels unlike other plots.

These values of around 39-56.8% SOC decline give support to the notion that intensive agrichemical farming depleted crop (and pasture) soils of their organic humus by about 50%.

Grace et al. (1995) on a long term (commenced 1925) rotation trial at Waite in South Australia showed that for the 11 rotations, soil organic carbon (SOC) in the top 10 cm declined from 2.75% in 1925 to a mean of 1.56% in 1993 (or by -43.3% in about 70 years). One plot, which had reverted to permanent pasture in 1950, showed the smallest decline with an SOC content of 2.46% in 1993 (-10%). Such low SOC values may be compared to Strzlecki's earlier figures.

Report on yields, soil and fauna after 120 years at Palace Leas, UK, is here (note acidification by up to 2 pH units!): <https://vermecology.wordpress.com/2022/05/04/worms-in-the-palace/>.

A dozen or so LTE results are overwhelmingly positive in almost all trials showing sustainability and many essential benefits of organics (such as conserving earthworms, microbes, carbon sequestration, etc.) with organic FYM (Farm-Yard Manure) beating synthetic NPK – despite, in most cases, neither optimal organic practices nor good composts being used – with summary data available online here: <https://vermecology.files.wordpress.com/2022/09/no-nox-2.pdf>.

Imperative to Reduce Nitrogen Fertilizers

Outside of any necessity to restore SOC to revive soil health and natural fertility, there is a corresponding driver to reduce artificial fertilizers that are conclusively shown to be deleterious.

Crop yields reportedly increased 200% or 3 x (correlated with doubled irrigation) since 1960, yet 800% or 9 x extra synthetic N was used (Figure 17) most lost as environmental contaminant. Cereal yields are not the only metric as other crops and smallholder production contribute, previously estimated as 70–80% recently revised to ~30% (Ricciadi et al. 2019), are excluded.

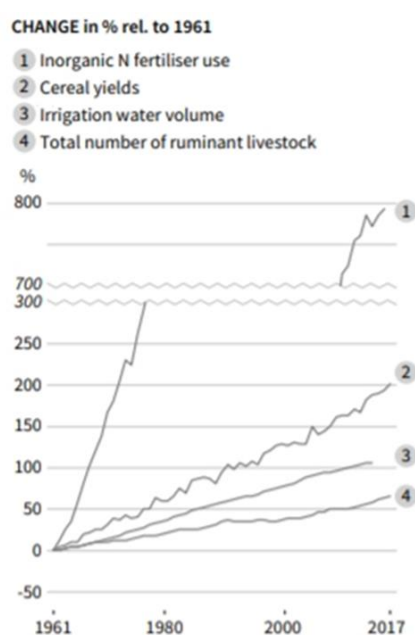


Figure 17. Source IPCC (2019a: Fig. SPM. 1D) also from <https://vermecology.wordpress.com/2020/01/16/solum-solace/>.

Mulvaney et al. (2009) report confirms: “Cereal production that now sustains a world population of more than 6.5 billion has tripled during the past 40 yr, concurrent with an increase from 12 to 104 Tg yr⁻¹ of synthetic N applied largely in ammoniacal fertilizers”. This is almost 9 x increase in N but, as already alluded to for Earthworms (that may contain ten times as much nitrogen), and biofilms (that may process 100 Tg N/y), both are more trivial to Bacteria or Archaea dry biomass of 400 Gt with 200 Gt C, 48 Gt N (= 48,000 Tg Nitrogen) the demise of which may deplete this vital nutrient resource. Re-evaluation of benefits is required.

Several LTEs and other reports (e.g Blakemore 2018a) show organic yields as high – or higher – than adjacent conventional, as exemplified in Figure above with yields that correlate more

with area and volume of irrigation over the time from 1960 (as in Figure 18). Organic food has higher minerals and nutrient contents (but less moisture content that adds considerably to supposed yield) from Mayer et al. (2022). Moreover, transition to smaller farms rather than larger gives more variety and higher production compared to broadacre arable. Allotments or smaller home gardens can yield two to ten times as much food per unit area (Watson 2015).

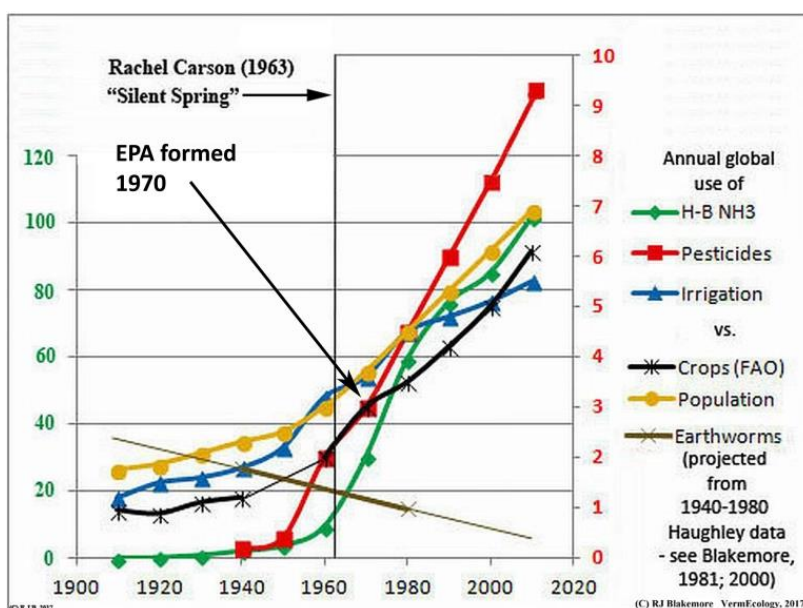


Figure 18. Farm variables mainly extracted from FAO data. Source: - <https://vermecology.wordpress.com/2020/10/16/nitrogen-necrosis/>.

FAO (www.fao.org/docrep/018/i3107e/i3107e.PDF, 2013: 130) says: "Of the approximately 2.3 billion tonnes of cereals currently produced, roughly 1 billion tonnes is destined for food use, 750 million tonnes is employed as animal feed, and the remaining 500 million tonnes is processed for industrial use, used as seed or wasted." An extravagance is to feed grain to stock.

Depletion of soil carbon is exacerbated by adding synthetic Nitrogen deliberately or vicariously via global rainfall pollution. A meta-analysis on 257 studies looking at the effect of soil N addition on soil respiration suggests a substantial stimulation of soil respiration (16%) and an enhancement in soil C mineralization (6%) within agricultural ecosystems (Lu et al. 2011) however, variable results were claimed from pot and field trials in Canada (Gagnon et al. 2016).

Since the Montreal Protocol implementation banned CFCs, synthetic nitrogen fertilizers again poses the greatest threat to our life-protecting ozone layer. Mohr (2021) shows it was known since the early 1970's, e.g. Crutzen (1970), that "Nitrous oxide emitted from the application of

fertilizer, among other processes, breaks down in the stratosphere and represents a source of ozone-depleting nitrogen oxides.” See also recent summary report - <https://vermecology.wordpress.com/2022/09/01/no-no/>). Nitrates are not the only problem.

Toxic Agrichemical Biocides

Amongst many as yet unbanned agrichemicals, formulations of glyphosate used as a herbicide or crop drying agent are especially counterproductive since it is patented as an anti-microbial (Patent No. US7771736B2) not limited to Enterobacteriaceae essential to our digestive health, also to soil microbes and seemingly mitochondria (van Bruggen et al. 2021, Strilbyska et al. 2022). Just how much destruction of soil microbes adds to CO₂ emissions is unclear at present.

Glyphosate now pollutes our air, water, food and bodies being linked to infertility and severe human and animal illnesses including cancer. Its deleterious effects on earthworms are reported (Gaupp-Berghausen et al. 2015). Wider ecological problems of agrichemical farming – as opposed to organic – are summarized by Blakemore (2018a) and Martinez et al. (2021).

Transitioning to synthetic fertilizer and pesticide free agriculture, i.e., 100% organic, is seen as an important objective in Europe (Jacquet et al. 2022). At the same time some terms like “regenerative” or “agroecology” have been misappropriated by chemical industry and research interests often with promotion of unproven or harmful methods such as chemical no-till or using ridiculous ideas of using uproven charcoal rather than composts (Beste 2022).

An EU study showed European food self-sufficiency if it converted wholly organic and reduced meat (www.cnrs.fr/en/organic-farming-could-feed-europe-2050) as shown by Billen et al. (2021: Graphical Abstract). This would apply to other regions with a small shift in eating habits and political will. Thus all “wastes” of global HANPP (~15 Gt C/yr) should be recycled under Howard’s (1945) “Law of Return”. Simply using vermi-composts to return nutrients and mulch to fields makes healthy soil fauna and plants as natural replacements for N-P-K and pesticides.

Undoubtedly and inevitably, synthetic reactive Haber-Bosch N needs to be cut by 75% (viz. Rockstrom et al. 2009: “*contain the flow of new reactive nitrogen to 25% of its current value*”); toxic agrichemical biocides eliminated entirely (Carson, 1962, Diamond et al. 2015, Persson et al. 2022); and meat consumption reduced (e.g Springman et al. 2018) in order to protect what remains of the Natural world and for our future to live comfortably as an integral part of it.

SOC Loss as the “Problem” and the “Solution” with Organic Ag Remedy

A recent paper by Georgiou et al. (2022) found mineral soils – those mostly used in agriculture, excluding tundra, peatlands, or deserts – are undersaturated by 21–42% of their carbon capacity; cropland deficit is 184–509 Gt C with potential sequestration total of ~104 Gt C to a depth of 1 m. This presumably represents an atmospheric CO₂ reduction by around ~50 ppm.

Many questions yet remain about historic losses of vegetation and soil, for example: The soil erosion of the Mediterranean (as noted by Plato and Lucretius), the timing of expansion of Sahara and other deserts and the possibility that Australian continent was once much greener. Australia is listed as third (behind China and USA) among countries with the highest recent loss of soil organic carbon (e.g. Sanderman et al. 2017, 2018), although it is likely it was much more vegetated in prehistoric times so may well have had greatest loss. A global imperative is to reverse expanding desertification (Figure 19) that impacts Europe and all other regions of the globe directly or indirectly. As well as North Africa, or West and Central Asia, three regions obviously contending gain from organic soil restoration are: China, USA in the North and Australia in the South, that are single political entities (if their peoples had access to proper information were less stubborn about excessive and unhealthy meat eating). Reduced clearing of forests for pasture and grazing on marginal lands are an obvious immediate remedies.

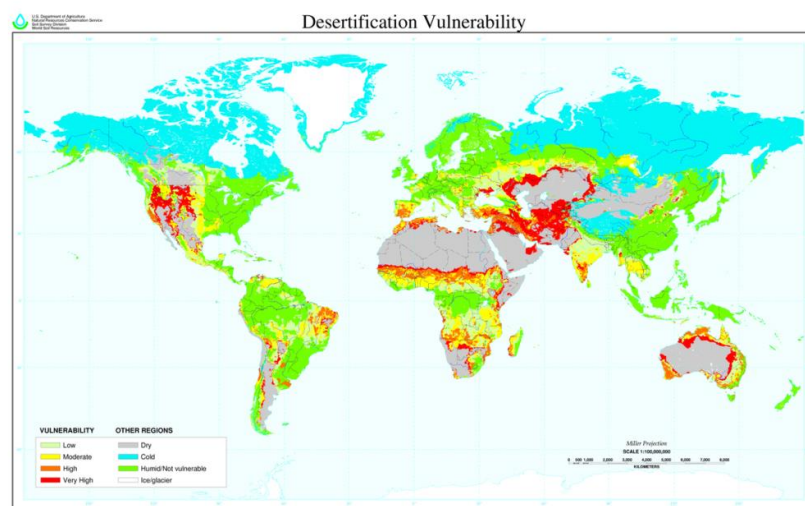


Figure 19. Red desert risk from https://en.wikipedia.org/wiki/File:Desertification_map.png with rate of expansion up to several Km per year (Balfour, 1943). Notable in the map above is Brecklands a tiny vulnerable part in East Anglia UK, while Australia’s desertification is nearly entire. Natural succession into cooler blue areas as they warm may offset some desertification.

Based on respective mean SOC contents, Buringh (1984: tab. 3.5 and in text) estimated that conversion from forest to grass or cropland depletes and may release (208 minus 109 =) ~100 t/ha C. This should be quite obvious given differences in leaf-area-indices (LAIs) of habitats.

In the Beagle Diaries, Darwin remarked upon smoke and fires of “Tierra del Fuego” also in Australia where: *“In the whole country I scarcely saw a place without the marks of a fire”* and *“large tracts of country in flames, volumes of smoke sweeping across”* (Keynes, 1981). The 2019–2020 bushfires across eastern Australia released up to 830 Mt of CO₂ to the atmosphere (DISER 2020b <https://soe.dcceew.gov.au/views/reference/45883>), or about 0.2 Gt C. For Australia’s pre-1750 era, a revised baseline estimate of maximum above-ground woody biomass potentially held 34.2 Gt of dry matter (Roxburgh et al. 2019), or about 17.1 Gt C, compared to approximately 5.6 Gt C in 2016, which translates to approximately 11.2 Gt of dry matter (DISER 2021d - <https://soe.dcceew.gov.au/views/reference/45894>); with nonforest vegetation including cropping lands, above-ground living biomass carbon stocks were estimated as 5.9 Gt C. In an independent study, which additionally included sparse woody vegetation, (Liao et al. 2020) predicted the woody biomass of Australia to be around 6.6 Gt C in 2018. Thus from 1750–2018 possibly as much as (17.1 minus 6.6 =) 10.5 Gt C forest carbon was lost (data from <https://soe.dcceew.gov.au/land/environment/carbon>). Loss from fires occurred earlier too.

Fossil tree kangaroos have been found in laval sink-holes in the now desertified Nullarbor (“no trees”) plain, actually from both Thylacoleo Caves and Mammoth Cave of WA (Prideaux & Warburton, 2008: 2009; *Australian Geographic*, March 24, 2021: www.australiangeographic.com.au/topics/wildlife/2021/03/ancient-species-of-tree-kangaroo-discovered/). This has been accounted for: *“despite having a remarkably similar climate to today, the Nullarbor Plain was once much better vegetated, a shift that may have been wrought by increasing frequency and/or intensity of bushfires (Prideaux et al. 2007; Warburton and Prideaux in press).”* This hints at the possibility for forest restoration of parts of Australia, where prescribed burnings to be curtailed. Reduction in tree clearance for grazing, especially reduction in sheep and goats, would be wise management for the large areas of marginal land.

How much carbon is in Australian soils? The CSIRO’s Australian Soil Carbon Mapping Project (Rossel et al 2014) provides national scale representation of an average amount of organic carbon in the top 30 cm of Australian soil at 29.7 t/ha and total stock for the continent at 25.0 Gt SOC (range 19.0 to 31.8 Gt). The total SOC stock in agricultural regions is 12.7 Gt (range of

9.9–15.9 Gt https://agriculture.vic.gov.au/_data/assets/pdf_file/0006/857607/Soil-Carbon-Snapshot-updated-May-2022.pdf). Doubled for depth and again for terrain is >100 Gt SOC stock. This is remnant soil as Chan % McCoy (2010) estimate at least 50% of original SOC stock lost in intensively managed Australian cropping systems, essentially SOC has been mined. Thus Australian agricultural soil >0.3 m deep doubles values, and terrain doubles again for $12.7 \times 4 = 50.8$ Gt SOC remaining, with about the same lost and open for restoration (= 24 ppm CO₂?).

In WA, Australia, most soils are low in SOC carbon, typically measuring 0.7–4% with 20–160 t C/ha (<https://www.agric.wa.gov.au/measuring-and-assessing-soils/what-soil-organic-carbon>). Yet when digging deeper, down to bedrock at 8 to 35 m depth, Harper & Tibbett (2019; tab. 1) found mean SOC mass densities of five WA locations in a 400–600 mm/yr rainfall zone varied from 21.8–37.5 kg C/m² or 218–375 t C/ha, and were *in toto* two to five times (median 3.5 x) greater than if sampled at the same site to a typical depth of 0.5 m, viz. 5.8 C/m² or 58 t C/ha. Average data from typical “Soil Sink Bank” have ~32 tons/ha, ~55 t/ha and ~138 t/ha SOC in the top 10 cm, 50 cm and 500 cm of soil, but deserts soils have much lower carbon contents.

In an earlier 26 year reforestation study in WA by Harper et al. (2012), SOC stores (to 0.3 m depth) ranged 33–55 t/ha with no statistical differences detected between trees and adjacent crop and pasture rotation farmland at that time. Yet reforested plots contained additional tree biomass carbon (23–60 t/ha from aboveground biomass with 1.2 x factor for roots added – note that from the data herein, root biomass is likely closer to 100% of the above ground plant mass) and in surface litter (19–34 t/ha). When SOC is upped ~3.5 x for depth plus litter and roots added, total soil carbon is likely 280–327 t/ha, with means ~7.5 x more than tree carbon biomass alone. This ratio is slightly less than the approximate global above-ground : soil biomass ratio of 1:10 from Blakemore (2020: fig. 1 <https://orgprints.org/id/eprint/38139/1/Veop-4.pdf>). Terrain further doubles soil/plant totals when sampled sites are extrapolate to regional areas. Thus these data are significant indicators.

A meta-analysis of the impact of land-use change on SOC concentrations by Guo & Gifford (2002) found that the SOC stocks increased by on average 19% after the transition from crop to pasture with Conant et al. (2017) providing soil carbon increase figures of ~ 0.87 t/ha/yr.

Their figure 1 shown below for summary showing positive and negative changes (Figure 20).

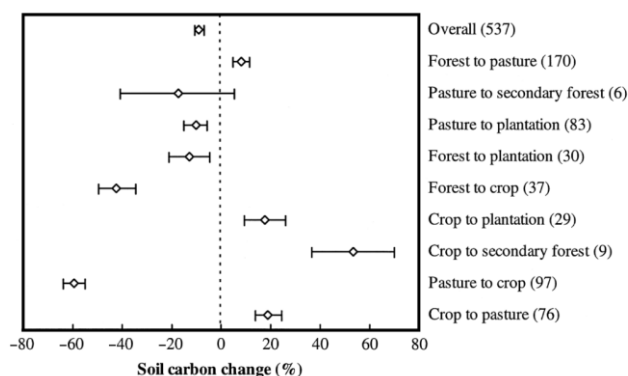


Figure 20 . After Guo & Gifford (2002: fig. 1). SOC responded to various LUC events (95% CIs). Their meta-analysis covered 16 countries but mainly: Australia, Brazil, New Zealand and USA.

Data in the Figure above compare to Buringh (1984); presumably, in time, some 50% SOC loss from deforestation may be restored with reduction in fires, less excess red meat consumption that consumes forests and half our crops, with the revival of a modern organic recycling ethos.

In a semiarid region of China, Gan et al. (2014: fig. 1) found SOC increase with 30 years better farming practices. Zhang et al. (2017) talk of higher crop footprints in China than in other countries, such as the United States, Canada and India with improvements in soil SOC using different techniques in several crops (maize, wheat or rice), with the most important factors for carbon sequestration including return of crop straw to the field (+41–90%).

Yet another example of restoration or reclamation possibilities, a desert study in Egypt reported in 30 years of organic agriculture with compost and crop rotations SOC stocks to 0.5 m increased from 3.9 to 28.8–31.8 t C/ha, a raise of ca 5–8 t C/ha (Luske & van der Kamp, 2009).

A stark possibility that Australia and other arid regions can be re-vegetated needs to be accompanied by a rationale to reduce fires, excess grazing of stock on marginal land, and forest clearance for pastures. As well as providing shade and windbreaks, evapo-transpiration especially from deep-rooted forests provides 60–95% of rainfall in most lands ([https://en.wikipedia.org/wiki/File:HumanIntegratedWaterCycle_\(2\).jpg](https://en.wikipedia.org/wiki/File:HumanIntegratedWaterCycle_(2).jpg) also <https://vermecology.wordpress.com/2021/05/27/h2o/>; Trenberth et al. 2007: fig. 1). Specifically, some 60% of land precipitation evaporates to the atmosphere, this figure exceeds 95% in arid climates (Zhan et al. 2019). Allowing natural tree regrowth is a self-perpetuating and expanding process helping to restore biotically rich topsoils and reverse desertification.

A first step to restoration, open to all, anywhere, is recycling organic wastes via vermi-compost.

Soils Critically Undervalued and Overlooked by UN's SDGs

UN's Agenda 2030 and SDGs have already failed most of their 2020 targets (<https://unstats.un.org/sdgs/report/2020/progress-summary-for-sdg-targets/>) and will surely fail those set for 2030. The present study clearly demonstrates an urgent need for context and triage in evaluating our global priorities and goals. Especially soil is ignored at our peril (Figure 21). SDGs focuses on Ocean or Water and Life **on** Land, but only mention "soil" twice in passing. A complete re-evaluation and review is required for a chance of any truly meaningful benefits.

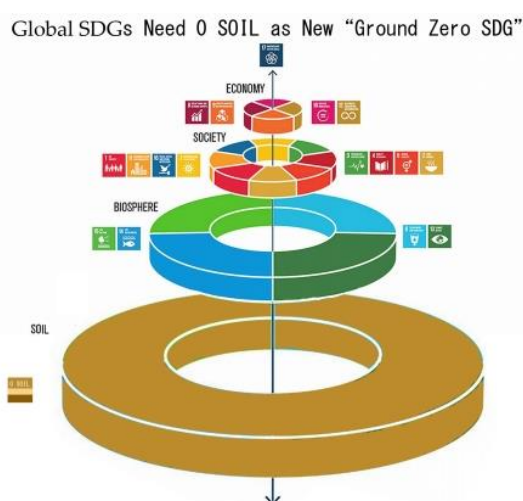


Figure 21. Source: Ame (雨) Power, <https://vermecology.wordpress.com/2020/07/30/ame-power/>. UN's SDGs require revision to recognize the Soil foundation upon which the Biosphere depends. Society and Economy are both entirely reliant on stable and secure Soil Ecology.

The dilemma is summarized in a quote from Koch *et al.* (2016: 3-4): *"Discussions around biodiversity loss seldom refer to soil even though soil contains the most diverse and complex ecosystems on the planet. Soils contain over 98 per cent of the genetic diversity in terrestrial ecosystems (Fierer *et al.*, 2007) however soil biodiversity is not addressed in the Global Biodiversity Outlook (GBO-3) from the UN Convention on Biological Diversity (Secretariat of the CBD, 2010), and is not referred to in the popular International Union for Conservation of Nature (IUCN) Red List of Threatened Species (IUCN, 2012). Recent attempts to develop a global framework for assessing planetary resources also fail to recognize the vital role of soil in the biosphere. The Stockholm Resilience Centre led an effort to define the key planetary boundaries that face anthropogenic pressure (Rockstrom *et al.*, 2009). This important work is influential in current reviews of sustainable development, but does not address soil as a critical contributor to buffering the thresholds of those boundaries."* A catastrophic situation, little changed today.

For example, the five EU missions to tackle major challenges to meet SDG goals (<https://ec.europa.eu/eip/agriculture/en/news/launch-eu-mission-soil-deal-europe>) seemingly have soil as their least important [with my comments added in braces]:

1. **Adaptation to Climate Change:** [as the current support shows, this depends on soil];
2. **Cancer:** [rather than genetic, most cancers have environmental causes not least from poisoned foods, water & air mainly from toxicity of agrichemicals on soils] – see Blakemore (2019b) and vermecology.wordpress.com/2018/05/27/wormageddon-destruction-in-our-soils/ ;
3. Restore our **Ocean and Waters** by 2030; [much less important/urgent issues than soil]
4. **100 Climate-Neutral and Smart Cities** by 2030; [only if all food is 100% organic]
5. **A Soil Deal for Europe:** 100 living labs and lighthouses to lead transition towards healthy soils by 2030. [A commendable goal that may also be met with several organic agro-ecological Soil Ecology Institutes working on a basis of context & triage as herein. Something less maritime than “lighthouse” may be a Boden-beacon or some such].

EU soil initiatives are here - ec.europa.eu/eip/agriculture/en/news/safeguarding-our-soils.

Conclusions

Results are summarized in the following Table 4.

Table 4. Summary Table of Results (to be completed post review).

| Factor | Range | Median | Terrain doubled | Source |
|--------------------------|--------------|-------------|-----------------|----------------|
| Current SOC Gt | 3,100-20,000 | 6,000-8,000 | 12,000-15,000 | Blakemore 2020 |
| SOC loss Gt C/yr | | | 2-15 | Current |
| Erosion rate Gt dry/yr | 35-75 | ~55 | 80-600 | Current |
| Aboveground Gt | 450–650 | 550 | 1100 | Blakemore 2018 |
| Roots Gt C | 300-600 | 500 | 916 | Current |
| Soil microbes Gt | 50 | | 200 | Blakemore 2022 |
| Soil fungi Gt C | 20 | | 50 | Current |
| Earthworms Gt | | ? | 2-4 | Current |
| NPP (SR) on Land Gt C/yr | 55-300 | 110 | 220 | Blakemore 2018 |

Footnotes: (See also <https://veop.files.wordpress.com/2020/06/veop-4-5.pdf>).

The stubborn idea that cutting FF will equally cut CO₂ is disproven by COVID shutdown that equated to 5–20% less FF in 2020–2021 but having little or no effect on CO₂ and other GHGs that increase due to bad agriculture and further forest burning (deliberate or accidental). Only 100% organic farming, essentially and effectively carbon farming for healthy, earthworm-rich

soils, can fix this and other problems. Yet there is no support for organic research and not one Soil Ecology Institute. Moreover, reducing air pollution is expected to result in instant increases in irradiation and temperatures: A lower aerosol radiative forcing of smog plus its cloud seeding effects that may increase temperatures several °C (e.g. Peace et al. 2020: fig. 4).

Shutdown failed, as Forster et al. (2020) summarized, despite Covid restrictions reducing fossil fuel CO₂ emissions, atmospheric carbon and global temperatures yet rise. Their fig. 4 further shows that from their estimates: *“declines in NO_x of as much as 30% will contribute a short-term cooling of up to 0.01 °C over the period 2020–2025 almost exclusively from reductions in tropospheric ozone. NO_x trends also contribute an insignificant warming effect from the decrease in nitrate aerosol... In contrast to NO_x, reductions in emissions of other short-lived pollutants, especially SO₂, cause warming from weakening negative aerosol forcing.* These two effects more-or-less cancelled out in their simulations, although on balance they expected a small warming effect. This conclusion was also made by NOAA (<https://web.archive.org/web/20201003215958/https://www.esrl.noaa.gov/gmd/ccgg/covid2.html> ; see too vermecology.wordpress.com/2020/08/31/barrow/).

Thus evidence mounts to the best way to lower GHGs is via SOC sequestration combined with synthetic N fertilizer reduction to safely drawdown CO₂ to desired levels, with no penalties, under a safety ozone layer “umbrella” and an acceptable/unavoidable aerosol pollution level.

Solution to excessive SOC loss may be found in soil humus restoration via vermi-composting. A most urgent needs is for completion of a global earthworm eco-taxonomic inventory with assessment of their conservation status in order to monitor – and to mitigate – any changes in soil health and its carbonization status. This could be a first task of new Soil Ecology Institutes.

Data presented in this study are best current estimates but all are open for review. Regarding topographic soil surface area, improvements and refinement of terrain are welcomed but – thus far – no study has improved upon topographical area nor invalidated a non-flat Earth. Detractors are invited to provide their estimate of fine topography, or prove a mirror-flat Earth.

Use of fossil fuels will likely continue, but better alternatives for limitless, non-polluting, free energy are geothermal and – anywhere it rains – trompe power as both provide pneumatic energy for cars, industry, etc. that combined with organic farming show us an honest, true trail.

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SUPPLEMENTARY INFORMATION

Appendices A-C (to be added). Strzeleki Excel file (to be added).

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