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Effect of Climate Changes on Soil Properties and Crop Nutrition

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ABSTRACT

Soil response to climate change is a slow multifaceted and complicated process affecting physical, chemical and biological properties and thus its productivity. Components of climate change *vis a vis* enhanced CO_2 levels, elevated temperature, altered precipitation and atmospheric nitrogen are important consideration. These parameters will shift the equilibrium both directly and indirectly of numerous soil processes which include carbon and nitrogen cycling, acidification, risk of erosion, salinization, all of which will impact soil health. Climate change affected soil would directly impact nutrient availability to plants and hence a decline in soil productivity. Adoption of climate smart agriculture would transform and reorient agricultural development under the new realities of climate change.

WITH progressing earth history, the parameters of climate such as temperatures and precipitation have globally, regionally and locally changed. Unravelling the likely extent and impact of climate change on soils is a complex process and progress has been slow. It is made all the more complicated by the fact that not only can soils be strongly affected by climate change directly, for example effect of temperature on soil organic matter decomposition, and indirectly, for example changes in soil moisture *via* changes in plant related evapotranspiration, but soils themselves can act as a source of greenhouse gases and thus contribute to the gases responsible for climate change. In addition changes in the functions and uses of soils may be driven more by socio-economic factors than environmental ones. The lack of specificity of the global circulation models (GCMs) at present, combined with the complexity of the interaction of various soil forming processes and the fact that there is still a limited knowledge of many of them, particularly biological ones, makes it difficult to quantify the changes that will ensue. On the basis of current knowledge, it is only possible to describe the likely impacts of climate change on soils in a qualitative or semi-quantitative way and highlight the key changes, their direction and, where there is adequate climate change information and their implications for management.

Climate change can have a very big impact on soils and the functions that soil performs. In agriculture, climate change will affect crop production as changes in soil, air temperature and rainfall affect the ability of crops to reach maturity and their potential harvest. As the climate heats up, reductions in the amount of water available may be made up initially by irrigation. However, scarcity of water may prevent water being used for irrigation. Increasing damage to the land, or land degradation, will occur in the form of soil erosion, desertification, salinisation, or loss of peat soils, further impacting the capability of soils to support the needs of agriculture.

The unique balance between the soils of the world and the climate affects the nature and distribution of the world's natural and semi-natural ecosystems, providing water, nutrients and a growing medium. As climate changes, so too will the soil's ability to support current ecosystems – this will lead to changes in the communities of plants growing in different parts of the world. For example, in certain places plants suited to wetter conditions may lose out to plants able to cope with drier conditions.

Soil response to climate change is expected to be multifaceted and rather complicated because of 1) The presence of an intricate network of sequential, simultaneous and / or coupled (often, time-dependent) chemical, biological and hydrological reactions and processes; 2) Chemical elements, nutrients, and contaminants involved in these reactions and processes are distributed in the soil solid, liquid, and gas phases; 3) The scale-dependent effects related to minera-logical, chemical, and physical heterogeneities and 4) Climate extremes (*e.g.,* heat waves and dry spells) induce interconnected short and long-lasting effects in soils that currently are not well understood (Qafoku, 2014).

Since soil has a major role in supplying macro and micro nutrients to all kinds of crops grown on it, studies on change of its physical, chemical and biological properties with respect to climate change is important.

Defining soil properties in relation to climate change should consider the impacts of a range of predicted global climate change such as rising atmospheric carbon dioxide (CO_2) levels, elevated temperature, altered precipitation (rainfall) and atmospheric nitrogen (N_2) deposition on soil chemical, physical and biological functions. Many studies have progressed our understanding of relationships between particular soil properties and climate change, *e.g.,* responses to temperature, CO_2 level or rainfall.

This paper describes the impact of climate change on different soil properties, their mitigation or adaptation strategies and thereby deriving a solution to the impact of climate change on physical, chemical and biological properties of soil.

Impact of Climate Change on Soil Functions

The impact of climate change on soils is a slow complex process because soils not only are strongly affected by climate change directly (for example effect of temperature on soil organic matter decomposition and indirectly, for example changes in soil moisture via changes in plant related evapotranspiration) but also can act as a source of greenhouse gases and thus contribute to the gases responsible for climate change. In addition changes in the functions and uses soils may be driven more by socio-economic factors than environmental ones. However the interaction of the various soil forming processes, particularly biological ones, makes it difficult to quantify the changes.

Direct impacts of climate change on soil functions: Soil-climate models assuming constant inputs of carbon to soils from vegetation predicts the expected changes in temperature, precipitation and evaporation with a concomitant increase in organic matter turnover facilitating increased losses of CO_2 in mineral and organic soils. These losses of soil carbon will also affect other soil functions like poorer soil structure, stability, topsoil water holding capacity, nutrient availability and erosion. The loss of soil carbon is also accelerated by the increase in temperature. However, these effects could be counteracted by enhanced nutrient release resulting in increased plant productivity *vis-a-vis* litter inputs. Increased rainfall could expect increased peat formation and methane release, whilst areas experiencing decreased rainfall could undergo peat, CO_2 loss, increased moisture deficit for arable crops (especially on shallow soils) and for forest soils thereby affecting foraging patterns, reproduction and survivability of the soil invertebrates (Chander, 2012) of the food web and natural plant pathogens. Increased droughts will increase the likelihood of shrink-swell in clay soils. Increased rainfall could increase atmospheric N deposition to soils, may promote soil disturbances, flooding and subsidence which changes in wetland and waterlogged habitats and also enhance soil erosion, potentially leading to the pollution of surface waters.

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) as a result of the combined effects of CO_2 fertilisation, radiation use efficiency and longer growing seasons which mostly applies to species with the C_3 photosynthetic pathway (Pathak *et al.,* 2012; Mihra and Rakshit, 2008) and not necessarily to species with the C_4 pathway (Allen, *et al.,* 1996) Elevated CO_2 increases the size and dry weight of most C_3 plants and plant components.

Relatively more photo assimilate is partitioned into structural components (stems and petioles) during vegetative development in order to support the light-harvesting apparatus (leaves) (Allen *et al.,* 1996). The harvest index tends to decrease with increasing CO_2 concentration and temperature. Increased yields were expected for sunflower, whereas, smaller increases in yield or possible decreases in yield for potatoes, oilseed rape and high quality horticultural crops was expected when grown under water stressed light textured soils. 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

Soil physical parameters

Soil Water: Water content in soils of semi-arid grassland systems is expected to be higher under elevated atmospheric CO_2, a condition attributed to reduced transpiration due to increased stomatal resistance (Kirkham, 2011). In short, different parts of the world will be impacted differently in terms of soil water (Kang *et al.,* 2009).

Doubling atmospheric CO_2 has been shown to reduce seasonal evapo-transpiration by 8 per cent in wheat (*Triticum aestivum* L.) and cotton and by 9 per cent in soybean [*Glycine max* (L.) Merr.] grown under day / night temperatures of 28 / 18°C (Hatfield, 2011). However, the reduction in transpiration by soybeans was eliminated if the plants were grown under temperatures of 40 / 30°C (Hatfield, 2011). In a study on rice doubling CO_2 decreased evapotranspiration by 15 per cent at 26°C, but, increased evapotranspiration at 29.5°C (Hatfield, 2011). Elevated CO_2 levels increase the water use efficiency and decrease evapotransporation rates of many plants. However, evapo-transpiration rates appear to be temperature dependent, meaning the water benefits of increased atmospheric CO_2 could be reduced or lost in areas where temperatures rise too high.

Soil temperature: Trends in soil temperature are important but rarely reported, indicators of climate change. 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 (Qian *et al.,* 2011).

As with soil moisture, soil temperature is a prime mover in most soil processes. Warmer soil temperature will accelerate soil processes, rapid decomposition of organic matter, increased microbiological activity, quicker nutrients release, increase nitrification rate and generally accentuate 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 (Defra, 2005).

Soil structure and texture differentiation: Soil structure is an important property which indicates how the soil particles combine together. Soil structure is responsible for the movement of gases, water, pollutants/contaminants, seepage, nutrients, maintenance of water quality, building foundations, soil fauna and the emergence of crops. The nature and quality of the structure is strongly influenced by the amount and quality of organic matter present, inorganic constituents of the soil matrix, cultivation methods and natural physical processes such as shrink-swell (soils with high clay contents, particularly smectitic mineralogy) and freeze-thaw behaviour. A decline in soil organic matter levels lead to a decrease in soil aggregate stability, infiltration rates and increase in susceptibility to compaction, run-off, furthermore, susceptibility to erosion (Bot and Benites, 2005).

In some areas there could be an increase in flash flooding as a result of increased cracking and change in structure. Texture is the differentiation of sand silt clay percentages is soil. It has direct impact of climate change.

Soil biological parameters

Soil organic matter : Soil organic matter is the most important soil component, influencing as it does soil structure, water holding capacity, soil stability, nutrient storage and turnover and oxygen-holding capacity, properties that are fundamental in maintaining and improving soil quality. A decline in organic matter content increases the susceptibility to soil erosion. Organic matter is particularly important as the prime habitat for immense numbers and variety of soil fauna and microflora, which play a critical role in the health and productivity of soils. It is highly susceptible to changes in land use and management and to changes in soil temperature and moisture. In the last decades changes in land use and management have already led to a significant decline in organic matter levels in many soils.

Soil organic matter is one of the major pools of carbon in the biosphere and unlike most other soil properties is important both as a driver of climate change and as a response variable to climate change, capable of acting both as a source and sink of carbon during climate change. How climate change will impact soil organic matter is a matter of considerable debate. On the one hand, it is recognized that global warming and increasing CO_2 levels in the atmosphere can favour increased plant growth, which in turn could provide more organic matter for the soil. On the other hand a rise in air temperature and that of the soil would be consistent with an increase in decomposition and loss of soil organic matter. There is thus, significant interest in the fate of such carbon, particularly the extent to which soils and land use can be used to regulate the sequestration of carbon from the atmosphere or the loss of soil organic carbon to the atmosphere. The opinion currently is that in the absence of mitigating action, losses through organic matter decomposition are likely to exceed levels gained from increased plant growth, thus adding to atmospheric CO_2 levels and the greenhouse gas effect and to lower levels of soil organic matter.

A group of soils that are particularly vulnerable to climate change are the peat soils. These are soils that are dominantly composed of organic matter throughout their whole depth. Already they have been under threat because of drainage for use in crop production. Further drying out of the soils in a warmer drier climate with concomitant oxidation could lead to losses of this important, highly productive soil type (Brinkman and Sombroek, 1996) so incurring large losses of carbon and therefore contributing to a potential positive climate feedback.

Soil Chemical Parameters

Climate – change induced accelerated soil-mineral weathering : Interest in soil-mineral weathering has increased over recent years because of the possible effects of climate change on soil properties and environmental quality and food security; the role soils play in controlling global C cycle; and the positive or negative feedback to a warming climate. The weathering of alkaline rocks, such as alkaline or alkaline earth silicates, is thought to have played an important role in the historical reduction of the atmospheric CO_2 (Kojima *et al.,* 1997), and will have an important role in the evolution of the global C cycle over the next century (Beaulieu *et al.,* 2012), when climate change is expected to be significant.

Accelerated weathering of the rocks and minerals in soils will be promoted by higher atmospheric CO_2 concentrations ($\geq$ 400 ppm) and temperature (which increase the extent and rates of weathering), intensive rainfall (which facilitates the removal of reaction products either by surface runoff or percolating water), and heat waves and extended periods of drought (which promote physical alteration of rocks and minerals). The results from a 44-year field study show that weathering rates are already increasing because of global warming. However, the spatial patterns, temporal trends, and controlling factors of the processes and reactions and their effects on different scales, especially regional, continental, and global scales, are not fully understood at this time (Moosdorf *et al.,* 2011).

The most rapid processes of chemical or mineralogical change under changing external conditions would be loss of salts and nutrient cations where leaching increases and salinization where net upward water movement occurs because of increased evapotranspiration or decreased rainfall or irrigation water supply. The clay mineral composition per mineralogy of the coarser fractions would generally change little, even over centuries but exceptions found regarding the transformation of halloysite formed under perennially moist conditions subjected to periodic drying or the gradual dehydration of goethite to haematite under higher temperatures or severe drying, condition or both. Changes in the surface properties of the clay fraction is generally slower than salt movement which take place much faster than changes in bulk composition or crystal structure. Such surface changes have a dominant influence on soil physical and chemical properties.

Changes in the clay mineral surfaces or the bulk composition of the clay fraction of soils are brought about by a small number of transformation processes, listed below. Each of these processes can be accelerated or inhibited by changes in external conditions due to global change as:

* Hydrolysis by water containing carbon dioxide, which removes silica and basic cations, may be accelerated by increased leaching rates

* Cheluviation, which dissolves and removes especially aluminium and iron by chelating organic acids, may be accelerated by increased leaching rates
* Ferrolysis, a cyclic process of clay transformation and dissolution mediated by alternating iron reduction and oxidation, which decreases the cation exchange capacity by aluminium interlayering in swelling clay minerals, may occur where soils are subject to reduction and leaching in alternation with oxidation: In a warmer world, this may happen over larger areas than at present, especially in high latitudes and in monsoon climates
* Dissolution of clay minerals by strong mineral acids, producing acid aluminium salts and amorphous silica e.g., where sulphidic materials in coastal plains are oxidized with an improvement of drainage; however, a rise in sea level would reduce the likelihood of this occurring naturally
* Reverse weathering, *i.e.,* clay formation and transformation under neutral to strongly alkaline conditions, which may create, e.g., montmorillonite, palygorskite or analcime; it could begin in areas drying out during global warming and would continue in most presently arid areas.

Soil reaction (pH)

Most soils would not be subject to rapid pH changes resulting from climate change. Exceptions might be found in potential acid sulphate soils, extensive in some coastal plains and estuaries, if they become subject to increasingly long dry seasons. Eventhough, most of such soils are clays with moderate or high cation exchange capacity, the amounts of acid liberated in such soils upon oxidation generally exceed this rapid buffering capacity. Therefore, pH values may temporarily reach 2.5 to 3.5 and a small part of the clay fraction may be decomposed. This then buffers the pH generally between 3.5 and 4 in the long run. Depending on the efficiency with which the excess acid formed can be leached out, the period of extreme acidity and aluminium toxicity may last between less than a year and several decades.

In calcareous soils, soil reaction may range between about 8.5 and 7 depending on the partial pressure of CO_2 in the soil; this range is maintained against leaching of basic cations by the different soil processes as long as a few percent of finely distributed lime remain. Buffering in non-calcareous soils is less strong, but depends on the cation exchange capacity at soil pH. In soils with variable-charge surfaces of the clay fraction, this decreases with acidification.

It should be noted that the simple modeling of accelerated $CaCO_3$ leaching under a doubled atmospheric CO_2 concentration generally does not hold true. In most soils, the ongoing decomposition of organic matter maintains CO_2 concentrations in the soil air far above atmospheric concentration even now, and $CaCO_3$ solubility is determined by the partial pressure of CO_2 in soil air and its activity in soil water, rather than in the atmosphere. Leaching of lime is thus positively related to rate of organic matter decomposition, negatively to gas diffusion rate, and positively to amount of water percolating through the soil.

In conditions where leaching is accelerated by climate change, it would be possible to find relatively rapid soil acidification after a long period with little apparent change. The soil might in fact be steadily depleted of basic cations, but, a pH change may start, or may become more rapid, once certain buffering pools are nearly exhausted.

Acidification, salinization and sodicity as related to climate change

While temperature increases are forecast for most parts, there is less certainty about precipitation changes. Significant increases in rainfall will lead to increases in leaching, loss of nutrients and increasing acidification, depending on buffering pools existing in soils. Direction of change towards increased leaching or increased evaporation will depend on extent to which rainfall and temperature change and consequent changes to land use and its management. In either case, situation could lead to important changes in soils.

Increased salinization and alkalization would occur in areas where evaporation increased or rainfall decreased (Varallyay, 1994). Transient salinity increases as capillary rise dominates, bringing salts into root zone on sodic soils. Leaching during episodic rainfall events may be limited due to surface sealing. Increased subsoil drying increases concentration of salts in soil solution.

Conversely, severity of saline scalds due to secondary salinisation may abate as groundwater levels fall in line with reduced rainfall; this development could have significant impacts on large areas semi-arid zones. In areas where salinity is a result of recharge processes, salinization would increase if upstream recharging rainfall increased (Peck and Allison, 1988). Increasing atmospheric CO_2 concentration can reduce impact of salinity on plant growth (Nicolas *et al.,* 1993).

Anticipated impacts of climate change are warmer conditions, increasing proportion of rainfall to occur from heavy falls, increasing occurrence of drought in many regions, increasing frequency of intense tropical cyclones, rising sea levels and frequency of extreme high seas. All these predicted impacts have direct relevance to coastal acid sulfate soils landscapes, through either exacerbating sulfide oxidation by drought, re-instating reductive geochemical processes or changing the export and mobilisation of contaminants.

Interaction of specific land management factors such as man-made drainage will have a significant role in how predicted impacts of climate change affect these landscapes. Understanding potential impacts of climate change for coastal lowland acid sulfate soils is particularly important, given utility of these areas for agriculture and urban communities, their unique capacity to cause extreme environmental degradation and sensitivity to climatic factors such as temperature and hydrology and susceptibility to sea-level inundation.

Soil fertility and nutrient acquisition

Climate change may have stronger or weaker, permanent or periodical, favourable or unfavourable, harmful (sometimes catastrophic), primary (direct) or secondary (indirect) impact on soil processes. Soil moisture regime plays a distinguished role. It determines water supply of plants, influences air and heat regimes, biological activity and plant nutrient status of soil. In most cases it determines agro-ecological potential, biomass production of various natural and agro-ecosystems and hazard of soil and/or water pollution.

Crop yields on soils in developing countries decrease exponentially with increasing aridity (Lal, 2004). Soil moisture deficit directly impacts crop productivity but also reduces yields through influence on availability and transport of soil nutrients. Drought increases vulnerability to nutrient losses from rooting zone through erosion (Gupta, 1993). Because nutrients are carried to roots by water, soil moisture deficit decreases nutrient diffusion over short distances and mass flow of water-soluble nutrients such as nitrate, sulfate, Ca, Mg and Si over longer distances (Mackay and Barber, 1985; Barber, 1995).

Roots extend their length, increase their surface area and alter their architecture in an effort to capture less mobile nutrients such as P (Lynch and Brown, 2001.). Reduction of root growth and impairment of root function under drought conditions thus reduces the nutrient acquisition capacity of root systems. Reductions in both carbon and oxygen fluxes and N accumulation in root nodules under drought conditions inhibit N fixation in legume crops (Gonzalez *et al.,* 2001; Ladrera *et al.,* 2007; Athar and Ashraf, 2008). Drought alters composition and activity of soil microbial communities like reduction of soil nitrifying bacteria.

Excessive precipitation causes significant source of soil nutrient loss in developing countries (Tang *et al*., 2008 and Zougmore *et al.,* 2009.) like nitrate leaching (Sun *et al.,* 2007). Agricultural areas with poorly drained soils or that experience frequent and / or intense rainfall events can have waterlogged soils that become hypoxic. The change in soil redox status under low oxygen can lead to elemental toxicities of Mn, Fe, Al and B that reduce crop yields and production of phytotoxic organic solutes that impair root growth and function.

Hypoxia can also result in nutrient deficiency since active transport of ions into root cells is driven by ATP synthesized through oxygen dependent mitochondrial electron transport chain (Drew, 1988;

Atwell and Steer, 1990). Significant N losses can also occur under hypoxic conditions through denitrification as nitrate is used as an alternative electron acceptor by microorganisms in the absence of oxygen (Prade and Trolldenier, 1990).

Soil warming can increase nutrient uptake from 100-300 per cent by enlarging root surface area and increasing rates of nutrient diffusion and water influx (Ching and Barbers, 1979; Mackay and Barber, 1984). Since warmer temperatures increase rates of transpiration, plants tend to acquire water soluble nutrients (*nitrate, sulfate, Ca, Mg primarily move towards roots through transpiration-driven mass flow*) more readily as temperature increases.

Temperature increases in rhizosphere can also stimulate nutrient acquisition by increasing nutrient uptake via faster ion diffusion rates and increased root metabolism (Bassirirad, 2000). However, any positive effects of warmer temperature on nutrient capture are dependent on adequate soil moisture. If under dry conditions higher temperatures result in extreme vapor pressure deficits that trigger stomatal closure (*reducing water diffusion pathway in leaves*) (Abbate *et al*., 2004), then nutrient acquisition driven by mass flow will decrease (Cramer *et al.,* 2009).

Emerging evidence suggests that warmer temperatures have the potential to significantly affect nutrient status (*especially reduced P acquisition*) by altering plant phenology (Nord and Lynch, 2009). Besides, higher temperature accelerates SOC losses from soil.

Other soil degradative parameters

Soil erosion and degradation : Soil erosion is movement and transport of soil by various agents, water, wind and mass movement; hence climate is a key factor. Increase in soil erosion is strongly linked with clearance of natural vegetation, to enable land used for arable agriculture and use of farming practices unsuited to land on which they are practised.

This, combined with climatic variation and a predicted increase in extreme weather events, has created ideal conditions for soil erosion. The main climatic factors influencing soil erosion are rainfall (amount, frequency, duration and intensity) and wind (direction, strength and frequency of high intensity winds), coupled with drying out of the soil. Land use, soil type and topography are other key factors.

Increased rainfall processes, amounts and intensities due to climate change lead to greater rates of erosion. Erosion will increase approximately 1.7 per cent for each 1 per cent change in annual rainfall. The dominant factor related to change in erosion rate is amount and intensity of rainfall that falls in storm, rather than number of days of precipitation in a year.

Linear relationship exists between precipitation volume and runoff like between precipitation and soil erosion. A - 20 to 20 per cent increase in precipitation resulted in an estimated - 40 to 40 per cent change in runoff. From relationship between runoff and precipitation intensity and frequency, rainfall intensity had greater effect than rainfall frequency on runoff. Each 1per cent change in precipitation amount resulted in 2.5 per cent change in runoff if a change in intensity accounted for all change in amount; 1.28 per cent change in runoff occurred if a change in frequency accounted for all of the change in precipitation amount and an average 1.97 per cent change in runoff occurred if a combination of change in intensity and frequency accounted for the change in precipitation volume.

The second dominant process related to erosion and climate change is biomass production. Biomass levels ill change under climate change due to changes in temperature, moisture and atmospheric CO_2 levels and biomass ranks next to rainfall in terms of its impact on erosion rates (Nearing *et al.,* 2004).

The third major process of erosion rate changes under climate change and the wild card is land use. Detailed land use changes as a function of future climates (*both weather related and economic climates*) are nearly impossible to predict with any degree of accuracy.

Soil erosion by water is more widespread and its impact greater than that by wind. Climate change is likely to affect soil erosion by water through its effect on rainfall intensity, soil erodability, vegetative cover and patterns of land use. General circulation models indicate marked change in soil moisture regime for some areas and therefore changes also in soil erodability, vegetation and land use. For many areas, they also predict seasonally more intense drying out coupled with increased amounts and intensity of precipitation at other times, conditions that could lead to a large increase in rates of erosion by water.

Soil erosion occurs by wind transport of soil particles by suspension, surface creep or saltation over distances ranging from few centimetres to hundreds of kilometres. Wind erosion is particularly a problem on sandy and organic soils where they are subject to intermittent low moisture contents and periodic winds. Those areas where climate change is predicted to lead to more droughty soils under increasing temperatures will become increasingly vulnerable.

Although, general circulation models have in the past have been unable to predict changes in wind speed and frequency with any certainty, the latest models are predicting increased summer continental drying and risk of drought in mid-latitude areas and an increase in tropical cyclone peak intensities in some areas, both sets of conditions favouring an increase in soil erosion by wind.

Erosion is site-specific and different permutation of conditions can increase or decrease it. Regarding soil degradation through climate change, potential impact of four main plausible climate scenarios on most important soil degradation process are summarized, indicating their determining natural and anthropogenic factors (Szabolcs, 1990; Varallyay, 1990; Varallyay, 2002; Varallyay, 1994).

Overall impact of climate change on soil health: Soil quality could, in part, be viewed as a static (qualitative) measure of the capability of soil, whereas ‘Soil health’ infers a dynamic state, where human impact causes a shift in quality. There are numerous potential indicators of soil quality / health. These indicators can be categorised broadly as visual (*e.g.,* runoff, plant response, weed species), physical (*e.g.*, topsoil depth, bulk density, aggregate stability, crusting, compaction), chemical (*e.g.,* pH, salinity, organic matter action exchange capacity, contaminant concentrations) and biological (*e.g.,* activity of micro-macro-organisms) indicators. Of the range of potential indicators used to infer soil health status, soil carbon is particularly important (Bruke *et al.,* 1989) (Dalal and Chan, 2001). Organic matter is vital because it supports many soil processes that are associated with fertility and physical stability of soil across the various ecosystem services. In particular organic matter provides an energy source for microbes structurally stabilizes soil particles, stores and supplied plant essential nutrients such as nitrogen, phosphorus and sulphur and provides cation / anion exchange for retention of ions and nutrients. Carbon within the terrestrial biosphere can also behave as either a source or sink for atmospheric CO_2 depending on land management, thus potentially mitigating or accelerating the greenhouse effect. Cycling of soil organic carbon is also strongly influenced by moisture and temperature, two factors which are predicted to change under global warming. Overall, climate change will shift the equilibrium, both directly and indirectly of numerous soil processes. These include carbon and nitrogen cycling, acidification, risk of erosion, salinisation, all of which will impact on soil health.

Climate change adaption measures related to agriculture soils

To equip against any negative effect of climate change, or against other extremes in external circumstances such as nutrient depletion or excess (pollution), or drought or high-intensity rains, the best that land users could do, would be:

– To manage their soils to give them maximum physical resilience through a stable, heterogeneous pore system by maintaining a closed ground cover as much as possible;
– To use an integrated plant nutrient management system to balance the input and offtake of nutrients over a cropping cycle or over the years, while maintaining soil nutrient levels low enough to minimize losses and high enough to buffer occasional high demands.

– Decision making regarding timing and type of agricultural operations used (*minimum tillage*) and erosion control measures such as buffer strips could help reduce negative impacts on soil structure, erosion and runoff

- Soil moisture conservation measures such as mulching and minimum tillage could help minimise increased crop irrigation needs in summer
- Careful planning of amounts and timing of applications of fertilisers and pesticides
- Land management practices to increase SOM content (*addition of cereal straw, animal manure, rotations*) could help maintain SOM contents and avoid increased CO_2 fluxes from soils. Correct farming techniques can sequester carbon into soil and reverse GHGs created by agriculture. Processes to increase soil carbon can be divided into three steps.

The Earth's climate system is changing – of that we are certain. Climate Change poses challenges in times to come with reference to scale and scope. How climate change will affect the nitrogen cycle and, in turn, how the nitrogen cycle will affect carbon sequestration in soils constitute a major research needs, 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 potential limitations in nutrients like nitrogen and phosphorus and how that affects 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. All of these questions involved highly complex and interconnected systems that make it difficult to isolate a single variable, such as temperature or precipitation patterns, to reach meaningful conclusions about how a change in that single variable affects the system being studied. However, we do know that there is the potential for some undesirable things to occur as a result of climate change. There is the possibility that soils could contribute increasing amounts of greenhouse gases to the atmosphere, losing their ability to act as a sink for carbon as global temperatures increase, and there is the chance that we will see negative impacts on the physical and chemical properties of our soils that are essential for the production of food and fiber products. Therefore, it is critical that continued research into these areas be supported, with the particular goal of understanding the complex interactions that take place in the natural environment.

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