Food and Agriculture Organization of the United Nations

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INTERGOVERNMENTAL TECHNICAL PANEL ON SOILS

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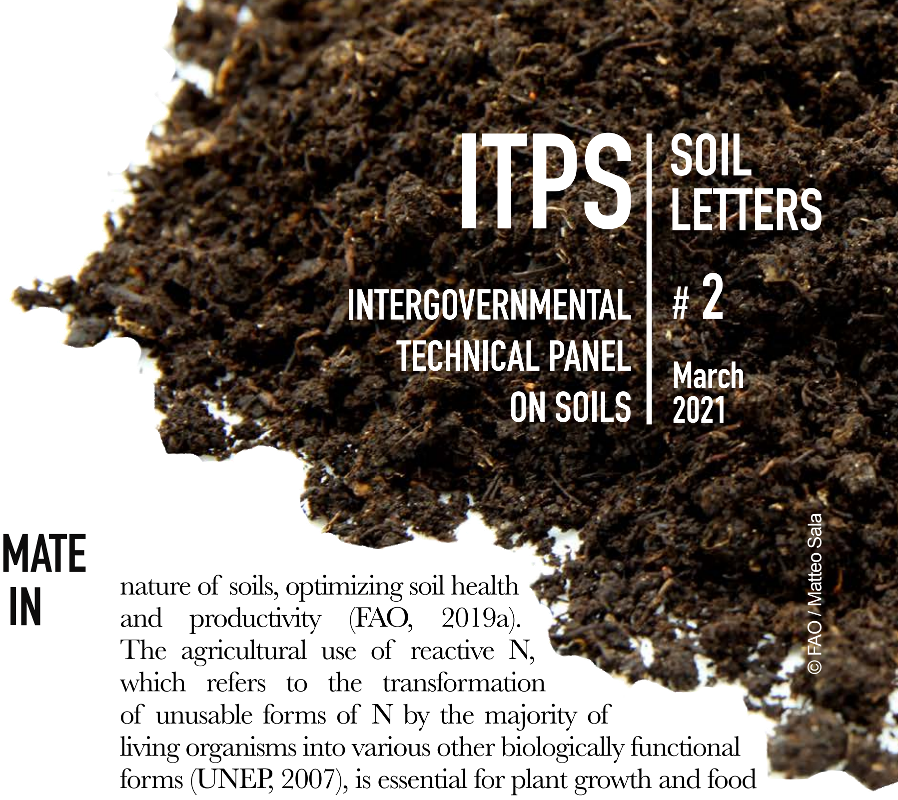
March 2021



SOIL ORGANIC CARBON AND NITROGEN

REVIEWING THE CHALLENGES FOR CLIMATE CHANGE MITIGATION AND ADAPTATION IN AGRI-FOOD SYSTEMS

The global nitrogen cycle has been severely modified transgressing boundaries that can erode the planetary resilience to a point we do not completely understand.
Steffen (2015).

An adequate supply of soil organic carbon and nutrients is essential to maintain crop yields and the nutritional values of the agri-food system. However, the global agri-food system needs to be reshaped to meet population needs, and become more productive, more inclusive of poor and marginalized populations while remaining environmentally sustainable and resilient (FAO, 2018). Healthy, productive soils are key to presently delivering wholesome and nutritious diets to all humans, and to avoid compromising food security and nutrition for future generations. An integrated understanding of carbon and nutrient cycling in the soil-plant-atmosphere continuum is crucial to adapt to current and future planetary changes and challenges, including sustainable production of food, feed, fuel, and fiber in a climate change scenario.

THE ROLE OF CARBON AND NITROGEN IN THE AGRI-FOOD SYSTEM

Carbon (C) and nitrogen (N) participate directly in a wide variety of soil processes that are key to the food system (e.g., soil organic matter formation and decomposition, N fixing, maintenance of food webs, etc.) and for the provision of ecosystem services. Soil organic carbon (SOC) is the main indicator of soil health and constitutes the backbone of the molecules that build soil organic matter (SOM), which is responsible for much of the multi-functional nature of soils, optimizing soil health and productivity (FAO, 2019a). The agricultural use of reactive N, which refers to the transformation of unusable forms of N by the majority of living organisms into various other biologically functional forms (UNEP, 2007), is essential for plant growth and food security. In soils, N is the most important element for ensuring crop production, as it is the limiting nutrient for plant growth in many agricultural settings. Given the importance of this element for plant growth, it is not surprising that more resources and effort are devoted to N management than to any other nutrient (Weil and Brady, 2017).

The synthesis of N was a major discovery, worthy of a Nobel Prize in 1918, which transformed agriculture and enabled large-scale food production. Since then, some estimates indicate that N fertilizers are responsible for feeding 48 percent of the world's population (data from 2008), and the trend is increasing; this means that inorganic N fertilization supports half of humanity (Erisman *et al.*, 2008). Now, one hundred years after this discovery, we are faced with a contrasting scenario in which some soils are N-deficient while others are over-fertilized, resulting in serious adverse environmental effects.

Oat and vetch mixed cropping favours the use of leguminous-fixed N by the cereal

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GLOBAL SOIL PARTNERSHIP

C AND N SYNERGIES AND THEIR ROLE ON CLIMATE CHANGE

The recent growth in N_2O emissions exceeds some of the highest projected emission scenarios underscoring the urgency to mitigate the emissions of this gas.
Tian (2020).

The agricultural sector is an important contributor to climate change, accounting directly for 10 to 12 percent of annual anthropogenic greenhouse gas (GHG) emissions worldwide (Tubiello *et al.*, 2015). Approximately 38 percent of agricultural emissions derive from the release of soil nitrous oxide (N_2O) (from synthetic fertilizers, manure and crop residues) and 11 percent from methane (CH_4) in rice cultivation (Tubiello *et al.*, 2015). Recent estimates indicate that global human-induced emissions of N_2O amount to 7.3 Tg yr^{-1} (1 Tg= 10^{12}g), with agriculture being the largest source, accounting for 52 percent of anthropogenic emissions, which are dominated by N additions to croplands (Tian *et al.*, 2020). Fluxes of non-CO_2 GHGs, such as N_2O and CH_4, can have a decisive impact on climate change mitigation (Gelfan and Robertson, 2015). A cropping system under conservation agriculture practices could store SOC and simultaneously (in case of unsustainable management of pesticides and fertilizers) release N_2O and CH_4, thus affecting the total GHG mitigation balance. Another example is the ‘earthworm-dilemma’, i.e., earthworms may enhance C sequestration by protecting it within soil aggregates, but at the same time may enhance the emission of GHG, in particular that of N_2O (Lubbers *et al.*, 2013). Due to the high global warming potential of CH_4 and N_2O (23 and 298, respectively) compared to CO_2, even small changes in non-CO_2 GHGs emissions could offset SOC increments and atmospheric CO_2 mitigation (Grandy *et al.*, 2006). An integrated approach to monitoring SOC accumulation, GHG emissions and effective N management in agricultural systems would be a step towards achieving sustainable agri-food systems.

THE DANGER OF POOR N MANAGEMENT IN FARMING SYSTEMS

A single reactive N molecule can cascade through a wide variety of environmental systems and contribute to multiple sequential effects. Furthermore, long-distance transport of reactive N causes harmful effects in countries distant from emission sources.
Galloway (2002).

As experts in N cycling have stated (Galloway *et al.*, 2002; Erisman *et al.*, 2002; Sutton *et al.*, 2011) we have had “too much of a good thing”. This phrase expresses how N fertilizers, although essential for human societies to develop and thrive, could also threaten the resilience of the Earth system functioning (Steffen *et al.*, 2015). Global N inputs from biological fixation amount to 21 Tg N yr^{-1}, while N inputs from synthetic fertilizers have reached 51 Tg N yr^{-1} (Uwiseye *et al.*, 2020). N inputs to soils are directly associated with N_2O and other NO_x gases emissions that contribute to climate change (Tian *et al.*, 2020) and cause other atmospheric modifications, including pollutant formation and ozone depletion in the stratosphere (Galloway *et al.*, 2003). Excessive N inputs to soils through fertilizers increase losses of reactive N to surrounding ecosystems (Delgado and Follet, 2010). Reactive N is highly mobile and is easily and widely dispersed by hydrologic transport processes, mainly in the form of nitrates (NO_3^-) (Galloway *et al.*, 2003), which is the most commonly detected drinking water pollutant in groundwater (Weil and Brady, 2017). Excess NO_3^- in farmland soils can also cause serious downstream water-quality problems, including eutrophication, hypoxia and biodiversity loss in lakes, streams and coastal ecosystems (Schlesinger, 2009), as well as biodiversity imbalances and species invasion such as *Sargassum* blooms in the Atlantic Ocean (Wang *et al.*, 2019).

Roots with rhyzobia nodules (N-fixing)

SUSTAINABLE SOIL MANAGEMENT FOR CLIMATE CHANGE MITIGATION AND ADAPTATION

The adverse effects of N use in agriculture impose global challenges that add to other major challenges such as global population growth, urban expansion, dietary shifts (with high protein consumption), climate change and soil degradation (FAO, 2017). In this scenario, achieving sustainable soil management (SSM) has never been more important as it relies on the establishment of practices that foster improved soil functions that enable ecosystem services and biodiversity (FAO, 2017). SOC-centred SSM practices are a promising approach not only to improve soil health, enhance food security and farm incomes, but also to mitigate climate change (FAO, 2019a). Considering the cascade of N effects originating from farming systems, a broader view of recarbonization programmes would be recommended to avoid mismanagement of N fertilization that could minimize the benefits of SOC sequestration. Efforts to increase SOC content through SSM practices may be subject to the antagonistic effects of N_2O emissions from unsustainable N fertilizer management. Rather than a source, croplands can be a sink of atmospheric CO_2 with the implementation of recarbonization programmes. Additionally, SSM can be an important part of the solution to N_2O emissions, soils degradation, and water contamination, through practices and tools to improve N use efficiency (FAO, 2019b). To this end, an integrated and joint N management framework, in conjunction with recarbonization programmes, would contribute to unlocking the potential of cropped soils to mitigate and adapt to climate change.

The northern part of the Caspian Sea is plagued by eutrophication process

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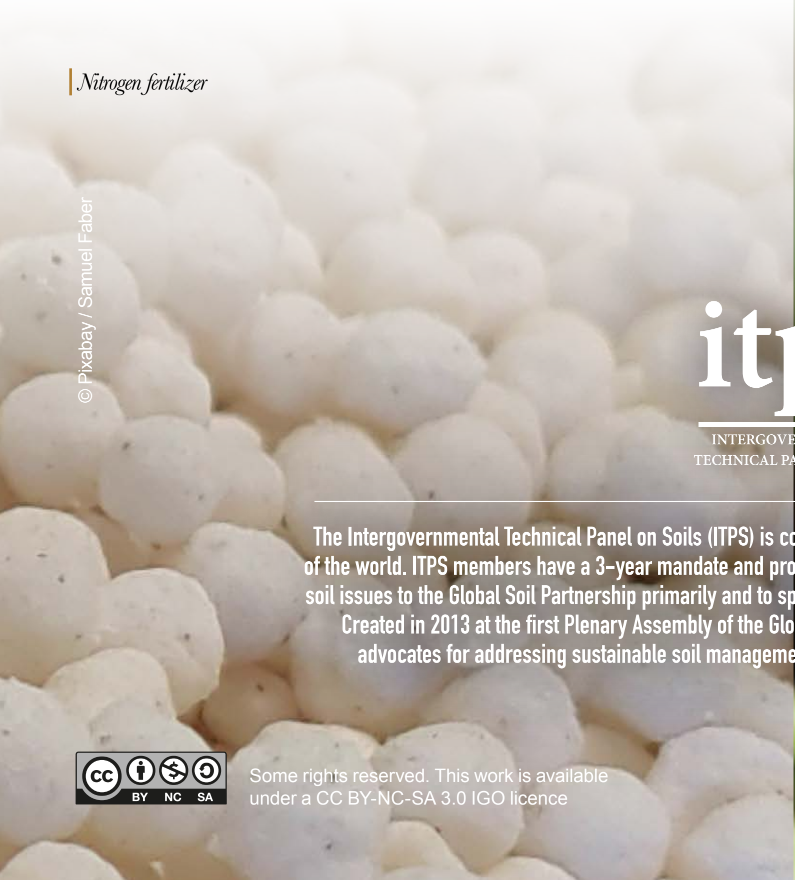

Nitrogen fertilizer

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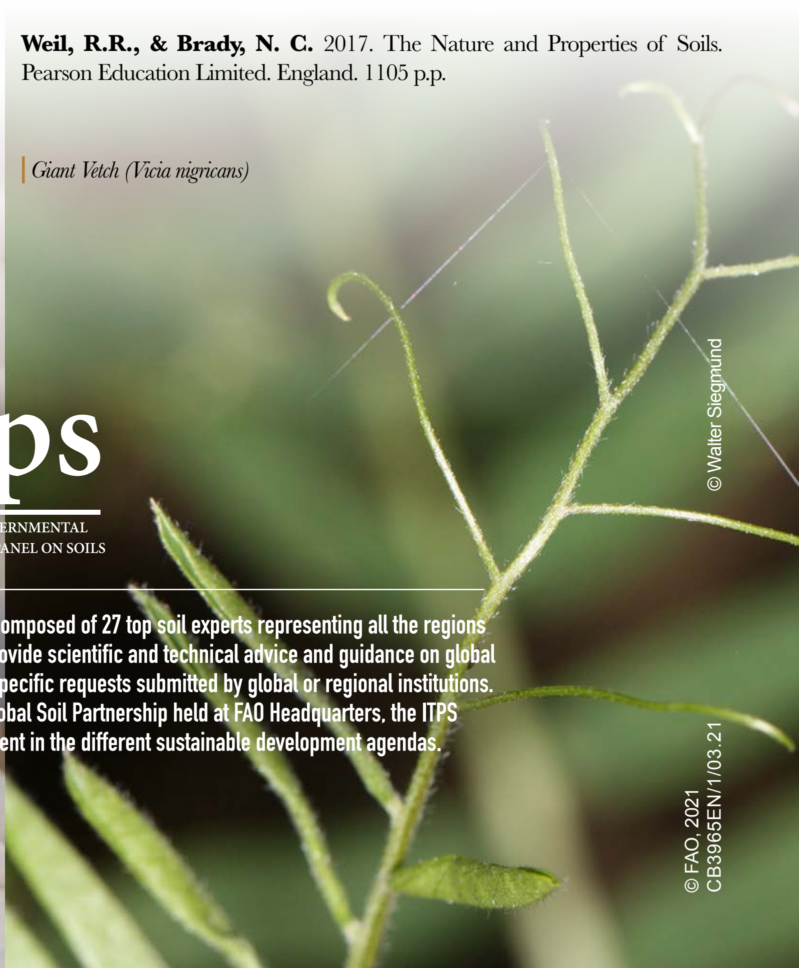

Giant Vetch (Vicia nigricans)

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INTERGOVERNMENTAL TECHNICAL PANEL ON SOILS

The Intergovernmental Technical Panel on Soils (ITPS) is composed of 27 top soil experts representing all the regions of the world. ITPS members have a 3-year mandate and provide scientific and technical advice and guidance on global soil issues to the Global Soil Partnership primarily and to specific requests submitted by global or regional institutions. Created in 2013 at the first Plenary Assembly of the Global Soil Partnership held at FAO Headquarters, the ITPS advocates for addressing sustainable soil management in the different sustainable development agendas.