Protecting the Soil is Protecting the Climate

WASWAC and IUSS Position Paper on the Inter Linkages of Soil and Climate Change

The World Association of Soil and Water Conservation (WASWAC) as a worldwide academic society, was established in the USA in August 1983. The WASWAC secretariat, initially located at the Soil and Water Conservation Society (SWCS), Iowa, USA, was moved on 1 April 2003 to the International Center for Research and Training on Seabuckthorn (ICRTS), Beijing, China, and from October 2010 to the International Research and Training Center on Erosion and Sedimentation (IRTCES), also in Beijing. Since its founding, the WASWAC has devoted itself to research and communication to solve scientific and technical problems related to soil and water conservation. Many cooperative research projects have been conducted, a series of international training courses, symposia and workshops have been organized, and several awards in the field of soil and conservation have been set up and sponsored by WASWAC. The aim of WASWAC is to promote the wise use of management practices that will improve and safeguard the quality of land and water resources so that they continue to meet the needs of agriculture, society and nature. The vision of WASWAC is a world in which all soil and water resources are used in a productive, sustainable and ecologically sound manner.

The International Union of Soil Sciences (IUSS) was founded as the International Society of Soil Science (ISSS) on 19th May 1924. The IUSS has been a scientific union member of ICSU (International Council for Science) since 1993. Since the merger of ICSU with the International Social Science Council to form the International Science Council (ISC) in 2018 the IUSS is a member of ISC (https://council.science/). The objectives of the IUSS are to foster all branches of the soil sciences and their applications, and to give support to soil scientists in the pursuit of their activities. In addition, the IUSS aims to put soils and soil science on the global agenda. Activities IUSS takes action to advance soil science, including arranging of meetings, conferences and the World Congress of Soil Science; It provides a structure for managing the science of soil science and arranges for the publication and distribution of material relevant to the interests of the Union, and its members as well as arranging for studies in particular fields, such as specific definitions, classifications and databases; It establishes cooperation with other related organizations and represents Soil Science to a wide external audience. The scientific activities of IUSS are undertaken through 4 Divisions and each Division has 4 to 6 Commissions. Meetings within the commissions as well as interdivisionally occur regularly on specific topics and enable the scientific exchange both regionally or as worldwide events.

Introduction

This position paper elaborates the significance and implications of the world's soil systems as climate regulators in their still unexploited potential to fight climate change and in the aspiration of modern society aiming at sustainable use of resources and safeguarding of life on the planet.

About twelve thousand years ago, in the Holocene, the stabilization and improvement of the climate made possible the start of agriculture, and as a consequence, the construction of the first cities, civilizations, science, technology and progress that we now enjoy.

Nowadays all this human development and progress is in danger from another climate change. But this time not naturally but triggered by man. The current anthropic climate change threatens the destabilization and collapse of basic productive systems and crucial socio-economic structures.

The main consequence is the chemical alteration of the atmosphere that implies the modification of climatic parameters and their feedback with terrestrial ecosystems. The current level of well-being and progress, at least in some parts of the planet, has its Achilles tendon in the consequences of the vast tonnage of greenhouse gases that we have continuously emitted into the atmosphere for more than two centuries.

It is a global threat unprecedented in human history. Most probably climate change is the greatest social, economic and environmental challenge of the 21st century. In many aspects, we are faced with problems of still unknown and unpredictable consequences, the control of which will require scientific knowledge and new responses and more intelligent ways of relating to the natural environment.

The current trend of global warming has a special impact on soil functionality. Climate change alters the drivers of natural climate variability and climate extremes, with subsequent impacts on terrestrial ecosystems and land processes. In turn, physical, physicochemical, and biogeochemical land forcing and feedbacks mechanisms affect the climate system.

According to the IPCC AR 6th Climate Change 2021, “Land surface air temperatures have risen faster than the global surface temperature since the 1850s, and it is virtually certain that this differential warming will persist into the future. It is virtually certain that the frequency and intensity of hot extremes and the intensity and duration of heatwaves have increased since 1950 and will further increase in the future even if global warming is stabilized at 1.5°C. The frequency and intensity of heavy precipitation events have increased over a majority of those land regions with good observational coverage and will extremely likely increase over most continents with additional global warming. Over the past half-century, key aspects of the biosphere have changed in ways that are consistent with large-scale warming: climate zones have shifted poleward, and the growing season length in the Northern Hemisphere has increased” Also, “The majority of the land area has experienced decreases in available water during dry seasons due to the overall increase in evapotranspiration. The land area affected by increasing drought frequency and severity will expand with increasing global warming".

As a significant consequence, the increase in climate variability, extreme climatic phenomena, torrential rains and floods are affecting the stability of soils and their ability to buffer extreme climatic phenomena and maintain productivity and biological diversity over the land. Conversely, soil degradation especially due to non-adjusted land management affects important parameters of climate regulation and the atmospheric chemical composition. Among others: changes in albedo, radiative forcing, soil moisture, surface roughness, evapotranspiration, emission and retention of greenhouse gases (carbon dioxide, methane, nitrous oxide), changes in the condensation surfaces and the emission of aerosols and dust particles.

Probably one of the most serious consequences of the global warming trend is the impact on the processes of soil degradation-desertification of dry areas of the planet through a perverse spiral that can not only affect the stability and functionalism of the natural environment but can also involve environmental security problems (Rubio and Recatalá, 2006) as forced migrations, water scarcity, food security, forest fires and important socioeconomic consequences after the disruption of the buffering role of the soil facing extreme climatic events (droughts, heatwaves, desiccant winds, torrential rains, floods, landslides and collapse of hillsides). The importance and implications of these interactions demand a world coordinated effort to increase scientific knowledge about the impact of different climatic factors on different processes of soil degradation, on the regulatory capacity of soil facing the global warming trend, and on the design of efficient measures to urgently be applied worldwide.

Nowadays there is an improvement in the perception of climate change and its consequences by society, scientific associations (like WASWAC or IUSS), administrations and international organizations in the sphere of the UN. Under this trend, numerous governments, super governments (e. g. the EU), and the international environmental conventions of the UN (UNFCCC, UNCBD, UNCCD) have announced important decisions and measures to act on the threat of climate change for example within the UNFCCC Paris Agreements, UN Sustainable

Development Goals and numerous New Green Deals and Green Agendas. Reducing greenhouse gas emissions to mitigate global climate change, ensuring food security by maintaining a sustainable and resilient land use (UN, 2013, 2014), having clean drinking water essential for human life and the maintenance of terrestrial and aquatic ecosystems (Laudato Sí, 2015), in order to finally meet the Development Goals (UN, 2015) are all objectives directly involving the natural resource soil. Therefore, achieving those goals will only be possible if we preserve Soil as a common good of humankind (FAO, 2012; UN 2013; SLCS: Declaration of Mar del Plata, 2012). Speaking, writing and making statements about the achievement of the Sustainable Development Goals is useless if you do not work to achieve them, and trying to achieve one to the detriment of the other is to move towards unsustainability, since the real achievement of one of those goals depends on everyone and each.

As a basic constituent of the terrestrial ecosystem, soil assets, soil science and the science of soil protection should certainly contribute to these elaborations and launching of ambitious approaches to combat climate change. Scientifically and logically, it cannot be understood to ignore any of the components of the terrestrial ecosystem, much less the soil as a cornerstone of the entire system. The scant consideration of soil received to date must change. It is now the time to do so without letting these circumstances go by. It should be noted that soil carbon was only considered for the first time in the negotiations on climate change at the Paris Conference (COP 21, UNFCCC 2015).

The inadequate consideration of the soil and its role as a climate regulator is hardly understandable or justifiable, it can prevent efficiency in the overall fight again climate change and can also avoid the success of costly measures applied in others sectors (energy, transport, urban).

The context

For the first time in history, humanity faces a planetary crisis with unforeseeable consequences. The chemical alteration of the atmosphere due to the emission of greenhouse gases, and the consequent climate change, has placed an environmental problem with local origins in the global dimension. With no doubt, climate change is the main social and environmental challenge of the XXI century.

Besides, there are other significant crises directly or indirectly related to climate change. These concern demographic explosion, food insecurity; water scarcity and water quality, arable-land scarcity, land degradation and desertification, soil erosion and salinization, environmental security and related forced migrations and conflicts, land-use changes (urban expansion, soil sealing, soil consumption), land contamination, residues and waste, loss of biodiversity and landscape quality, alternative sources of energy: biofuels, natural disasters (forest fires, flooding, landslides) and others.

An increasingly psyched and committed society wants to contribute and change the course of events, but it needs information, guidelines and strategies that support and ensure expectations of progress, well-being and truly sustainable use of natural resources. A concerned society demands the mobilization of all available resources and the enhancement of the natural mechanisms of climate regulation and buffering to unrest the climate emergency. Surprisingly, there is a strategic and overspread natural media, which is soil, that remains almost forgotten. Unexpectedly in the actions taken so far, no significant attention has been paid to the potential role of soil in combating climate change. This is an omission that simply neither humanity nor the planet can afford. The core of this position paper is to call attention to the most cost-effective ways to fight climate change, which are literally under our feet.

Planet Earth has a very peculiar design. Of all its enormous volume, terrestrial life is concentrated in a thin, fragile, exposed surface layer. This living organism that embraces, interconnects and gives life to the planet is called the soil. The rest of the entire mass of the planet is inert and lifeless mineral material. Owing to its biological component soil is very sensitive to temperature and water fluctuations. Terrestrial biodiversity, the production of almost all food, the landscape, the regulation of water resources, the buffering of climate processes, the stability and resilience of the territory and the psychological influence of human belonging and enrichment … depend on that fragile living membrane attached to the Earth. However, and perhaps due to its everyday life, society is not aware of the implications and significance of the living skin of our planet, nor of the crucial functions that it develops nor of its vulnerability. For the public, and in general, it is something dark and unknown that is taken for granted.

Informing and raising social awareness is the first action required to redirect and improve a much-needed better perception. The public needs to discover and enjoy the role of soil as a life support system and their interrelationships, not only with climate but with flora, fauna, food production, landscape, and biodiversity, among others.

Historically, the relationship between man and the soil has been an intimate and a long one, and there is an extended record of successes but also difficulties. History reveals soil and water conservation as crucial to the permanence of any civilization. The management and conservation of the land have shaped human history. It is very illustrative and clarifying to analyze world history from the point of view of man´s relation to productive soil.

A common pattern in the initial development of cultures was a tight dependence on rich land to rise. Historical records reveal that after a flourishing period, and unfortunately in many cases, the unwise management of soil resources by disregarding the limited soil resilience or climatic alterations drove to the depletion of the land capital. This led to a progressive decline in agricultural productivity (yields). When, in the course of this negative trend, the available knowledge or improvised solutions were not enough to find solutions, the scarcity of vital resources easily led to social instability, social disruption, forced migrations, conflict, violent confrontations and wars.

Although there is no general agreement among experts on the reasons for the decline, collapse and disappearance of numerous civilizations over time, there is a consensus in pointing out that the mismanagement or abandonment of soil and water conservation systems is a crucial factor triggering soil security consequences including the collapse of civilizations. Some of them were Indus Valley Harappa, Mesopotamia and the Fertile Crescent, Mesoamerica (Olmec, Maya, Chacooans, Huori) and some others in North Africa and the Mediterranean. Numerous authors have documented the decline of civilizations throughout history in parallel with the destruction of their soil (Hyams, 1952, ed.1976; Carter and Dale, 1955, ed 1974; Lowdermilk, 1999; Lindert, 2000; Montgomery, 2007).

All of them contributed with significant thoughts, reflections, and conceptual developments to the historical role of soil conservation in human history and its influence on the rise and fall of civilizations. Climatic alteration has been in some cases, identified as a triggering factor. As indicated, the flourishing of civilization from about 10,000-7 000 years ago was critically dependent on the stabilization of climate conditions. But some of them like Egyptian, Mycenaean, Hittites, Mesopotamian, and Indus Valley civilizations declined about 4,200 years ago (early bronze age) supposedly due to severe drought period (A. Glikson, 2015). In many cases, more than “climate change” which basically has remained the same in the last 10,000 years, the misuse of the land by wrong or inadequate management is identified as a significant factor.

This seems to be the fate of many ancient civilizations that mined soil and accelerated soil erosion well beyond the pace of soil formation and soil capacity to sustain life. In some climatic or social changing circumstances, the incapability to adapt land management to a changing condition or the lack of reaction under a too little, too late perspective was the cause of the decline. The technological revolution to obtain better access e. g. to metals caused a widespread cutting of forests, with the increase of soil water and wind erosion, accelerated during dry spells. The phenomenon was so widespread that aeolian sediments can still be found all around the Mediterranean basin (Yaalon and Ganor, 1973; Costantini et al., 2009; Costantini et al., 2018).

History tells us that management and conservation of the land have determined the life expectancy of civilizations. Such problems are not just ancient history. Some recent great catastrophes like the Dust Bowl, in the 1930s and the Droughts of Sahel, in the 1970s demonstrate the persistence of errors and their consequences in the management of land resources. Also more recently, there has been a substantial increase in different climatic catastrophes due to extreme climatic phenomena of local or regional scope that are taking place all over the planet.

Today we confronted with climate change, increase land degradation, and shrinking land available for food production. Considering the dimension and perspectives of present world problems, history tells us that we cannot repeat mistakes of the past, including errors on soil and water conservation issues. It seems advisable to ask what can we learn from the past and find clues that may apply to our present situation. An embarrassing development for the future could be that now we know all the facts, but is the future world going to suffer the same fate of the past?

Soil and climate change

There is clear but, in some cases, difficultly measurable interactions between soil functionality and climate, as one requires and affects the other and vice-versa, which call for new research efforts and integrated policies and management.

The soil as a limiting layer of the terrestrial ecosystem interacts permanently with the atmosphere from which it receives moisture and maintains a continuous exchange of gases, and energy flows. The soil as a complex living system is in a continuous dynamic co-evolution which tends to adjust to the prevailing climatic conditions into a dynamic equilibrium in which it evolves adapting and oscillating under the influence and impacts of climate factors and human uses (Horn 2021). The ability to recover from these impacts constitutes the so-called resilience of the soil. Conversely, climate receives the influence of soil processes and characteristics.

The soil system constitutes a living environment with enormous biological activity and precisely because of these intrinsic biological implications, it is a very sensitive medium to the availability of water, gases and heat as well as to the variation of climatic parameters.

The organic carbon deposits in the soil constitute a gigantic reservoir with a global content that is estimated at 1,550 Pg, which is just behind the oceans, with 38,000 Pg, and far ahead of the 750 Pg stored by the atmosphere and the 500 Pg of plants. The loss of this natural resource, non-renewable in terms of the period of human life, means the loss of clean and fresh water to drink; at the same time without fertile soil and water, there would be a reduction in the vegetation that captures carbon dioxide and releases oxygen needed for life. The soil organisms that capture carbon dioxide would be reduced, as well as the soil biodiversity. By losing the soil we also lose water, and we would be losing two of the major compartments with real capacity to capture CO_2 to mitigate climate change (Reyes-Sánchez, 2018). Soil degradation and erosion can easily release large amounts of carbon dioxide fixed in humus into the atmosphere, further affecting the storage of available water and oxygen essential for plant. The growing and living conditions of microbes, the limited nutrient storage and availability for plant uptake all further influence the functionality of soils as essential component of life.

Therefore, the soil can act significantly as a sink or as a source of atmospheric carbon but it depends on the site-specific soil management strategies. A worrying issue is that the release of soil carbon is threatening to undermine the costly efforts in reducing emissions from industry, cities and transport (http://ec.europa.eu/environment/soil/review_en.htm).

Predictions of current climate change trends point to soil, land, terrestrial biodiversity, and productive resources as one of the most susceptible elements. The climatic forecast indicates an appreciable decrease in precipitation, an increase in the frequency of extreme events, an increase in evapotranspiration, a decrease of soil moisture reserve, and greater impact of drought periods. These climate patterns imply a general trend of aridification. In the land, this trend leads to an increase in mineralization and a loss of organic components of the soil. It is estimated (Lal et al, 2003) that the loss of soil humus has been increasing since the Industrial Revolution, and is currently about 760 million tons per year. The tendency is to increase due to soil degradation and the effects of global warming. In the vast range of soils present on Earth, and especially among the eroded ones, there are great opportunities not only to capture and sequester carbon to reduce CO_2 emissions and greenhouse gas but also to increase the organic material in the soil, with the consequent increase of moisture available for crop systems. At the same time, it contributes to the lag of the impacts of extreme hydro-meteorological events, and it helps to decrease the actual consequences of hunger and poverty, displacement, inequality, and injustice (Reyes-Sánchez, 2012, 2015 and 2018).

Each of the aforementioned issues, though complex correspond to partial perspectives on the same problem to solve: the preservation of life on Earth; therefore, addressing each one separately when in reality they are interrelated and affect each other because they are part of the same system, does not advance as much as it could to achieve this fundamental objective (UN, 2015).

The arid zones of the planet (including hyper-arid, arid, semi-arid, and dry sub-humid zones) are characterized by a chronic deficit in the availability of environmental humidity, because of having potential evapotranspiration (EPo) higher than precipitation (P). This situation of structural shortage of water affects the functioning, characteristics, and potential use of the soils of these zones and establishes a situation of vulnerability to impacts as desertification processes. In their initial phases, these processes occur in an insidious and not perceived manner, with no apparent consequences in the function or stability of the soil. However, after continued impacts such as unfavorable climatic events, inadequate land management that persist for years, forest fires, and subsequent erosion processes or lack of restitution of organic components, the soil begins a progressive loss of biological quality and productive capacity. If the misuse of land, or climate aridity conditions, are maintained, the soil progressively loses its capacity to recover and to return to the situation of fertility and initial equilibrium. In this impoverishment of the soil, the decreasing levels of organic matter play a significant role, due to their influence in maintaining an adequate edaphic structure, which is one of the crucial properties of the soil. The decrease in the proportion of humus in the soil and its consequences in the degradation of the soil structure both alter the capacity of the soil to manage and maintain moisture reserves. It also affects aeration, the dynamics of nutrients, and therefore the chemical fertility and biological life of the soil. The degradation of the structure also impacts the physical properties of the soil, decreasing the intrinsic capacity of the soil to withstand erosive processes and misuse.

If the trend of progressive degradation continues, at a certain threshold or tipping point, the system passes at a low level of biological quality, in which the possibilities of recovery become very difficult or irreversible. Soils have generally under all climatic conditions a defined and limited soil strength which quantifies the resilient processes while exceeding them results in irreversible changes. These are the circumstances of non-linear response that could include irreversible damage or extreme conditions of desertification in which all the biospheric potential of the area can catastrophically lose both biological and economic productivity. Some regional abrupt changes and tipping points could have severe local impacts, such as unprecedented weather, extreme temperatures, and an increased frequency of droughts and forest fires (IPCC,2021).

The United Nations Convention to Combat Desertification (UNCCD), defines the process of desertification as the degradation of the lands in arid, semi-arid, and dry sub-humid zones resulting from various factors, such as climatic variations and inadequate human activities. The processes of degradation include, among others: water and wind erosion, salinization and sodification, sealing and compaction, loss of organic matter, and permanent loss of vegetation cover. In its latest consequences, desertification represents the conversion of the affected land to waste and unproductive territory.

Some existing predictions for the drylands of the planet indicate temperature increases between 2 and 6.3 ºC, appreciable decrease in precipitation, increase in the frequency of extreme events, increase in evapotranspiration, decrease of soil moisture reserve, and greater impact of drought periods. These climate patterns imply a general trend of aridification with a concomitant loss of organic components of the soil. This degradation can release huge quantities of CO_2 into the atmosphere. Soils also regulate other greenhouse gases such as the fearsome methane or nitrogen oxide. It is estimated that one-third of atmospheric carbon dioxide of anthropic origin, comes from soil degradation.

The warming trend will also affect the maintenance of the salts in the profile of the soil and its eventual rise to the surface by reducing rainfall and increasing evapotranspiration processes. This trend can significantly aggravate existing salinization and sodification problems and, in general, water quality for agricultural, urban and industrial uses.

As already mentioned, another important aspect related to soil functions is its capacity as a buffer against extreme weather events. Among the impacts of droughts, there are the effects of torrential rains. A degraded soil is intrinsically less stable and is more easily disaggregated and mobilized. Its infiltration capacity is affected by increasing the relative values of runoff due to an altered pore diameter and continuity over depth. In these circumstances, the effects of water floods, landslides, avalanches, and floods increase. As the volume of eroded soil increases, runoff also increases its destructive energy. The effects give rise to damages in agricultural production, impacts on inhabited areas and infrastructures, silting of hydro-electrical dams and wetlands, damage to communication infrastructures and increase economic demands to the administration and insurance sectors concerning the damage produced.

The conditions of extreme land degradation or desertification lead to the loss of the biological potential of the affected land and with it of its economic productivity. Without soil, we cannot speak of biodiversity, agricultural production, stabilization and resilience of the territory, efficient management of water resources, enabling landscape and, in a word, of a favorable, productive, and empowering environment to the development of natural life and the best human development.

Feedbacks mechanisms between soil and climate system. Albedo and radiation balance.

The albedo is the ratio, expressed in percentage, of the radiation that a surface reflects in relation to the radiation that falls on it. A surface without reflected light would have an albedo of zero value while a surface that reflected all incident radiation would have an albedo of 100%. The average albedo of the Earth is around 30% but depending on the characteristics of the Earth's surface its values vary widely. The recent snow has an albedo of around 90% and the oceans oscillate between 5-10%. Soil albedo also varies widely depending on its characteristics (organic matter content, color) and its vegetation cover or specific use. Soils devoid of vegetation, of an arid or semi-arid zone, can have an albedo between 15-25% (high reflection) while a dense forest or the surface of humid forest soil can have an albedo of around 8%. The deserts of the planet show the highest albedos of the emerged land not covered by ice or snow.

Degraded or decertified areas tend to change in color towards lighter shades due to a decrease in vegetation cover, a reduction in topsoil or leaf litter, loss of soil organic matter, or due to the characteristics of the soil, which can often be loamy, whitish-greyish or even with superficial saline efflorescence. The lighter tones imply an increase in albedo, that is, an increase in the reflection of the radiations that affect the surface of the soil. The different albedos values influence local climatic conditions, affecting convection processes and the development of precipitations (Rubio, 2007). However, the quantification of their effects on the global warming trend is not yet adequately established and is currently the subject of numerous investigations. According to the hypothesis of

Otterman (1974) and Charney (1975), the increase in albedo induces a net reduction in the emission of shortwave radiation. This tends to induce a cooling of the soil surface that increases the subsidence processes. This, in turn, causes a reduction in convection and cloud formation. As a consequence of this reduction in atmospheric instability, the precipitation possibilities in the area are reduced.

The opposite happens with the albedo decrease, that is, with the decrease in reflection. This circumstance corresponds to darker colors on the surface of the soil, such as situations of a dense vegetation cover, the presence of abundant superficial organic mulch, or the existence of a superficial edaphic horizon rich in humus and as a consequence of black or brownish-dark color. These characteristics do not correspond to decertified areas but quite the opposite. In these situations of scarce albedo, greater heating of the surface of the soil takes place that tends to increase the processes of convection. This increase in instability will increase the chances of precipitation in the area.

So, what emerges from the Otterman-Charney hypothesis is that decertified areas are likely to increase their risk of desertification to a greater extent by causing conditions that diminish the chances of receiving the rainfall that would alleviate the spiral of degradation. On the contrary, stable, fertile areas with good vegetation cover are more likely to increase their levels of water reserves.

Other effects linked to desertification would be those that affect radiative forcing. The Earth’s surface receives a continuous flow of solar energy of 341 W / m^2. A part of this energy is absorbed by the earth's surface and by the atmosphere and another part is reflected and returned to space. At the same time, the Earth itself and its atmosphere emit energy to outer space. The result is a balanced equilibrium between the energy received and the energy emitted. Human activities (emissions, changes in land use, degradation) can alter this balance causing disturbances or forcing. Radiative forcing is the difference between the energy of incoming and outgoing radiation in a given climate system. When there is a positive radiative forcing, ie more incoming than outgoing energy, the system tends to heat up. If the forcing is negative, the tendency is towards cooling. The concept of radiative forcing has been used in the IPCC reports in the context of an assessment that allows detecting changes in the radiation balance of the Earth's climate system, caused by disturbances (forcing) external to the system (for example, human activities). The greenhouse gases (CO_2, CH_4, N_2O, CFC), tropospheric ozone, the decrease of albedo and stratospheric water vapour, have a positive forcing that hypothetically contributes to warming. On the other hand, aerosols (above all sulfides) or the increase of albedo, would have a cooling effect. Radiative forcing is one of the many parameters of interaction between desertification processes and climate regulation systems. According to IPCC 2021: "Land use and aerosol forcing and land-atmosphere feedback play important roles in modulating regional changes, for instance in weather and climate extremes. These can also lead to higher warming of extreme temperatures compared to mean temperature, and possibly cooling in some regions. The soil moisture–temperature feedback was shown to be relevant for past and present-day heatwaves based on observations and model simulations".

Besides changes in albedo, the effects of radiative forcing, and the emission of greenhouse gases, there are other mechanisms involved in the interaction of soil-climate change. Some of them are the influence of levels of soil moisture, the pattern of surface roughness, the evapotranspiration processes, changes in the condensation surfaces and the emission of aerosols and dust particles that operate with different degrees of intensity in the different biomes of the earth according to their specific characteristics. Like other diverse aspects of the interactions soil-climate change, there is a growing interest in deepening and quantifying these two-way implications. The synergies between studies from different disciplinary perspectives are very much needed in the effort of better appraisal, prediction, and overall prevention of climate change.

Some conclusions. What is necessary to do

Generally, there has been scarce consideration to the appraisal of soil mismanagement and land resources depletion in the study of evolution and survival of cultures. However, history reveals soil and water conservation as crucial to the permanence of any civilization. Management and land conservation have shaped human history. Today we confront climate change, increasing land degradation and shrinking land available for food production. Considering the dimension and perspectives of present world problems history tells us that we shall not repeat mistakes of the past, including errors on soil management issues.

There is an important and close relationship between climatic factors and processes and soil performance and characteristics. The soil receives and evolves under the influence of the climate and this, in turn, acts by regulating and modifying the climatic parameters. Therefore, the potential of the soil as a climate regulator is an important option that has not yet been adequately developed in the fight against climate change.

New perspectives and visions are evolving in a world in rapid transition that demands the addressing of new and crucial societal and environmental expectations driven in many aspects by the ongoing climate change.

A much-needed vision is to achieve the adequate appraisal of soil as a crucial and essentially non-renewable natural resource and as a natural system that provides many socio-economic benefits and important ecological functions, including the paramount importance of regulation and mitigation of climate change. This vision should include primarily the raising of social awareness for soil conservation and sustainable use of the land through advisory and educational approaches.

Given the intrinsic transversely characteristic of soil/land, there are many sectors to consider in the interconnection of soil and climate change, including agriculture, forestry, biodiversity, urban and land planning, nature conservation, landscaping, water resources, and the specific soil aspects most directly focused on mitigation and adaptation to climate change.

The increasing demand for land for urban development and infrastructures is consuming our most fertile soils. At the same time, inappropriate or unsustainable use of soil and how we deal with our waste is affecting soil health, which in turn, disrupts the capacity of soils to carry out the vital services that they perform. Climate change is putting further pressure on soil health.

For the previous reasons, soil condition is at the heart of the new Green Deal for Europe (European Commission, 2020) and the United Nations Sustainable Development Goals, both of which aim to reduce biodiversity loss and pollution, reverse climate change while striving for a healthy environment and sustainable land use. It is needed to activate the mechanism to assume the actions required to fulfill the aims of the UN SDG, especially on the ones related to soil and land as human life quality support under global and common legislative frameworks.

On the risk of food insecurity, we need to enhance agricultural productivity, but at the same time, we face the enhanced soil environmental requirements in order to maintain or to restore soil ecological functions and services. It is needed a new approach on Sustainable Land Management (SLM) to enhancing the biological component of the soil operating at the multi-scale-scope approach from soil structure to landscape dimension. Fortunately, SLM and Soil and Water Conservation Practices are increasingly reinforcing approaches on soil ecological functions and the provision of agroecosystem services. These will represent the improvement of agricultural production in terms of its efficiency and its adaptation to climate change, highlighting the fundamental role of technological and biotechnological improvements. Land base adaptation-mitigation approaches to climate change offer opportunities for innovative scientific and technological advances. Many management strategies have the beneficial effect of reducing emissions and sequestering carbon, such as the use of cover crops and planting and protecting trees and other perennial plants. Reduced tillage can reduce machinery load on fields and soil compaction. The amount and timing of nutrient application should be closely tied to precipitation frequency, duration, amount, and intensity.

In general, producers need to know which strategies will be the most impactful in their unique situations but scientific certainty is often lacking on precisely how well many of these strategies work in different regions and production systems amidst a changing climate

As for human behavior, it is necessary to introduce changes in the dietary guidelines towards healthy products with fewer emissions and land use. Likewise, it is necessary to reduce food waste, both in the supply chain and in households and to reuse them according to the principles of the circular economy.

It is necessary to regain and redefine climate change mitigation measures based on enhancing the potential of the soil as a sink for atmospheric carbon through the application of afforestation, land restoration measures, and soil carbon sequestration as indicated in the last IPCC reports.

To keep our existing levels of progress and development we are forced to a radical change on environmental, social, and economic approaches and attitudes and to seeking out social innovations and different ways to live for not to repeat the mistakes of the past. The carbon cycle in the soil, and the protection of the land, are at the center of the paradigm shift and are crucial factors in the fight against climate change. Under this large paradigm, there are today three main global issues for the sustainable use of soil resources: 1) To increase food production through a more ecological and site-specific agriculture 2) Enabling soil conservation and soil ecological functions to preserve land resources and biodiversity and 3) Reinforcing the soil regulation capacity for climate change mitigation.

We are more aware now of the likely consequences of our choices than any society in history. Wouldn't it be disconcerting if we continued to make the wrong ones? How we will be judged by future generations?

Only a profound and intelligent radical change in the way we behave with the planet that supports us will allow us to face this first and greatest global challenge caused by ourselves. Now is the time to take action.

From WASWAC and the IUSS we call on all scientific societies to join the common cause indispensable to the existence of life on Earth: FERTILE SOIL AND WATER PRESERVATION.

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