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A review paper on Climate change and its impact on soil

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ABSTRACT: According to the Intergovernmental Panel on Climate Change, global temperatures are expected to increase 1.1 to 6.4°C during the 21st century, and precipitation patterns will be altered by climate change. Soils are intricately linked to the atmospheric–climate system through the carbon, nitrogen, and hydrologic cycles. Altered climate will, therefore, have an effect on soil processes and properties, and at the same time, the soils themselves will have an effect on climate. Study of the effects of climate change on soil processes and properties is still nascent, but has revealed that climate change will impact soil organic matter dynamics, including soil organisms and the multiple soil properties that are tied to organic matter, soil water, and soil erosion. The exact direction and magnitude of those impacts will be dependent on the amount of change in atmospheric gases, temperature, and precipitation amounts and patterns. Recent studies give reason to believe at least some soils may become net sources of atmospheric carbon as temperatures rise and that this is particularly true of high latitude regions with currently permanently frozen soils. Soil erosion by both wind and water is also likely to increase. However, there are still many things we need to know more about. How climate change will affect the nitrogen cycle and, in turn, how the nitrogen cycle will affect carbon sequestration in soils is a major research need, as is a better understanding of soil water–CO_2 level–temperature relationships. Knowledge of the response of plants to elevated atmospheric CO_2 given limitations in nutrients like nitrogen and phosphorus and associated effects on soil organic matter dynamics is a critical need. There is also a great need for a better understanding of how soil organisms will respond to climate change because those organisms are incredibly important in a number of soil processes, including the carbon and nitrogen cycles.

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I. WHAT IS CLIMATE CHANGE?

Climate change refers to any significant change in the measures of climate lasting for an extended period of time. In other words, climate change includes major changes in temperature, precipitation, or wind patterns, among other effects, that occur over several decades or longer. Earth's average temperature has risen by 1.5°F over the past century, and is projected to rise another 0.5 to 8.6°F over the next hundred years. Small changes in the average temperature of the planet can translate to large and potentially dangerous shifts in climate and weather.Over the past century, human activities have released large amounts of carbon dioxide and other greenhouse gases into the atmosphere. The majority of greenhouse gases come from burning fossil fuels to produce energy, although deforestation, industrial processes, and some agricultural practices also emit gases into the atmosphere.Greenhouse gases act like a blanket around Earth, trapping energy in the atmosphere and causing it to warm. This phenomenon is called the greenhouse effect and is natural and necessary to support life on Earth. However, the buildup of greenhouse gases can change Earth's climate and result in dangerous effects to human health and welfare and to ecosystems.(3)

II. DOES CLIMATE CHANGE AFFECT SOIL?

Along with changes in temperature, climate change will bring changes in global rainfall amounts and distribution patterns. And since temperature and water are two factors that have a large influence on the processes that take place in soils, climate change will therefore cause changes in the world’s soils.In fact, there are several ways that climate change will affect soil. Soils are also part of the global carbon and nitrogen cycles. The carbon-based gases carbon dioxide (CO2) and methane (CH4), and the nitrogen-based gas nitrous oxide (N2O), are important greenhouse gases. So, as carbon dioxide, methane, and nitrous oxide levels change in the atmosphere, there will be corresponding changes in the soil.(3)The major challenge for soil scientists today is to figure out exactly how climate change will affect soils, because some of the possible effects counteract each other. For example, organic matter is very important in soils. Many scientists expect increased carbon dioxide levels in the atmosphere to increase plant growth, which would mean more organic matter could potentially be added to the soil.However, higher temperatures also mean increased rates of organic matter decomposition by soil microorganisms. If the microorganisms decompose organic matter more rapidly than it's replaced, then soil organic matter levels will decline. Working out relationships like this are key to our understanding of the exact effects of climate change on soil and the ramifications for those effects on resources we rely on, like food crops and timber, that depend on soil.(2)

III. CLIMATE CHANGE AND SOIL PROCESSES

Climate change is expected to have several effects on the soil system. Changes in atmospheric concentrations of CO_2, temperature, and precipitation amounts and patterns will modify the soil–plant system and influence decomposition rates, which will have impacts on soil organic carbon levels. Organic carbon in turn has a significant influence on soil structure, soil fertility, microbial processes and populations in the soil, and other important soil properties. The challenge in figuring out how climate changewill influence soil properties and processes is in working out the complex interactions that take place as conditions change.(2)

Impact of Climate change on soil organic carbons:

soil organic carbon is an important component of global carbon cycle, and the changes of its accumulation and decomposition directly affect terrestrial ecosystem carbon storage and global carbon balance. Climate change would affect the decomposition and transformation of soil organic carbon, and further, affect the storage and dynamics of organic carbon in soils.(7) Temperature, precipitation, atmospheric CO2 concentration, and other climatic factors all have important influences on the soil organic carbon storage. Understanding the effects of climate change on this storage is helpful to the feasible options for climate change mitigation. This paper summarized the research progress about the distribution of organic carbon storage in soils, Increased temperature is likely to have a negative effect on carbon allocation to the soil, leading to reductions in soil organic carbon and creating a positive-feedback in the global carbon cycle as global temperature rise observed that soil warming and drying led to a 32% reduction in soil carbon during a 5-yr time period. Modeling of carbon responses to climate change in Canada predicted small increases in aboveground biomass in forest and tundra ecosystems, but larger decreases in soil and litter pools, for an overall increase in atmospheric carbon . Another modeling study predicted decreases in soil organic carbon of 2.0 to 11.5% in the north-central United States measured humus respiration rates under increased temperatures in samples from European Scots pine stands and concluded that the ecosystems studied would switch from net sinks to net sources of atmospheric carbon with global warming.(1)

What this all means from a soils perspective is that soils cannot necessarily be expected to become massive carbon sinks as atmospheric CO_2 levels rise. The actual impact of elevated atmospheric CO_2 on carbon storage in soils is very difficult to predict. However, if the results of the studies above are representative of what does occur, soils may actually lose organic matter as atmospheric CO_2 levels and global temperatures increase, creating a positive feedback system that could push temperatures even higher.
If too much organic matter is lost that will also have negative impacts on soil physical, chemical, and biological properties.(5)

Impacts of climate change on soil properties:

The effect of climate on the physical and chemical properties of soil, Physical and chemical characteristics of soils can vary as climate changes. A change in certain physical and chemical characteristics of soils can have either a positive or negative effects on erosion rates.(4)

Direct impacts of climate change on soil functions

Assuming constant inputs of carbon to soils from vegetation, soil-climate models predict that expected changes in temperature, precipitation and evaporation will cause significant increases in organic matter turnover and increased losses of CO_2 in mineral and organic soils across the UK. This will result in a positive feedback between CO_2 emissions from soils and further temperature increase. These broad predictions have been partially corroborated by the changes in national soil carbon stocks measured in the National Soil Inventory.(3) However further work is required to separate effects of climate change and land use change. Losses of soil carbon will also affect other soil functions. The greatest losses, relative to existing soil carbon content, are expected in south east England, where rates of temperature increase are greatest. This could lead to poorer soil structure, stability, topsoil water holding capacity, nutrient availability and erosion. However, these effects could be offset by enhanced nutrient release resulting in increased plant productivity and hence litter inputs. Relatively little comparative research has been done on organic soils, although scoping work suggested drying out of Welsh bogs might occur in the absence of deliberate management intervention, resulting in increased GHG fluxes and thus a positive climate feedback. In Scotland, areas experiencing increased rainfall could expect increased peat formation and methane release, whilst areas experiencing decreased rainfall amounts could undergo peat, and hence CO_2 loss.(5) Changes in soil moisture content have also been predicted – including increased moisture deficit for arable crops (especially on shallow soils) and for forest soils in south east Scotland. Thiscould have direct impacts on soil invertebrates affecting foraging patterns, reproduction and survivability, with potential indirect impacts on other parts of the food web which are dependent upon them. Similarly changes in the survival of natural plant pathogens could alter susceptibility of ecosystems to non-native invaders.Increased droughts will increase the likelihood of shrink-swell in clay soils, and disturbance to building foundations and need for underpinning/repair. Increased soil temperature may also exacerbate chemical attack to foundations. There is a potential risk to engineered structures based on clay caps (e.g. in contaminated landfills), with likelihood of increased leachate generation and release of landfill gases.Variable and largely unknown overall effects on pesticide fate and losses could be expected, due to the complex nature of interactions between pesticides and the environment under a changing climate. For example, increased applications of pesticides could result from an increased incidence of pests and diseases, although higher temperatures could cause more rapid degradation. Changes in rainfall patterns could lead to increased losses via bypass flow and increased degradation in winter, but increased persistence could occur as a result of drier conditions during summer and increased transfer to groundwater could result from more intense and frequent storm events. Careful planning of the amounts and timing of application of fertilizers and pesticides would help to minimize these effects. Increased winter rainfall, and particularly an increased frequency and intensity of extreme rainfall events could increase problems with land stability and landslips. Generally small effects on erosion are expected in Scotland, although increased erosion might occur during winter. Increased rainfall could increase atmospheric N deposition to soils. Increased winter water logging due to higher precipitation may promote soil disturbances as a result of tree wind throw. If good practice guidelines are not adhered to, then an indirect effect of climate change would be soil compaction and deterioration in soil structure. Leaching of nitrogen and DOC may also be enhanced by increased winter rainfall which will consequently affect water quality.Flooding and subsidence could affect archaeological sites and changes in wetland and waterlogged habitats could result in damage to artefacts, although drier summer conditions would improve reconnaissance activities for archaeology. Increased flooding and more intense rainfall events will enhance soil erosion. An additional risk on Brownfield land is the erosion of contaminated soil materials, potentially leading to the pollution of surface waters. Drainage systems may therefore need to be re-designed to accommodate more extreme and frequent floods. Soil and vegetation changes might occur, leading to degradation of sensitive montane habitats, particularly in Wales and Scotland. There will be impacts on the decomposer community.(5)

Indirect impacts of climate change on soils

The integrated impact of climate change is expected to generally increase crop yields (with winter wheat, sunflower and sugar beet having been investigated in detail), as a result of the combined effects of CO_2fertilization, radiation use efficiency and longer growing seasons. Increased sunflower yields might enable this crop to become competitive with oilseed rape in East Anglia. Smaller increases in yield or possible decreases are expected for light soils in southern England, and parts of south east Scotland suffering increased water stress. Decreased yields could also be expected for potatoes in Cornwall, oilseed rape in south and southeast England and high quality horticultural crops in Scotland. Increased CO_2 concentrations should lead to greater plant productivity. Increased temperatures might, however result in decreased yields (and hence litter inputs), although this would generally be offset by the CO_2fertilization effect. Increases in grass yields are also generally expected. Both climatic warming and rising CO_2 levels in the atmosphere will enhance tree growth in the short term. However, no UK-based research has corroborated these contentions in the longer term or for mature canopies, with current predictions based on a combination of impact studies on young trees and modeling. Reduced N inputs to crops might be needed with the exception of some areas in Scotland where small increases in N inputs could be required. Reduced N inputs could result in lower N leaching, although this will also depend on how changes in rainfall and temperature affect the N cycle and water movement. (3)

Climate change impact on soil water:

The main effects of climate change on soils will be through changes to soil moisture regimes. Soil moisture is a key driver to most soil processes and is instrumental in the use that can be made of soils. As climate changes, soil moisture levels will be influenced by direct climatic effects (precipitation, temperature effects on evaporation), climate induced changes in vegetation, different plant growth rates and different cycles, different rates of soil water extraction and the effect of enhanced CO_2 levels on plant transpiration. Changes in soil water fluxes may also feed back to the climate itself and even contribute to drought conditions by decreasing available moisture, altering circulation patterns and increasing air temperatures. Soil water can be influenced in a number of ways by climate change. Changes in precipitation will rapidly affect soil water since the time-scale for response to rainfall in the soil is usually within a few hours. (6)Increasing temperatures will also lead to greater evapotranspiration and hence loss of water from the soil. Much will depend on land use also, which itself will change, together with its water needs. Several soil forming processes, including organic matter turnover, structure formation, weathering, podzolisation, clay translocation and gleying, are strongly affected by soil moisture contents. The type of soil structure that develops under a particular climatic regime is particularly important because it affects the processes of runoff, infiltration, percolation and drainage, processes that are vital in the distribution of water across the landscape. Those areas predicted to have warmer temperatures and less rainfall will have less soil moisture with potentially large implications for the crops that can be grown and the natural and semi-natural ecosystems that can continue to exist. The temporal nature of changes in climatic variables is particularly important, for example less soil moisture in summer, more soil moisture in winter. It is, however, difficult to predict, given the many different interacting influences on soil moisture levels, what the effect of climate change will be on soil water at regional or local level. This difficulty is accentuated because soil water contents are highly variable in space, with different impacts identified in different parts of the UK and general climate change models are some way from predicting the climate changes likely at regional and particularly local level. (7)

Climate change impact on soil temperature:

There is a close relationship between air temperature and soil temperature and a general increase in air temperature will inevitably lead to an increase in soil temperature. The temperature regime of the soil is governed by gains and losses of radiation at the surface, the process of evaporation, heat conduction through the soil profile and convective transfer via the movement of gas and water. As with soil moisture, soil temperature is a prime mover in most soil processes. Warmer soil temperatures everywhere will accelerate soil processes, leading to more rapid decomposition of organic matter, increased microbiological activity, quicker release of nutrients, increased rates of nitrification and generally increased chemical weathering of minerals. However, soil temperatures will also be affected by the type of vegetation occurring at its surface, which may change itself as a result of climate change, or adaptation management.(7)

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