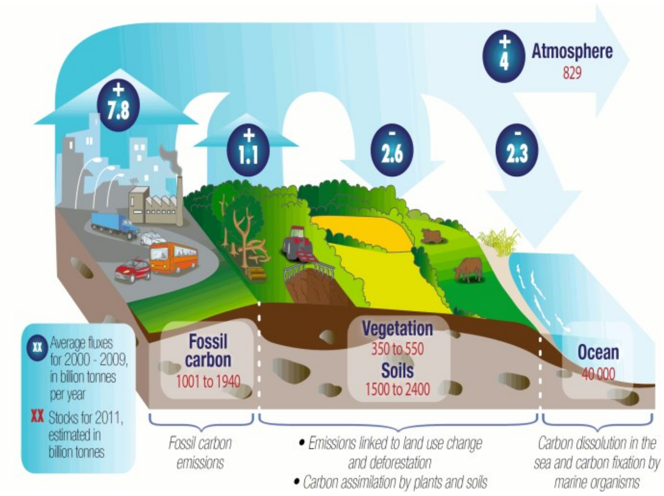
Briefing 3 — **Storing more carbon in soils: a challenge for climate and food** — March 2018

Storing more carbon in soils: a challenge for climate and food

Carbon stocks and fluxes



Source: Castagnon/IPCC

Summary

- *Soils can store more carbon than they emit, under certain conditions, still subject to uncertainties from a scientific point of view.*
- *Storing more carbon in soils is of major interest to offset anthropogenic CO_2 emissions, on the one hand, and to enhance food security, on the other hand.*
- *Research programs which, through better soil knowledge, will enable the implementation of favourable practices for carbon storage in agricultural and forestry soils, such as the "4 per 1,000" initiative, must be pursued and encouraged.*

Mr Roland Courteau, Senator, Vice-President

Background of the note

Global warming and food security are hot topics. Soils, which represent **important reservoirs of carbon** (C) in the form of organic matter (OM), are an essential element, although long underestimated, of these two issues. Indeed, although soils are often seen as mere surfaces, they form volumes with complex physicochemical properties which are necessary for life. Thus, their preservation is important not only at the local level, since even small changes in the carbon stock of soils have major effects on their fertility, and therefore on agricultural productivity, but also on a global level, through the global cycle of greenhouse gases (GHGs). **Soils emit GHGs**, in the form of carbon dioxide (CO_2), when the organic matter they contain is degraded, but at the same time, they contribute to carbon storage when they accumulate organic matter, which is made up of more than 50% carbon. Under certain conditions, **soils can store more than they emit**. In total, there is more carbon in the soil than in the vegetation that covers it and the atmosphere together, since there is an estimated minimum of 1,500 billion tonnes of carbon in the organic matter of soils globally, i.e. more than twice the carbon of atmospheric CO_2.

The 2015 OPECST report "*De la biomasse à la bioéconomie : une stratégie pour la France*" (in French)(1) called for continued investigations on the question of the relationships between soil and carbon, and particularly on the stakes of soil carbon storage(2). This is the purpose of the present note.

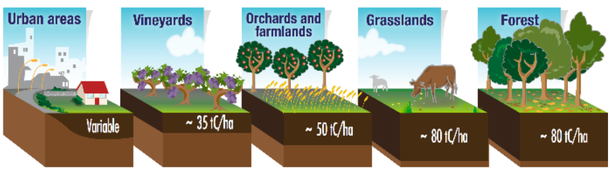
Scientific knowledge on the role of soils in carbon storage

In a visionary study published in 1853 entitled "Climates and the influence of wood and non-wooded soils"(3), Antoine-César Becquerel explained that "*the numerous and varied facts presented in this work show how complex the question of the influence of deforestation and clearing on climates is, since we must take into consideration a number of secondary causes which are usually neglected in the discussion*". 165 years after this work, the multifactorial complexity in the interactions between soil and climate continues to be verified.

Climate influences soil organic carbon content by controlling inputs, through plant productivity for instance, and outputs, through biological activity and erosion. Soil is a key player in the biogeochemical cycle of carbon. Carbon fluxes in soils depend on many factors: the nature of the ecosystem; the nature and quantity of inputs of organic matter; biological activity on which both humification and mineralization depend, the balance between the two being mainly a function of physicochemical conditions, the temperature and the possibility for interactions between organic matter and mineral particles. Mineralization is favoured by increases in temperature, decreases in soil moisture or mechanical soil cultivation methods.

Soils present a great diversity: the maximum amount of OM they contain can fluctuate greatly from one ecosystem to another, depending on the variations of the different factors previously mentioned. Depending on the nature of the soil and its use, **soil carbon storage is very uneven**: between peatlands, forest soils, agricultural soils, or degraded, artificialized or even waterproofed soils, the differences are large[(4)].

Organic carbon stocks depending on land use



Source: ADEME (estimates for the first 30 centimetres of soil)

The residence time of carbon in soils is a few decades on average, but it **is very variable** since it can range, for the same soil, from a few hours to several millennia, depending on several factors[(5)]. The residence time of carbon in soils is increased by the association between organic matter and soil mineral particles, particularly with clays, as they provide physical and physicochemical protection from decomposer micro-organisms[(6)]. The physical protection of organic matter is a process whose magnitude is difficult to estimate, and which is likely to be affected by both cultural practices and climate change. Thus, fine grinding of soil aggregates leads to an increased mineralization of organic carbon. Favoured by mechanical soil cultivation methods and by the absence of plant cover, erosion is, as a result of water run-off, a factor of soil degradation and soil organic matter loss. **Soil degradation**, through the destruction of organo-mineral complexes or through erosion, **reduces the soils' ability to store carbon** and to generate agricultural and forest products. It leads, at worst, to desertification. Yet it takes several thousand years to "make a soil"[(7)]. Soils are a non-renewable resource at the time scale of human activities. Today, 25% of the world's soils are severely degraded (41% for cultivated soils), to which 12 million hectares are added every year. **The artificialisation of soils**[(8)] has the following consequences: waterproofing (soils render no other service than to support constructions and transport routes), ecosystem fragmentation and biodiversity losses, urban sprawl which threatens the agricultural land, decreased regulation of water flows (worsening floods) and hot temperatures in cities.

The thickness of soils is also very diverse, it can range from a few centimetres to a few meters and plays an essential but differentiated role in the cycles of water, carbon, phosphorus and nitrogen, depending on its depth and its physicochemical nature. The use of soils to store more carbon, thanks to the organic matter they contain, makes it necessary to evaluate the maximum level of organic matter that soils can hold, knowing that this level depends on many factors: the humification to mineralization ratio, organic matter inputs and humus destruction as a result of its mineralization, but also soil depth (to which organic matter inputs are linked), soil mineralogy or the granulometry of soil particles (clay, silt, sand ...).

Artificialisation and waterproofing of soils

Artificial soils risk becoming irreversibly impermeable. Waterproofing induces a profound transformation of the soil, it damages biodiversity and considerably reduces carbon stocks in vegetation and soils. After a peak of 830 km^2 per year between 2006 and 2008 (+ 1.8% per year), artificial surfaces in France grew by 540 km2 per year between 2008 and 2014 (+ 1.1% per year). Depending on the calculation method used, the estimate of the total artificialized surface varies from 5.6% to 9.3% of the French national territory. The challenges are to limit the net artificialisation of soils, to limit the waterproofing of artificial spaces and to compensate as much as possible for artificialisation, while ensuring our ability to meet social needs, especially housing needs.

There are two types of soil carbon quantification methods: so-called "conventional" laboratory methods, which rely on dry combustion or chromic acid oxidation of soil samples, and spectroscopic measurements (ultraviolet -visible and infrared), of more recent use for the quantification of soil carbon. These measurements are based on the treatment of the soil reflectance spectrum that depends, among other parameters, on its organic matter content. The results vary according to the depth considered for the analysis: 30 or 40 first centimetres of the soil, one meter, two meters ... In France, agricultural and forest soils (about 80% of the territory) currently store 4 to 5 Gt of carbon (i.e. 15 to 18 Gt of CO_2 equivalent), of which nearly one third in biomass (mainly trees) and more than two thirds in soils, in the strict sense. Any positive or negative variation of this stock influences national GHG emissions. For the record, these emissions are estimated at 0.5 Gt CO_2eq/year (2011 value). The dynamics of carbon stock changes in our soils are, however, highly uncertain.

Scientific uncertainties

Storing more carbon in soils is of interest for offsetting anthropogenic CO_2 emissions to address global warming and for food security as the increased presence of organic matter improves the physicochemical structure of the soil, its resistance to erosion and its fertility, and hence crop yields. Improving scientific knowledge on soil carbon storage, particularly on the age of stored carbon and on biogeochemical cycles at different scales of time and space, remains necessary. In fact, depending on the context, the same practice favourable to carbon sequestration does not produce the same effect. For example, peatlands and some grasslands and forests are already approaching a maximum level of storage. Efforts can therefore affect only part of the soils. In addition, the saturation or maximum level of global carbon sequestration potential remains uncertain. Additional carbon storage in soils would therefore be a relevant solution only in the medium term, and would be limited in time, because the soils would reach a new equilibrium after a few decades which would correspond to the saturation of their storing capacity (the time needed for soils to reach their new equilibrium can go from 20 years to more than 100 years, depending on local conditions). In addition, storing more carbon requires an increased availability of nitrogen (N) and phosphorus (P) to allow plant growth and to stabilize organic matter, which - to avoid synthetic fertilizers - advocates for effluents' recycling (livestock manure) and legumes cultivation[(9)]. Emissions of other GHGs, such as methane (CH_4) and nitrogen oxides (NO_x), need to be monitored, to make sure that the effort to store carbon in soils does not lead to their increase[(10)].

Political and research perspectives

International discussions have continued since 1997 when the Kyoto Protocol, which aims to increase carbon sinks[(11)], completed the United Nations Framework Convention on Climate Change (UNFCCC), adopted at the Rio de Janeiro Earth Summit in 1992. The Intergovernmental Panel on Climate Change (IPCC) is increasingly including the role of soils in its analyses. This will be the case for three of its special reports planned for the end of 2018, on the topics of: 1.5 °C global warming[(12)]; the ocean and cryosphere in a changing climate[(13)]; and on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems[(14)]. The FAO has carried out specific work on the subject[(15)].The European Union, which has committed itself to reduce its GHG emissions by 2030 by at least 40% compared to 1990, gives increasing importance to the storage of carbon in soils: the **LULUCF regulation** (for land use, land use change and forestry), currently being adopted[(16)], makes soil carbon one of the Union's climate objectives; the **draft directive on soil protection**[(17)] identifies the reduction of soil organic matter as one of eight threats against which to fight; and since 2017, the agri-environment measures of the Common Agricultural Policy (CAP) have been enriched by a **"soil" agri-environment measure**, aiming at the reduction of tillage, the establishment of plant cover and the diversification of crop rotations with the goal of increasing soil OM, among other things[(18)].

The "4 per 1,000" initiative

Launched on December 1st, 2015 as part of COP21, this ambitious initiative aims to help offset global CO_2 emissions in the atmosphere worldwide (4.3 billion tonnes of carbon per year), by increasing soil carbon stocks by 0.4% or 4 per 1,000 every year. This target represents, depending on the calculation method, 3.4 billion tonnes of carbon out of a total of 860 billion in the first 40 cm of soil, or 6.3 billion out of a total of 1,580 billion in the first meter of soil. These two different results explain some of the controversies surrounding the initiative.

This initiative for climate and food security aims to unite voluntary public and private stakeholders (States, communities, companies, research organizations, NGOs ...). It brings together around 150 members in a Consortium, whose president is Ibrahim Mayaki and vice-president Stéphane Le Foll, and 281 partners in an advisory Forum. It also relies on a Scientific and Technical Committee (CST) of fourteen members whose French members are Claire Chenu, Professor at AgroParisTech, and Jean François Soussana, Vice President of INRA.

The implementation of the initiative, through projects and research, is underway and France is particularly committed, with a national agro-ecological project. INRA, ADEME and ARVALIS will publish a "4 per 1,000 France" report by the end of 2018, in order to identify suitable agricultural and forestry practices, to evaluate their cost, to quantify and map the storage potential, quantify the other induced effects (yield, other GHG emissions, nitrate leaching, water consumption, etc.), identify the obstacles to adoption and propose policy incentives.

The global sequestration target set by the initiative is high and will be difficult to monitor each year. It should therefore be seen as a horizon on which to set our sights, in addition to our efforts to reduce overall greenhouse gas emissions.

In France, the climate change mitigation policy is embodied in the **national low-carbon strategy** (*stratégie nationale bas carbone, SNBC*)[19], the **French bioeconomy strategy** and the **national strategy for mobilizing biomass** (*stratégie nationale de mobilisation de la biomasse, SNMB*)[20] provided by the Law of 17 August 2015 on energy transition for green growth (*loi relative à la transition énergétique pour la croissance verte, TECV*). The SNBC has created a "low-carbon" label and the SNMB includes a carbon sequestration component. This is particularly sensitive because the SNMB could have many negative impacts on the challenge of soil quality protection: the economic valuation of biomass is often greater than that of maintaining the soil as it is, because specific incentives are lacking (this valuation can however be beneficial, when harvesting more wood is accompanied by the promotion of agroforestry). The trend towards the artificialisation of agricultural land and the development of non-food uses of biomass from agriculture and forestry implies maintaining a special attention to the possible land-use conflicts which can be generated. The national implementation of the "4 per 1,000" initiative will therefore need to be carefully monitored and will require a research effort[21] at national, European and international levels.

■ Recommendations of the Office

- **Pursue and amplify, at the international level, the "4 per 1,000" initiative**, in its "research" component, as well as in its "projects" component: soil sciences, which are interdisciplinary by nature, should make it possible to shed light on which measures to implement and on which practices favour carbon sequestration in agricultural and forest soils (agroforestry, intercropping, cultivation of cover crops, conservation agriculture to reduce tillage ...).

- **Build an incentive for soil carbon storage in the CAP**: pay for the ecosystem services provided by farmers, disseminate good practices, avoid leaving the soil bare and thus extend the duration of soil cover, with the cultivation of legumes for instance, support grasslands and eliminate the rule which defines temporary pasture as grasslands with a duration of less than five years only, which has the perverse effect of encouraging grassland ploughing. The carbon storage potential in EU agricultural lands[22], of the order of 115 million tonnes of carbon per year, represents € 3.5 billion (6% of the € 56 billion CAP annual budget) at a price of 30 euros per tonne of carbon. Given the difficulties to rigorously monitor the annual variations in storage in each farm, this new CAP should be based less on a control system than on a contract agreement system specifying objectives and means, within for example "homogeneous zones" delimited by Member States in their territory.

- **Develop a national soil strategy** and implement the "4 per 1,000" initiative based on a territorial approach, ensuring that the actions carried out are coherent. Particularly those carried out by the Ministry for the Ecological and Inclusive Transition and by the Ministry of Agriculture and Food: the SNBC and the SNMB should in no way contradict each other. The steering of these policies should be based on the expertise of INRA and the French "*GESSOL*" program ("*GEStion du patrimoine SOL*") and on the inventories of the interprofessional technical centre for studies on air pollution (*centre interprofessionnel technique d'études de la pollution atmosphérique, CITEPA*), which accounts for GHG sources and sinks, as well as the Soil Information System and the Soil Quality Monitoring Network (*réseau de mesure de la qualité des sols, RMQS*) of the "*GisSol*" ("*groupement d'intérêt scientifique sur les sols*"). The measurement of carbon stocks at a given moment is satisfactory, but a detailed understanding of their evolution over time remains an issue for scientific research. More generally, soils are a compartment of the superficial zone of our planet, called the "critical zone" by geologists, whose overall functioning remains poorly understood but which regulates soil formation, atmosphere's composition, water quality and ecosystems' durability.

OPECST Office websites:

http://www.assemblee-nationale.fr/commissions/opecst-index.asp

http://www.senat.fr/opecst

Endnotes

(1) See https://www.senat.fr/notice-rapport/2015/r15-380-notice.html (in French).

(2) Reports which can be cited (in French): A.Bispo, C.Guellier, E.Martin, J.Sapijanskas, H.Soubelet et C.Chenu, "Les sols : Intégrer leur multifonctionnalité pour une gestion durable", éditions Quae, 2016, M.-C.Girard, C.Schvartz et B.Jabiol "Étude des sols. Description, cartographie, utilisation", éditions Dunod, 2017, Leaflet of ADEME "Carbone organique des sols", 2016, INRA-ADEME Report "Quelle contribution de l'agriculture française à la réduction des émissions de gaz à effet de serre ? ", 2013, Reports of the IPCC and of "GISSol" (See "Climate Change: The Physical Science Basis", 2013), R.Calvet, C. Chenu S.Houot "Les matières organiques des sols : rôles agronomiques et environnementaux", éditions France Agricole, 2011, M.-C.Girard, C.Walter, J.-C.Rémy, J.Berthelin et J.-L.Morel, "Sols et environnement", éditions Dunod, 2011, N.Thybaud "Capter et stocker le CO2 dans le sous-sol", 2007 éditions BRGM, R.Calvet, "Le sol, propriétés et fonctions", 2003, éditions France Agricole and the Expert Review by INRA "Stocker du carbone dans les sols ? ", 2002.
Scientific articles which can be cited (in English): B.Minasny et al. "Soil carbon 4 per mille" Geoderma, n° 292, 2017, J.W. van Groenigen et al. "Sequestering Soil Organic Carbon: A Nitrogen Dilemma", Environmental Science & Technology, n° 51 (9), 2017, M.-F.Dignac, D.Derrien, P.Barré, S.Barot, L.Cécillon, C.Chenu, T.Chevallier, G.T.Freschet, P.Garnier, B.Guenet, M.Hedde "Increasing soil carbon storage: mechanisms, effects of agricultural practices and proxies. A review", Agronomic Sustainable Development, n° 37-14, 2017, A.Chabbi et al. "Aligning agriculture and climate policy", Nature Climate Change, 2017, R.Lal, "Beyond COP 21: potential and challenges of the "4 per Thousand" initiative", Journal of Soil and Water Conservation, n° 71(1), 2016, D.Derrien, M.-F.Dignac, I.Basile-Doelsch, S.Barot, L.Cécillon, C.Chenu, M.Hedde "Stocker du C dans les sols. Quels mécanismes, quelles pratiques agricoles, quels indicateurs ? " Étude et Gestion des Sols, n° 23, 2016, U.Stockmann et al. "The knowns, known unknowns and unknowns of sequestration of soil organic carbon", Agriculture, Ecosystems & Environment, n° 164, 2013, D.S.Powlson, A.P.Whitmore, K.Goulding, "Soil carbon sequestration to mitigate climate change: a critical re-examination to identify the true and the false", European Journal of Soil Science, n° 62 (1), 2011, R.Lal "Soil carbon sequestration impacts on global climate change and food security", Science, n° 304 (5677), 2004, J.Six, R. T.Conant, E.A.Paul, K.Paustian "Stabilization mechanisms of soil organic matter: implications for C-saturation of soils", Plant and soil, n° 241(2), 2002, W.H.Schlesinger, "Carbon sequestration in soils: some cautions amidst optimism", Agriculture, Ecosystems & Environment, 82(1), 2000.

(3) Antoine-César Becquerel, « Des climats et de l'influence qu'exercent les sols boisés et non boisés », éditions Firmin Didot Frères, 1853 (in French).

(4) Peatlands cover only 3 to 5% of the land surface but would contain 30% of the total organic carbon of all soils. Their additional storage potential is very low. Conversely, the potential for carbon sequestration is estimated at 1.4 Gt C/year for agricultural soils and at more than 2 Gt C for other soils, including forest and agroforestry for which a third of the additional carbon would be stored in soils.

(5) Among these factors the composition of organic matter and various local conditions (temperature, humidity, aeration, erosion ...) can be mentioned.

(6) The ability of minerals to protect organic matter from mineralization, through organomineral interactions, is a critical variable which strongly affects mineralization rates (some of the organic matter is not biodegraded as fast as its chemical nature would allow).

(7) These assessments are demonstrated by paleoclimatic reconstructions and the study of lake sediments.

(8) INRA and Ifsttar have published a scientific expert report on the artificialisation of soils, in December 2017: https://inra-dam-front-resources-cdn.brainsonic.com/ressources/afile/420284-12ef6-resource-artificialisation-des-sols-rapport-en-francais.pdf (in French).

(9) Like trees, legumes have a higher potential to fix atmospheric nitrogen in soils.

(10) Agriculture will have to focus on controlling its emissions of other GHGs especially since practices that tend to increase carbon storage in soils could have undesirable effects at the farm level, such as methane or nitrogen oxide emissions or, still, the diffusion of nitrates. For the record, agriculture and forestry already account for 20% of national GHG emissions: 10% for nitrous oxide (N_2O), as a result of nitrogen fertilizers; 8% for methane (CH_4), linked to livestock, and 2% for carbon dioxide (CO_2), due to the use of fossil energy.

(11) The Kyoto Protocol plans to limit GHG emissions and, in particular, to increase carbon sinks. The Bonn, Marrakesh and Durban Conferences of Parties included the possibility of accounting for soil carbon stocks. See http://unfccc.int/kyoto_protocol/items/2830.php

(12) IPCC Special Report: "Special Report on impacts of global warming of 1.5°C" or "SR 1.5".

(13) IPCC Special Report: "Special Report on oceans and the cryosphere in a changing climate" or "SROCC".

(14)) IPCC Special Report: "Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems » or "SR Land".

(15) See Report by FAO "Unlocking the Potential of Soil Organic Carbon" following the Global Symposium on Soil Organic Carbon (21 to 23 March 2017): http://www.fao.org/documents/card/en/c/25eaf720-94e4-4f53-8f50-cdfc2487e1f8/

(16) See the "LULUCF" legislative proposal: https://ec.europa.eu/clima/lulucf_en

(17) See the proposal for a Directive on soil protection: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=LEGISSUM:l28181

(18) The "soil" agri-environment measure is optional: regions are free to implement it or not.

(19) National low-carbon strategy (Stratégie nationale bas carbone) 2015. For the record, the objective of the law on energy transition for green growth (loi relative à la transition énergétique pour la croissance verte, TECV) is the reduction of greenhouse gas emissions by 40% in 2030 and by 75% in 2050, compared to 1990.

(20) See the Decree of 26 February 2018 corresponding to the publication of the national strategy for the mobilization of biomass: https://www.ecologique-solidaire.gouv.fr/biomasse-energie (in French).

(21) An effort to coordinate international and European research on soil carbon sequestration is under way around the CIRCASA initiative ("Coordination of International Research Cooperation on soil carbon sequestration in agriculture"). This project is funded in particular by the EU's Horizon 2020 program with the Consultative Group on International Agricultural Research (CGIAR). In addition, France and Europe have invested in major research infrastructures to study and monitor soils and gas and energy exchanges between the soil, the atmosphere and water in the context of global environmental changes: ICOS (Integrated Carbon Observation System https://icos-france.fr/), AnaEE (Analysis And Experimentation On Ecosystems https://www.anaee-france.fr/) and OZCAR (Observatoires de la Zone Critique, application et recherche http://www.insu.cnrs.fr/node/5680) coordinated by the French Alliance for Environmental Research (AllEnvi). The "4 per 1,000" initiative should also contribute to this research (see https://www.4p1000.org/).

(22) See the CAPRESE-SOIL Report (CArbon PREservation and SEquestration in agricultural soils) of the JRC (Joint Research Centre) of the European Commission, 2013; see http://publications.jrc.ec.europa.eu/repository/bitstream/JRC88295/caprese_final%20report-v2.pdf

List of scientific experts consulted

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Ms Claire CHENU, Professor at AgroParisTech, member of the scientific and technical committee of the "4 for 1000" initiative, Chair of the “Gessol” Scientific Council and Ambassador of the International Year of Soils (2015)
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Mr François LAURENT, Head of the agronomy-economy-environment department at ARVALIS - Institut du végétal
Mr Philippe CIAIS, Research Director at the laboratory of climate sciences and the environment (LSCE), CNRS silver medal in 2017
Mr Jérôme GAILLARDET, Professor at the Institut de physique du globe de Paris
Ms Delphine DERRIEN, Research Director at INRA (Nancy)
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List of persons interviewed

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