

Review Article

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## Effect of Climate Change on Soil Chemical and Biological Properties-A Review

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### ABSTRACT

Climate change influences composite set of measurable physical, chemical and biological soil properties attributes which relate to functional soil processes. Climate change impacts soil chemical, physical and biological functions through a range of predicted global change drivers such as rising atmospheric carbon dioxide (CO<sub>2</sub>) levels, elevated temperature, altered precipitation (rainfall) and atmospheric nitrogen (N) deposition (French *et al.*, 2009). The exact direction and magnitude of these impacts will be dependent on the amount of change in atmospheric gases, temperature, and precipitation amounts and patterns. Many studies have progressed our understanding of relationships between particular soil properties and climate change drivers, e.g. responses to temperature, CO<sub>2</sub> or rainfall. The complexity and interdependence of many of the climate change drivers influence soil microbial properties like microbial biomass and biomass diversity, rate of organic matter decomposition, C and N cycles, chemical properties of soil like pH, EC, nutrient availability and physical properties like porosity, aggregate stability, soil erosion, etc.

#### Keywords

Climate, Soil Properties, CO<sub>2</sub>

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### Introduction

The most recent report of the Intergovernmental Panel on Climate Change (IPCC) indicates that the average global temperature will probably rise between 1.1 and 6.4°C by 2090 – 2099, as compared to 1980–1999 temperatures, with the most likely rise being between 1.8 and 4.0°C (IPCC, 2007). The idea that the Earth's climate is changing is now almost universally accepted in the scientific community (Cooney, 2010; Corfee- Morlot *et al.*, 2007), and even many scientists who dispute that climate change is

anthropogenic are in agreement that it is happening (i.e., Kutilek, 2011; Carter, 2007; Bluemle *et al.*, 1999). Therefore, even if we can't agree on why climate change is happening, it should be possible to agree that it is happening, and with climate change happening, there will be effects on the environment, including the soil. In the last century considerable changes took place in the gas composition of the atmosphere due to natural processes and human activities, such as increasing energy consumption, industrialization, and intensive agriculture, urban and rural development. This has led to a

rise in global temperature and high spatial and temporal variability. The changing the temperature regime would result in considerable changes in the precipitation pattern. Soils are intricately linked to the atmospheric–climate system through the carbon, nitrogen, and hydrologic cycles.

### **Factors of soil formation**

Soil is a naturally occurring body, that has been evolved owing to combined influence of climate and organisms acting on parent material as conditioned by topography over a period of time. Living things: Plant roots physically break rocks into small pieces; lichen dissolves rock; burrowing animals mix the soil and help aeration. Climate: heat and water accelerate chemical changes (so moist, temperate areas have different soils than arid, tropical, or polar areas). Topography: Loose soil stays in place in flat areas, allowing more thorough physical and chemical alteration of its grains. On steep slopes, the soil moves downhill before complete alteration can occur. Parent material: Chemical changes during soil formation depend on what minerals and rocks are present. *Ex:* Calcium-rich soils generally form from calcium-rich rocks (like limestone) but not from calcium-poor rocks like granite. Time: When bedrock is exposed at the surface, chemical, biologic, and physical processes combine to produce a thin soil layer.

Over time, the processes extend vertically downward, developing soil horizons whose position and thickness change over time. Climate is the average weather at a given point and time of year over a long period. The average weather includes all the associated features such as temperature, wind patterns and precipitation. Any change in climate over time, whether due to natural variability or as a result of human activity is called as climate change. Climate change and its hydrological

consequences may result in the significant Modification of soil conditions. The impact analysis of *potential* future changes is Rather difficult, due to the uncertainties in the forecast of global and long-term Temperature and precipitation patterns (including their spatial and temporal variability) Combined here with the changing hydrological cycle and the complex and integrated Influences of natural vegetation and land use pattern (partly due to the changes in the Socio-economic conditions). Consequently the long-term and global ‘*soil change Prognosis*’ can only be a rather rough, sometimes imaginative estimation and allows only for the drawing of general conclusions. In the natural *soil formation processes* the pedogenic inertia will cause different Time-lags and response rates for different soil types developed in various regions of our Globe (Scharpenseel *et al.*, 1990; Lal *et al.*, 1994; Rounsevell and Loveland, 1994).

### **Drivers of climate change**

Climate change impacts soil chemical, physical and biological functions through a range of predicted global change drivers such as CO<sub>2</sub>, N deposition, Temperature and Rainfall.

The CO<sub>2</sub> concentration reached a level of 386 ppm in 2009 and increased further to 389 ppm. This is an increase of about 110 ppm (+38%) compared to the pre-industrial levels (i.e. before 1750) (NOAA, 2011). Atmospheric CO<sub>2</sub> concentration increased globally by nearly 30%, Temperature by approximately 0.6°C, and these trends are projected to continue more rapidly. The suggested increase in mean annual surface temperature of 2-7°C by 2100 is the largest change globally. The Nitrous oxide (N<sub>2</sub>O) concentration in 2009 was 322 ppm, up 0.6 ppb from the year before (Encyclopedia Britannica). The atmospheric carbon dioxide

increased in 2012 at a faster rate than the average over the past 10 year because of a combination of continuing growth of emissions and a decreasing in land carbon sinks. The carbon dioxide emissions recorded high in 2012, the emission trend of carbon dioxide by different countries as followed the decreasing order: China>Japan>Middle East >India>European Union>United States. China is the major contributor for carbon dioxide emission. India contributes about 7.7 percent to the total world emission. The carbon dioxide released to the atmosphere is more compare to the carbon sequenced in soil due to human activity and natural processes. The N<sub>2</sub>O enters to the atmosphere through Emitted during agricultural and industrial activities, as well as during burning of fossil fuels and solid waste. The nitrous oxide concentration in the atmosphere increases 19% above the pre-industrial level. Emission trend of nitrous oxide by different sources as followed the decreasing order: soil>agriculture>rivers >oceans>fossil fuel= biomass>human activity. Soil is the major contributor for nitrous oxide emission. Soils contribute about 6.6 percent to the total emission of nitrous oxide (world energy outlook special report 2012).

According to the Intergovernmental Panel on Climate Change, global temperatures are expected to increase 1.1 to 6.4°C during the 21st century. When the green houses gasses increases in the atmosphere that leads to increases the earth temperature. Some of the infrared radiation passes through the atmosphere and some of the radiation is absorbed and re emitted by the green house gasses molecule. The effect of this warm up the earth surface and lower atmosphere. As average global temperatures rise, the warmer atmosphere can also hold more moisture, about 4 percent more per degree Fahrenheit temperature increase. Thus, when storms occur there is more water vapor available in

the atmosphere to fall as rain, snow or hail. Worldwide, water vapor over oceans has increased by about 4 percent since 1970 according to the 2007 U.N. Intergovernmental Panel on Climate Change report.

### **Why should we be interested in climate change?**

Climate determines the type and location of human managed ecosystems, such as agricultural farmlands. Climate affects the weathering of rock, the type of soil that forms, and the rate of soil formation. Climate helps to determine the quantity and quality of water available for human use. Climate determines the severity of droughts, storms, and floods. Climate largely determines the nature and locations of biomes (major terrestrial ecosystems, defined based on their plant communities).

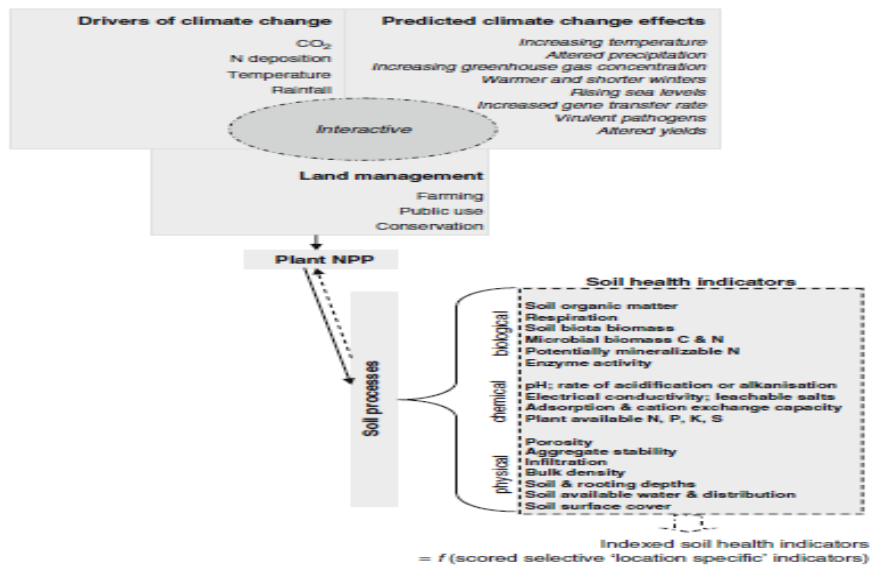
The climate change affect the net primary productivity in interactive effect with land management practices by affecting soil processes like physical, chemical and biological processes (Adapted from Dalal and Moloney, 2000; Gregorich *et al.*, 1994; Haynes, 2008; Idowu *et al.*, 2009; Kinyangi 2007; Reynolds *et al.*, 2009; Stenberg, 1999).

Climate change influences composite set of measurable physical, chemical and biological soil properties attributes which relate to functional soil processes. By considering know I interested to know the impact of climate change on chemical properties of soil

### **Soil chemical properties affected by the climate change**

Soil pH, Rate of acidification or alkalization, Electrical conductivity, Leachable salts adsorption, CEC, Plant available N,P,K,S. etc., are affected by climate change

**Schematic representation of the potential links between climate change, land use and management change, and soil health indicators (modified from Dalal and Moloney, 2000; French *et al.*, 2009; Karlen *et al.*, 2003; Nuttall, 2007)**



**Soil health indicators and relations to processes and functions under projected climate change scenarios**

Soil health indicators	Soil processes affected
<b>PHYSICAL</b>	
Soil structure	Aggregate stability, organic matter turnover
Porosity	Air capacity, plant available water capacity, relative yield capacity
Infiltration	Soil water availability and movement.
Bulk density	Soil structural condition, compaction
Soil depth and rooting	plant available water capacity, sub soil salinity.
Soil plant available water and distribution	Field capacity, permanent wilting point, macro pores flow, texture.
Soil protective cover	soil water and nutrient movement, soil stabilization, C and N fixation
<b>CHEMICAL AND BIOLOGICAL</b>	
pH	Biological and chemical activity thresholds
EC	Plant and microbial activity thresholds.
Plant available N, P,K.	Plant available nutrients and potential for loss
Soil organic matter light fraction or Macro-organic matter Mineralisable C and N	Plant residue decomposition, organic matter storage and quality, macro aggregate formation, metabolic activity of soil organisms, net inorganic N flux from mineralization and immobilization
Soil total C and N	C and N mass and balance.
Sol respiration	Microbial activity
Microbial biomass C and N	Microbial activity
Microbial quotients	Substrate use efficiency
Microbial diversity	Nutrient cycling and availability

## Soil pH

Brinkman and Sombroek (1999) suggested that most soils would not be subjected to rapid pH changes resulting from drivers of climate change such as elevated temperatures, CO<sub>2</sub> fertilization, variable precipitation and atmospheric N deposition. Similar findings are founded by DeVries and Breeuwsma (1987); McCarty *et al.*, (2001). Drivers of climate change will affect OM status, C & nutrient cycling, plant available water & hence plant productivity, which in turn will affect soil pH (Reth *et al.*, 2005).

They sampled at locations arrayed in an elevation transect up the slope of Rattlesnake mountain (1093 m) located on the ALE(Arid Land Ecology reserve). Twenty-five sites were identified for sampling starting at an elevation of 228 m and continuing every 25 m to a maximum elevation of 844 m. Average precipitation increases from 180 mm at the lowest elevation to 270 mm at the 844 m elevation site. The Soil pH decreased with increasing elevation, the trends of decreasing soil pH could be due to increased leaching of basic cations in the higher elevations from greater precipitation and from increased nitrification. Therefore the pH of soil decreases when move from lower elevation to higher elevation as shown in the Figure 1 (Smith *et al.*, 2002).

## EC

Pariante (2001) examined the dynamics of soluble salts concentration in soils from four climatic regions (Mediterranean, semi-arid, mildly arid and arid) and found a non-linear relationship between the soluble salts content and rainfall, with sites that received <200 mm rainfall contained significantly high soluble contents and vice versa. They sampled at locations arrayed in an elevation transect up the slope of Rattlesnake mountain (1093 m) located on the ALE(Arid Land Ecology

reserve. Twenty-five sites were identified for sampling starting at an elevation of 228 m and continuing every 25 m to a maximum elevation of 844 m. Average precipitation increases from 180 mm at the lowest elevation to 270 mm at the 844 m elevation site. They reported that soil EC increased with elevation with the top two sites significantly greater than the lower sites The increase in EC with elevation would seem to contradict the hypothesis that the leaching of bases is causing the lower soil pH values with increasing elevation. However, in both the grass and crust soil there was a significant amount of nitrate in the higher elevations which could contribute to the increase in EC over the 500 m elevation transect as could greater H<sup>+</sup> ion concentrations from the lower pH as shown in Figure 2 (Smith *et al.*, 2002).

## CEC

CEC of coarse-textured soils and low-activity clay soils is attributed to that of SOM, the increasing decomposition and loss of SOM due to elevated temperatures may lead to the loss of CEC of these soils (Davidson and Janssens, 2006). Low CEC of soil may result in increased leaching of base cations in response to high and intense rainfall events, thus transporting alkalinity from soil to waterways.

## Acidification

Decreasing precipitation may reduce downward filtration and leaching. Climate determines the dominant vegetation types, their productivity, the decomposition rate of their litter deposits, and influences soil reaction in this indirect way.

## Salinization/Sodification

A consequence of the expected global 'warming' is the rise of eustatic sea level: increase of inundated territories (especially in

the densely populated delta regions and river valleys), and the areas under the influence of sea water intrusion.

### **Plant available nutrients**

Nutrient cycling, especially N, is intimately linked with soil organic C cycling and hence drivers of climate change such as elevated temperatures, variable precipitation and atmospheric N deposition are likely to impact on N cycling and possibly the cycling of other plant available nutrients such as phosphorus and sulphur, *etc.* (Weil and Magdoff, 2004, Kumar and Swarup, 2012). The soil N in the surface 5 cm of the forest soil increased linearly during 5 years of exposure to elevated CO<sub>2</sub> as shown in the Figure 3. While N in the ambient plots remained relatively constant, consistent with vegetative effects on soil formation, increases in soil N storage, particularly in forests, are more likely to occur near the surface, where inputs from roots and above ground litter are greatest (Jastrow *et al.*, 2005).

The positive feedbacks amplify system responses to changes in constraints. Thus, responses to boreal and temperate forests to carbon dioxide induced climate change may depend on the balance between changes in hydrological cycle that constrain the forest response and the positive feedbacks between the carbon and nitrogen cycles that amplify this response. If the vegetation response to drought decreases nitrogen availability, then the positive feedback between the carbon and the nitrogen cycles weakens, resulting in a decline in productivity. Conversely, if climate change alters forest composition, thus enhancing growth of species which can further enhance soil nitrogen availability through the chemistry of their litter, then the same positive feedback results in an increased productivity. Therefore, interactions between vegetation and water and nitrogen

availabilities may produce a bifurcation in the forest ecosystem response that is increased productivity where soil water is not limiting and nitrogen availability is enhanced, decreased productivity where water and nitrogen become more limiting. Forest responses to climate change are as sensitive to the indirect effects of climate and vegetation on soil properties as they are to direct effects of temperature on tree growth. The heterogeneity of landscape, particularly the distribution of various soils, becomes an important factor determining forest responses to climate change, because these bifurcations can occur within as well between, biomes (Paster and Post, 1988).

### **Biological Properties Affected by Climate Change**

While the chemistry (and physics) of the soil system provides the context... it is the soil biota which is adaptive to changes in environmental circumstances” (Kibblewhite *et al.*, 2008).

### **Soil microbial biomass**

Soil microbial biomass has been shown to be responsive to short term environmental changes (Haynes, 2008 and Pregitzer *et al.*, 2008). Recent studies revealing significant decline in the soil microbial biomass during long-term simulated climatic warming experiments (Rinnan *et al.*, 2007)

The relative abundance of bacterial phyla was clearly impacted by the precipitation treatment, which led to shifts in the relative abundance *Proteobacteria* and *Acidobacteria*. The other two factors, carbon dioxide and temperature, did not have a major impact on the distribution of these groups. The relative abundance of *Proteobacteria* was greater in the wet relative to the dry treatments, whereas *Acidobacteria* abundance was greater in dry

treatment as shown in Figure 4. Because *Acidobacteria* is ubiquitous phylum in soil they required aerobic condition for their metabolism, *Proteobacteria* required anaerobic condition for their metabolism (Castro *et al.*, 2009).

**Soil respiration**

Soil respiration, particularly its temperature response is widely acknowledged to be a critical link between climate change and the global C cycle (Wixon and Balsler, 2009). Studies have also shown that soil respiration is relatively responsive to changes in the seasonal timing of rainfall, which is predicted to change according to global and regional climate models (Chou *et al.*, 2008)

This research was conducted by FACTS-II FACE project is located near Rhinelander, WI, USA (45°40.5'N, 89°37.5'E, 490 m elevation). The experiment is a randomized complete block design with three replicates of factorial CO<sub>2</sub> (ambient and elevated to 560 µl l<sup>-1</sup>) and O<sub>3</sub> (ambient and elevated to 50 nl l<sup>-1</sup>) treatments. Seasonal soil respiration for

2005, 2006 and 2007 was significantly greater under +CO<sub>2</sub>, but was not significantly affected by +O<sub>3</sub> (Fig. 5). The +CO<sub>2</sub> +O<sub>3</sub> treatment tended to have the greatest values for seasonal soil respiration across all community types (5–10% greater than +CO<sub>2</sub>), but values for the +CO<sub>2</sub> +O<sub>3</sub> treatment were not significantly greater than those for +CO<sub>2</sub> alone. Across treatments, seasonal soil respiration was significantly greater in the aspen community than for the birch/aspen and maple/aspen communities during 2005 and 2006, but not in 2007 (Pregitzer *et al.*, 2008).

**Enzyme activity**

Soil enzyme activities show rapid response to changes in soil management (Aon *et al.*, 2001; Ruiz *et al.*, 2009). Studies of individual enzyme activities report strong temporal & spatial variability, often leading to conflicting results (Aon *et al.*, 2001; Ruiz *et al.*, 2009). Dorodnikov *et al.*, (2009) showed that by altering the quantity and quality of below ground C input by plants, elevated CO<sub>2</sub> may stimulate microbial enzyme activities (Castor *et al.*, 2009).

**Enzyme activities and elevated CO<sub>2</sub>**

Enzyme	Ambient CO <sub>2</sub> (µmol kg <sup>-1</sup> h <sup>-1</sup> )	Elevated CO <sub>2</sub> (µmol kg <sup>-1</sup> h <sup>-1</sup> )
α-1,4-glucosidase	1.0 ± 0.9	2.1 ± 0.8
β-1,4-glucosidase	145.7 ± 18.6	129.5 ± 7.8
Alk phosphatase	332.4 ± 6.3	234.8 ± 7.6
N-acetylglucosaminidase	48.0 ± 2.1	6.7

**Potentially mineralizable C and N**

These processes are closely connected with the soil moisture regime and with the abiotic & biotic transformation phenomena (fixation, immobilization / release, mobilization; changes in solubility and redox status, etc.). High precipitation increases leaching, filtration loss (potential groundwater pollution) and reductive processes. Low precipitation (dry conditions) may reduce the solubility, mobility and availability of

available elements and compounds. Groffman *et al.*, (2009) reported that the rates of in situ net mineralization and nitrification were increases with soil moisture content in summer (Fig. 6).

The rates of in situ net mineralization and nitrification were faster in summer than in winter and in high elevation plots than in lower elevation plots (Fig. 6). Net nitrification was particularly slow on the lower valley low elevation plot. Winter mineralization activity

ranged from 14 to 57% of annual activity in 2002/2003 and 7% to 23% of annual activity in 2003/2004 and was faster in high elevation plots. Winter nitrification ranged from 6 to 25% of annual activity in 2002/2003 and from 0 to 29% of annual activity in 2003/2004 and was faster in high elevation plots. Summer activity was strongly correlated with soil moisture. In winter, sites with more soil freezing had slower rates of nitrification, but the correlation between maximum soil frost and winter nitrification was not significant. Because there were markedly different amounts of soil frost in the two winters of the study, correlations between soil frost and N cycling (Groffman *et al.*, 2009).

Castro *et al.*, (2009) reported that potential mineralization and nitrification is more in case of ambient carbon dioxide treatment compare to elevated condition. In both the treatment in the beginning there was decreasing in potential mineralization and nitrification. This is more in ambient condition because of more microbial activity.

### **Soil organic matter**

Generally, increase in temperature has been reported to enhance SOM decomposition, but rising temperature, precipitation, CO<sub>2</sub> fertilization and atmospheric N deposition may support high plant productivity and OM input to soil and consequently increase SOM. Davidson and Janssens (2006) reported that accessibility and availability of SOM to micro-organisms govern SOM losses rather than rate-modifying climate factor (i.e. temperature). The rate of decomposition is exceeds the rate of humus formation when moving from cold to hot climate. Therefore the amount of humus is low in their profile of soil in hot dry condition (Fig. 7) because of more microbial activity (Brinkman *et al.*, 1990).

A higher biomass production of wild plants as well as more crop residues as a consequence of higher crop yields increases the nutrient offer for soil organisms. Higher soil temperatures also stimulate the activity of soil organisms. Here for, aerated soils of the lower and middle latitudes higher humus contents can be expected. In contrast, in the soils of higher latitudes smaller humus contents will occur. Wet soils with low air content, even in humid tropical areas, will be characterized by increasing humus contents. Higher soil temperatures will also stimulate the activities of aggregate forming and soil mixing animals among the soil organisms, in fact mainly the activities and efficiency of earth worms (Blume, 2011).

The organic C in the surface 5cm of the forest soil increased linearly during 5 years of exposure to elevated CO<sub>2</sub>, while C in the ambient plots remained relatively constant. No significant changes in the soil C were found at deeper depths for either elevated or ambient CO<sub>2</sub> as shown in Figure 8. Consistent with vegetative effects on soil formation, increases in soil C storage, particularly in forests, are more likely to occur near the surface, where inputs from roots and above ground litter are greatest. If we sampled to 15cm in one increment, the C accrued in the surface 5cm would have been diluted with the unchanged C pool at 5 to 15 cm and we would not have detected a significant change (Jastrow *et al.*, 2005).

The atmospheric carbon dioxide had significant effect on soil properties after 5 years of cropping system but varied for the two different cropping systems, for soil carbon, a significant cropping system by carbon dioxide interaction was noted. In this case, soil carbon was unaffected by elevated CO<sub>2</sub> in the sorghum system. In the soybean cropping system, elevated CO<sub>2</sub> increased soil carbon significantly as shown in Figure 9.



Because that CO<sub>2</sub> enrichment had more effect on increasing soybean residue compared with sorghum to the soil (Prior *et al.*, 2003). Similarly carbon dioxide increases the soil carbon as reported by Shakiba (2000).

In conclusion, higher temperature speeds up the natural decomposition of OM and soil degradation processes, accelerate the cycling of carbon, nitrogen, phosphorus, potash & sulphur in the soil – plant – atmosphere system, Increase the process of nitrogen fixation due greater root development. Higher rainfall Increase the vulnerability to water erosion, leaching rate, causes temporary flooding or water saturation, hence OM decomposition reduces. Lower rainfall increases the vulnerability to wind erosion, Suppress both root growth & deposition of organic matter and it increases the salt accumulation. Higher CO<sub>2</sub> concentration increases the photosynthetic rates and also it increases the water use efficiency of crops, hence increase in organic matter supplies to soils. Increase CO<sub>2</sub> would tend to counteract adverse effects of temperature rise, such as increased night time respiration. Increases productivity is generally accompanied by more litter or crop residues, a greater total root mass and root exudates, increases mycorrhizal colonization and activity of other rhizosphere or soil microorganism, positive effect on N supply to crop. Increases microbial and root activity in the soil would entail higher CO<sub>2</sub> partial pressure in soil air and CO<sub>2</sub> activity in soil water, hence increased rates of plant nutrient release from weathering of soil mineral. Mycorrhizal activity would lead to better phosphate uptake. Increased production of root material (at similar temp) tends to raise soil organic matter content. Temporary immobilization and cycling of greater quantities of plant nutrients in the soil. Higher C/N ratios under high CO<sub>2</sub> condition cause slower remobilization of plant nutrients from the litter and uptake by the root.

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