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Impacts of Climatic Changes and Water Use Deficit on Contribution of Integrated Soil Fertility Management, Nutrients Gradient: A Review

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ABSTRACT

Global climatic has been changed and will continue to change because of the activity of unreasonable controlled of human activities, which gradually increase the concentrations of greenhouse gases in the atmosphere. Population is gradually increased at the same time and due to climate change, soil and water resources is threastened due to natural resource degradation. Many reports, by IPCC has clearly stated that warming of the climate system is unmistakable and it is very likely caused by natural and human activities. Climatic changes always affect hydrological cycle components, such as precipitation, evapotranspiration, temperature, stream flow, ground water and finally surface runoff, and may have stronger or weaker, permanent or periodical, favorable or unfavorable, harmful, direct or indirect impact on soil processes. Climatic changes will result in stimulated floods and drought, which will have significant impacts on the soil and the availability of water resource availability. Soils are linked to the climatic system through cycles of nitrogen, the carbon, and hydrologic. Because of climatic changes, soil processes and their characteristics will gradually be affected, by changing in temperature, that causing changes in global amounts of rainfall and their distribution patterns. Temperature and water are very important factors influencing the processes of soils, which causing changes in the soils throughout the world. Managements of water resources can affect on the counter balance of climatic changes on stream flow and water availability at certain level. This review studies the impacts of climate change on soil, water resources. Studies also dealing on hydrological responses to climate change, and possible adaptation options in the realm of climate change impacts on soil and water resources. Deficit of soil moisture affects crop productivity through its influence on the availability and transportation of nutrients which gradually increases vulnerability to nutrient losses from the rhizosphere soil by erosion. Nutrient elements are carried by soil moisture to the roots. Decreasing moisture in root zone resulted in decreasing nutrient diffusion and their availability, consequently decreasing mass flow of water-soluble nutrients such as nitrate, sulfate Ca, Mg and Si over longer distances. Roots extend their length, gradually increase their surface area and alter their architecture in an effort to capture less mobile nutrients such as phosphorus. Reduction of root under drought conditions reduces the nutrient acquisition capacity of root systems. Also reduce both carbon and oxygen fluxes, furthermore minimize the accumulation of nitrogen in root nodules particularly, in legume crops, furthermore, alters the composition and activity of soil microbial communities like the reduction of soil nitrifying bacteria.

Keywords: climate change, soil formation, elevated carbon dioxide, root adaptation, nutrient gradients, crop yield.

1. Introduction

Peter, (1993) reported that about 97.5% of the water on earth is salt water presented in the seas and the oceans. However fresh water accounts about 2.5%, about 68.6% of it is in the form of ice and permanent snow cover in the Arctic, the Antarctic, and mountain glaciers. 30.1% is in the form of fresh groundwater. About 0.3% of the fresh water on Earth is in easily accessible lakes, reservoirs and river systems Fig. (1).

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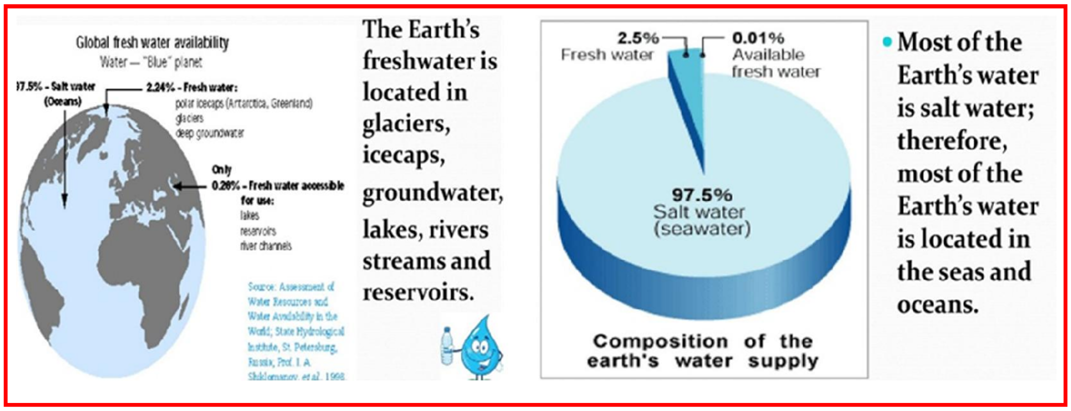


Fig. 1: Represents the distribution of water on the earth

IPCC, (2014) reported that the effects of climate change on the quantity and quality of water resources has attracted a great deal of attention, particularly at a regional and global scale Fig. (2).

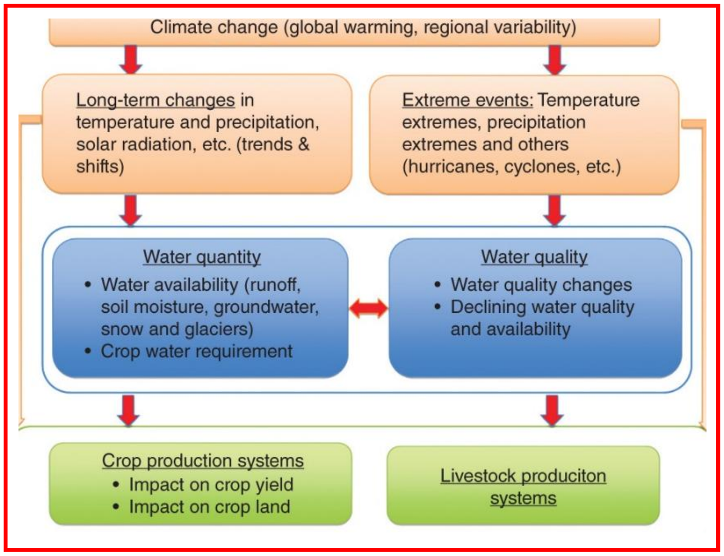


Fig. 2: Illustrates a framework to assess climate change affects water quantity, quality, and agricultural production systems

The most recent report from Intergovernmental Panel on Climate Change (IPCC) indicates that average global temperature will probably increase between 1.1 and 6.4°C by 2090–2099 comparing with 1980–1999 temperatures, with increasing between 1.8 and 4.0°C. Most dominant climate drivers for water available are precipitation, temperature and evaporative demand (determined by net radiation at the ground, atmospheric humidity and wind speed, and temperature). Brevik, (2012), stated that climatic changes would have effects on the environment, which including soils, which are also important to food security Lal, (2010); Blum and Norcliff, (2013) and Brevik, (2013). Climate change has the potential to threaten food security through its effects on soil properties and processes Brevik, (2013). Changes in rainfall and temperature have a direct effect on the amount of evapotranspiration and both quantity and quality of the surface runoff. Consequently, the spatial and temporal availability of water resources, and can be significantly altered with any changes in temperature. Water and food security are the key challenges under climate change as both are highly vulnerable to continuously changing climatic patterns Fig. (3).

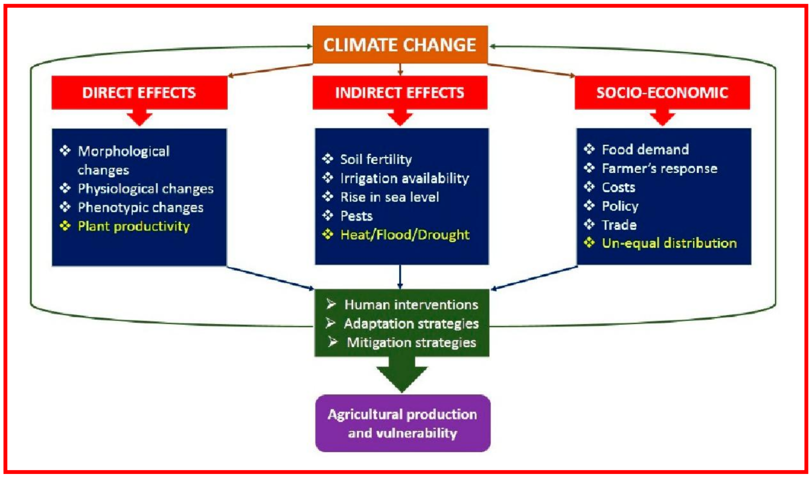


Fig. 3: Direct, indirect and socio-economic effects of climate change on agricultural production.

Batino and Waswa, (2011), reported that Africa is one of the world's driest continents that facing a severe water crisis. Over 90% of Sub-Saharan Africa agriculture is rainfed, particularly, under smallholder management, by 2050 rainfall may be drop up to 10%, that would reduce drainage by about 17% Anil, 2014) Fig. (4). Although most studies have been confined to modeling hydrological responses to climate change Warburton *et al.,* (2011), stated that land use and land cover play a significant role in controlling hydrological responses.

Fig. 4: Right photo represents water crisis facing the South African city of Cape Town, people in the Ha Makuya community go without potable water for months, however Egyptian farmer tries to irrigate his land with water from a well.

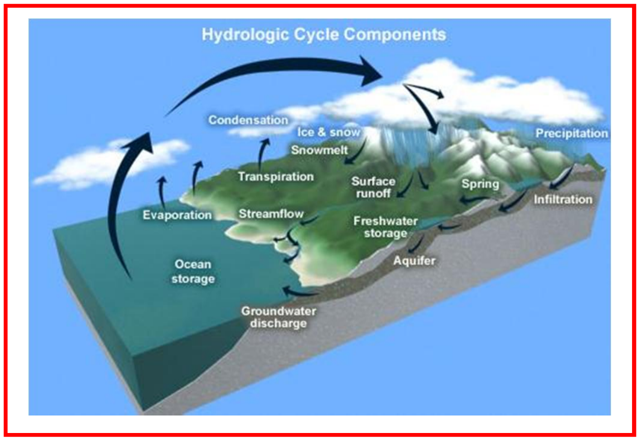


Fig. 5: Represents the hydrological cycle, After: GOESR (2014)

USGS (2011) describes the hydrological cycle that water movement from the movement of water from surface and ground into the atmosphere and back again by various mechanisms namely as condensation, precipitation, infiltration, run off and evaporation, since solar energy is the mainly force driving the hydrologic cycle. Due to solar radiation, consuming Earth's surface's about half of for water evaporation. Sun acts as a massive water pump, elevating water into the atmosphere. Fig. (5), similarly, water leaves the soil and the leaves of plants and trees through evaporation and transpiration respectively Pal *et al.,* (2014); USGS (2011). Water vapour have lower density than some major components of the atmosphere like O_2 and N_2 rise higher. As the water gains more altitude, the pressure decreases. This decrement in pressure causes the water vapour to condense, as clouds and eventually falls as precipitation (rain, snow, hail, etc.). Furthermore, flows on the surface of the earth is known as surface run off and come back into rivers, oceans etc. Pal *et al.,* (2014); USGS (2011). It is important to note that not all runoff flows into rivers and oceans, some run into the ground as infiltration replenishing aquifers. Over the years, some ground water seeps back to the surface and run into rivers and oceans which is then evaporated and the water cycle repeats itself again and again Pal *et al.,* (2014); USGS (2011).

Moreover, Warburton and Schulze, (2005) reported that stream flow is influenced by numerous other human activities such as catchment land use changes, inter-basin water transfers, water abstractions, return flows or reservoir construction. Astaraie (2012) reported that influences of urbanization that considered as one of the causes of poor water quality today, most urban catchments in the world. Kazemi (2011) stated that urbanization could change in the land use Fig. (6). Doulatyari (2014) stated that because of increasing the population and human activities progressively increasing the waste outcomes include obstruction of water flows leading to flooding; alterations of watercourse leading to increases runoffs; or even transportation of dissolved litter, organic matter, Heavy metals which generally affects the water hydrology and water quality within a given catchment. Ephraim *et al.,* (2014) showed that rapid increase in some urban areas gradually increasing sewage problems within the area, however with increasing borehole constructed in order to provide drinking water are major causes of concern, contributing to the high levels of ground water contamination. Sohoulande and Singh (2016) stated that climatic changes will have major effects on precipitation, evapotranspiration, and runoff and furthermore, on the nations water supply, This review describes the brief impacts of climate change on soil and water resource and their future adaptation strategies.

Fig. 6: Illustrates impact of urbanization impacts on poor water hydrology. After: Astaraie (2012).

2. Climate change and water resources

2.1. Water cycles

IPCC, (2014) describes water cycles as a dynamic process of water masses (liquid, vapor or solid), which circulated, move and finally stored within the earth system. These processes gradually continuous among ocean, atmosphere and land. The main components of water cycle are the precipitation, evaporation, runoff, groundwater, and soil moisture, and always characterized with changes in atmospheric temperature and radiation balance. Water cycle is one of the main components of the planetary system regulating human, animal and plant life. Such cycle forms the foundation of other cycles, such as carbon cycle, nitrogen cycle. Therefore, water cycle is critical for the sustainability of other biological populations and ecosystem. Stability of the hydrologic cycle is being threatened by climatic changes which empirical observations allude that, human civilizations developed along the banks of major rivers, primarily because of easy access to usable water. Mithen and Black, (2011); reported that most major cities of the world have major rivers flowing through them, therefore the engineering of water resources systems has played a critical role in the birth and growth of several ancient civilizations. Technologies of water engineering count is important among the factors, which have favored the demographic growth during the last century. However, the demographic growth has worsen pressure particularly on land use, water, and natural resources. Huntington, (2006), reported that, results of such actions has been drastic for the natural environment and the terrestrial climate system, as well affected the water cycle, because of climate changes a remarkable hydrologic alteration have been observed. Climatic Changes alter in the hydrologic cycle have become more frequent in the terrestrial ecosystems. Changes are expressed by abnormal frequency of both water crisis and hydrologic hazards which impact extend to economic, social, political and cultural sectors, so that engineering cannot controlled the changes in the water cycle. Hanjra and Qureshi, (2010), stated that changes are consider as alarming threat for the stability and sustainability of human societies and natural ecosystems before, prolonged deficits of water budget might contribut to different scenarios, such as decline of civilizations, desertification phenomena, and sometimes extinction of ecological systems. Under natural environment such as vegetation can perfectly manage the water hydrology, however, urbanization stop vegetation and animal trampling river banks results to massive of pollutants material of these sediments into attached waters. In most cases, pollutants attach themselves to sediments and are transported down steam. This blocks sunlight into the water, obstructing and contaminating the water and often results in flooding and poor water quality. Toxic chemicals: which include chemicals from diffuse pollution from various activities within the catchment, Monaghan, (2009). Today, substantial concerns about the future of the planet and the society, since the Earth has been facing serious and repeated water cycle issues for the past few decades. Climate change and its impact have increased considerably during the past decade.

2.2. Water resources

Increasing temperature and reducing rainfall may reduce stream flows in major catchments, reducing the recharge of groundwater, and furthermore causing droughts. Water resources are particularly vulnerable to increased temperature and alternations in precipitation patterns; water precipitation is the main driver of variability in the water balance on global earth. Changing in precipitation has very important for hydrology and water resources. Several reports, by IPCC, (2014) stated that particularly in subtropical regions, climatic changes are reduceding renewable surface water and groundwater resources in the 21st century which intensifying competition for water among sectors. Several reports stated that changes in surface runoffs and groundwater flows in shallow aquifers are part of the hydrological processes such as lakes and reservoirs, that can be affected by climatic changes Tao *et al.,* (2003a, b); Hyvarinen, (2003); Walter *et al.,* (2004), Milly *et al.,* (2005). IPCC, 2014. Kevin and Nicholas (2010), stated that climatic changes significantly affected water resources through increasing the temperatures of surface resulting a melting of snow and glaciers, and furthermore high sea level. In addition, extreme weather events such as phenomena of droughts and floods. The potential impact of climatic changes on water resources particularly, in Africa, including flooding, drought, change in the frequency and distribution of rainfall of rivers, melting of glaciers, receding of water bodies, landslides, and cyclones among others. The relation between the changes in temperatures, precipitation patterns, will have various impacts on river flows, groundwater recharge, lake levels, as well as Fig. (7), (8), (9). Munang *et al.,* (2013), reported that, economies of most of developing countries depend on climate-sensitive sectors such as water, agriculture, fisheries, energy and tourism, climate change therefore poses a serious challenge to social and economic development in developing countries.

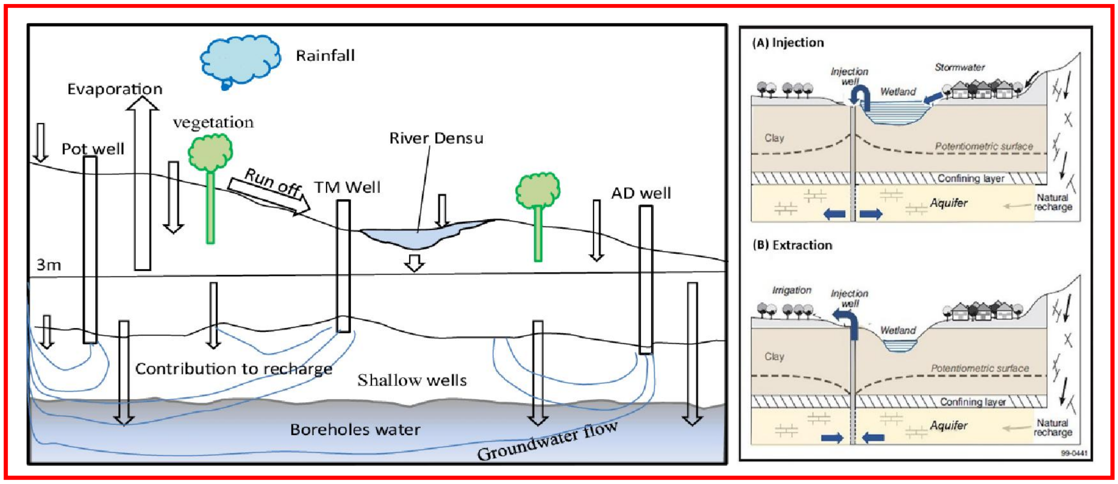


Fig. 7: Illustrates the conceptual diagram of the groundwater recharge processes and groundwater flow in the Densu River basin

Fig. 8: Illustrates impact of climatic changes on groundwater, since groundwater naturally fills "aquifers" layers of porous rocks and sediment that can hold water, and used as a source of drinking and irrigation water, in Densu River Basin, Ghana.

Fig. 9: Represents ground water using for agriculture in Siri Lanka

3. Causes of climate change

Several researchers among them Kondrat′ev *et al.,* (2003); Blasing, (1985), reported that climatic changes are not a new occurrence, through different geological epochs, the global of climate has changed in different ways. Changes took place gradually over centuries, and observed during last century and become more rapid. These changes are not driven by natural factors but are more embedded in the global carbon cycle, referring to exchange of carbon between the lithosphere, the biosphere and the atmosphere. Kondrat′ev *et al.,* (2003); Jepma and Munasinghe, (1998), stated that during the last century anthropogenic emission emanating from fossil energy sources and industries, combined with land use change, have disrupted the natural equilibrium existing within the different components of the global carbon cycle Fig. (10). the biogeochemical cycle in which carbon is exchanged between Earth's terrestrial biosphere, hydrosphere, geosphere, and atmosphere is called the carbon cycle. The global carbon budget is the balance of the fluxes of carbon between these four reservoirs. The terms source or sink define whether the net carbon flux is out of or into the reservoir, respectively.

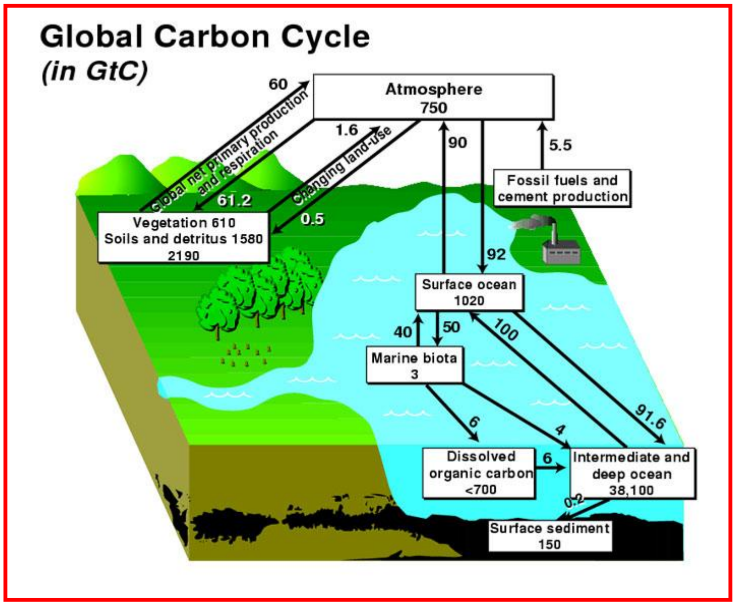


Fig. 10: Represents the schematic representation of the global carbon cycle, showing the stores of carbon and the fluxes (exchanges) of carbon between them. Note: GtC= gigaton of carbon.

The carbon cycle is important to understand climatic changes because it includes two of the most important greenhouse gases such as carbon dioxide (CO_2) and methane (CH_4). Most atmospheric carbon is in the form of CO_2, while CH_4 is present only in trace concentrations. Carbon dioxide (CO_2) is chemically inert gases, and mixed within the atmosphere away from forest canopies. However, methane (CH_4) is active and oxidized to carbon dioxide and water that quickly removed from the atmosphere. The overall atmospheric concentration of these greenhouse gases has increased during the past century and contributed to global warming. Carbon is removed from the atmosphere through: the photosynthetic conversion of carbon dioxide into carbohydrates by plants, releasing oxygen in the process; the formation of carbonic acid as circulating ocean surface waters cool near the poles, thereby, absorbing more atmospheric CO_2;

- The conversion of reduced carbon to organic tissues or carbonates to hard body parts, such as shells, by marine biota in ocean surface waters.
- The reaction between carbonic acid and silicate rock that leads to the production of bicarbonate ions, which are carried to the ocean and eventually deposited in marine carbonate sediments.

Carbon can be input to the atmosphere by a variety of processes, including:

- Plant and animal respiration, an exothermic reaction that involves the breakdown of organic molecules into CO_2 and water;
- Decay by fungi and bacteria that break down carbon compounds in dead animals and plants and convert the carbon to CO_2 if oxygen is present, or methane if not;
- Organic matter combustion (including deforestation and burning fossil fuels), which oxidizes carbon-producing CO_2;
- Cement production, when limestone (calcium carbonate) is heated to produce lime (calcium oxide), a component of cement, and CO_2 is released;
- Release of dissolved CO_2 back to the atmosphere through warming of surface ocean water; and
- Release of water vapor, carbon dioxide, and sulfur dioxide from volcanic eruptions and metamorphism.

Inorganic carbon is exchanged between the atmosphere and ocean. Carbon is released to the atmosphere at oceanic through the mechanisms that dissolved carbon oxides by upwelling and down sites Fig. (11), such mechanisms are important for controlling the pH of ocean water. When carbon (CO_2) enters the ocean, carbonic acid is formed by the reaction: $CO_2 + H_2O = H_2CO_3$. Carbonic acid dissociates to form bicarbonate ions (HCO_3^-), the form in which most of the carbon in the oceans exists; lesser amounts of carbon exist as carbonic acid (H_2CO_3 or dissolved CO_2), and carbonate ions (CO_3^{-2}) paired with calcium and magnesium and other cations. Most of marine organisms build up their skeletons and shells out of the minerals calcite ($CaCO_3$) through the incorporation of bicarbonate ions. These phenomena created by dissolving from death of the organism, others settles to the sea floor which can be buried and stored as limestone.

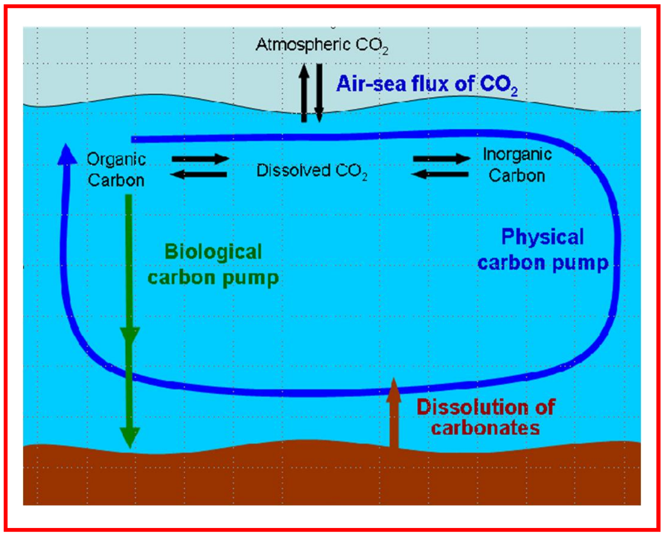


Fig. 11: Illustrates the oceanic carbon cycle, including air-sea flux, biological pump, physical pump and dissolution of carbonates.

Carbon is an essential part of life on the earth, which plays an important role for all living cells, such as in the structure, biochemistry, and nutrition. Autotrophs are organisms that produce their own organic compounds by using carbon dioxide from the air or water that they live in. Requiring an external source of energy, such as solar radiation (photosynthesis), or chemical energy (chemosynthesis). Trees, forests, and phytoplankton are the most important autotrophs in air and ocean for consuming the carbon, respectively.

Large quantities of carbon transfer between atmosphere and biosphere on short time during photosynthesis. The following reaction represent respiration as follow $CO_2 + H_2O = CH_2O + O_2$ amount of energy equivalent is released as heat. Oxygen is present, an aerobic respiration occurs, which releases carbon dioxide into the surrounding air or water. Anaerobic respiration occurs and in the absence of oxygen, producing methane gases to environment, which eventually makes its way into the atmosphere or hydrosphere. The biosphere is capable of storing ~10% of atmospheric carbon at any given time. However, carbon storage in the biosphere is influenced by a number of processes on different time-scales: while follows seasonal and annual cycles, carbon can be stored up to several hundreds of years in trees and up to thousands of years in soils. Changes in those long-term carbon pools may thus affect global climate change.

IPCC, (2014), reported that human activities have generated huge quantities of greenhouse gases (GHGs) and aerosols in the atmosphere, resulting a considerable concentration in the atmosphere. Moreover, considerable forestlands have been changed because of urbanization, expansion of agricultural lands, wood industry and wildfires. IPCC, (2013); Blasing, (1985), reported that natural reservation process controlled by photosynthetic activities of plants are disturbed and significantly minimized, resulting in significant alterations of the atmospheric energy balance. Moreover, the situation is aggravated by increasing of solar radiation flux, particularly in the absent of ozone layer depletion, explaining the actual increase of the global temperature Figure (10). The GHGs causing the increase in temperature or global warming are carbon dioxide (CO_2), followed by methane (CH_4), nitrous oxide (N_2O), and ozone (O_3).

3.1. Impact of climatic changes on precipitation and recharging groundwater

Increasing heat is the only primary physical expression of climatic changes on the earth system. In addition to that, increasing atmospheric moisture content is a consequence of more oceanic evaporation due to the increase of sea surface temperature discerning the effect of increasing heat on precipitation is not systematic phenomenon. However, the terrestrial water cycles are unclear yet. The impact of climate change on precipitation is experienced in different ways across the globe. Tu *et al.,* (2009), reported that annual precipitation scenarios present heterogeneous trends, depending on the latitude band. However, the more frequent impact is probably the high disorder in precipitation patterns. The recurrence of typhoons in the Asia-Pacific region has been linked with climate change particularly, during the last decades, as well as tropical cyclones has intensified in the North Atlantic during the last three decades and important socio-economic damages have been reported in the North and Central American countries Fig.(12).

Fig. 12: Diagram represent the relation between anthropogenic activities and tropical cyclone impacts as experienced in the 2017 Atlantic Hurricane Season.

Several regions facing consistent of alterations of the regular precipitation patterns. Such alterations can be clearly noted in terms of changes in case of frequencies of the precipitation events, prolonged dryness, decrease in the number of precipitation and increasing of extreme precipitation. The impacts of these disturbances are significant for the society. The impact of climatic changes in precipitation pattern often causes an important agricultural loss. Fig. (13), the persistence of low precipitation is risked on the sustainability of groundwater, since it is often utilized as an option to overcome the deficit of water supply. Whereas, the option of using groundwater has resulted in serious depletion issues. Subsequently, there are more policies aiming to regulate the groundwater across the globe. Impact on groundwater system may by referring to its quality, quantity, and functionality. These cannot be dissociated because of the consistency of their mutual effects. Such phenomena is more a pool of sub consequences related to low precipitation, persistent drought, and l degradation of land cover. Under natural systems, groundwater plays a vital role, as it sustains stream flow Fig. (14). Groundwater is particularly the main supplier of water during periods of non-precipitation systems. Under rainy season, the stream flow behavior balanced by stream flow and base-flow. However, unbalanced condition are often resulted in low-flow regime and impairments. Therefore, sustainability of aquatic life depends on the ground water flux extremely

Fig. 13: Illustrates, some agricultural losses due to impact of climatic changes in precipitation pattern

Rechargeable of groundwater is controlled by several factors among of these, soil physical properties which are verey important for penetration of precipitation water through the soil profile (infiltration), land-cover, and precipitation. Through disturbances of climate change, e.g., precipitation regime in combining with land-cover degradation, significantly alter ground water recharge. Increasing of runoff and exceptional discharge peaks are clustered in short periods. However, in the long run, water supply becomes difficult for streams, since groundwater is not recharged adequately. As groundwater is directly consumed for irrigation, domestic and industrial can be used. Therefore, using of groundwater has become an option for compensating for water deficit Fig. (14).

Fig. 14: Illustrates groundwater is particularly the main supplier of water during periods of non-precipitation

3.2. Impact of climatic changes on evapotranspiration

Evapotranspiration is considered as a critical component of water cycle, and its rate depending on functionality of biophysical, and their amounts determinant for the local climate. Sohoulande Djebou *et al.,* (2015) reported that relation between both evapotranspiration and precipitation particularly, for long time governed and affected the gradient of both aridity and land-cover features. The relation between evapotranspiration and precipitation created the local climate. Increasing evapotranspiration and reducing precipitation gradually increasing aridity condition Fig. (15).

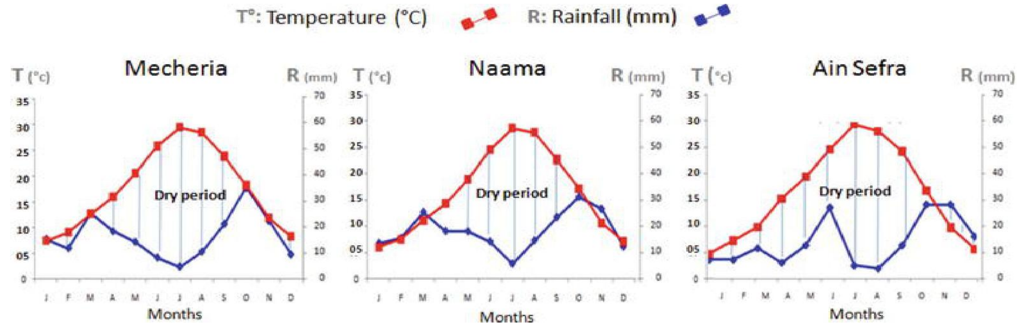


Fig. 15: Illustrates comparison between the two periods (1913–1938) and (1990–2014), to observe a period of drought varies from 5 to 7 months in the resorts of the northern in Naâma Region (Algeria). After: Abdelkrim *et al.,* (2021)

Climatic changes can increase the global temperature that affects the atmospheric water demand directly. Therefore, actual moisture release in the atmosphere is higher than normal. Water vapor in the atmosphere resulted from the pressure exerted on soil moisture, water bodies, transpiration of the plant, particularly, under longer term.

3.3. Impact of climatic changes on drought stress.

Drought considers as a deficit of water relative to need, due to insufficient water supply, resulting from low precipitation and high evapotranspiration. Four types of drought including hydrologic, agricultural and economic. However, the hydrologic, agricultural and economic droughts are often the impact of meteorological drought. Its occurrence is due to less precipitation thresh-old derived from a long-term record at least 30 years. The concept of drought is challenging, due to the impact of drought varies depending on the region. However, several drought indices have been devised in order to assess drought severity. Although several indices are proposed for drought measurement. *The standard precipitation index (SPI)* and the Palmer drought severity index (PDSI) are the most frequently used. However using the computation of these indices are rather difficult, they have triggered drought assessment and helped the depiction of drought across the entire globe. Several regions of the globe have revealed persistent droughts with rare severity. Westerling and Swetnam, (2003) stated that repeating of droughts phenomena and their preferential measure during the last decades are evidence of profound changes in the global climate system. Consequently, the droughts persistent for the society as well as the environment are considerable, also reported that the deficit in municipal water supply, drought may increase the risk of wildfire and contributes to the ecological extension reported by Condit, (1998); Ehrlich *et al.,* (1980).

Aridity index (AI), is defined as the ratio of annual precipitation to annual potential evapotranspiration, and the decrease in AI denotes drying trends and vice versa. The AI is a comprehensive index for water availability in dry lands. Drying and wetting trends are widespread climatic phenomena in a long time series Sheffield *et al.,* (2012), He *et al.,* (2019), which substantially affect plant growth and vegetation cover in global dry lands Feng and Fu (2013), Huang *et al.,* (2015). Increasing aridity would decrease soil water availability, thus limiting photosynthesis and ecosystem carbon sequestration Peng *et al.,* (2013), Doughty *et al.,* (2015), Frank *et al.,* (2015), and Xu *et al.,* (2019) Fig.(16). In contrast, dry lands can rapidly become large carbon sinks in wet years as vegetation productivity increases because soil water is less constrained (Poulter *et al.,* 2014, Chen *et al.,* 2021).

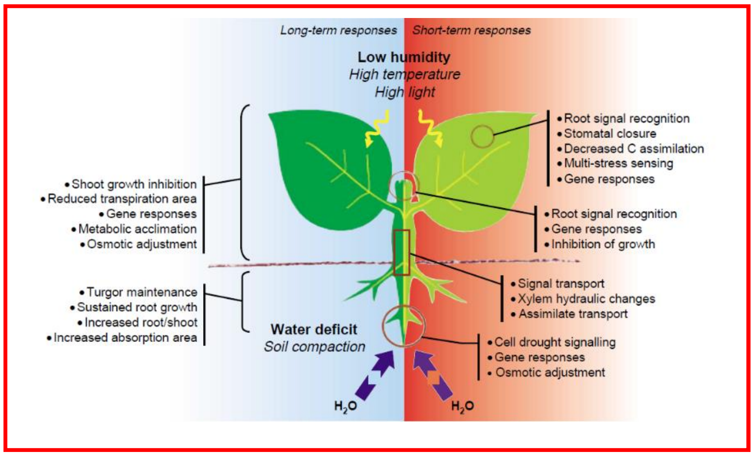


Fig. 16: Illustrates plant responses to water stress. After: Santos *et al.,* (2009)

Recent research has indicated that 'Vegetation decline', which can be observed in satellite data, is a key feature in the first stage of ecosystem transition (Berdugo *et al.,* (2020). Differences in the direction and magnitude of the vegetation productivity response to long-term drying and wetting trends along the spatial aridity gradient are not clear. Therefore, clarifying the trajectory and magnitude of vegetation activity in dry lands, in response to changes in the temporospatial.

Aridity index (AI), could improve terrestrial carbon cycle predictions under aridity changes and provide an early warning signal of the ecosystem transition Fig. (17). Dry lands account for 40% of the world's land area and provide support for 38% of its population Smith *et al.,* (2019), Li *et al.,* (2019b), their geographical extent varies over time largely because of climate change Feng and Fu (2013), Huang *et al.,* (2017). By the end of the 21st century, the area of dry lands is projected to increase by 10% over that evident in 1961–1990 Feng and Fu (2013), and aridity strengthening would result in half of the global land surface being covered with dry lands Huang *et al.,* (2017).

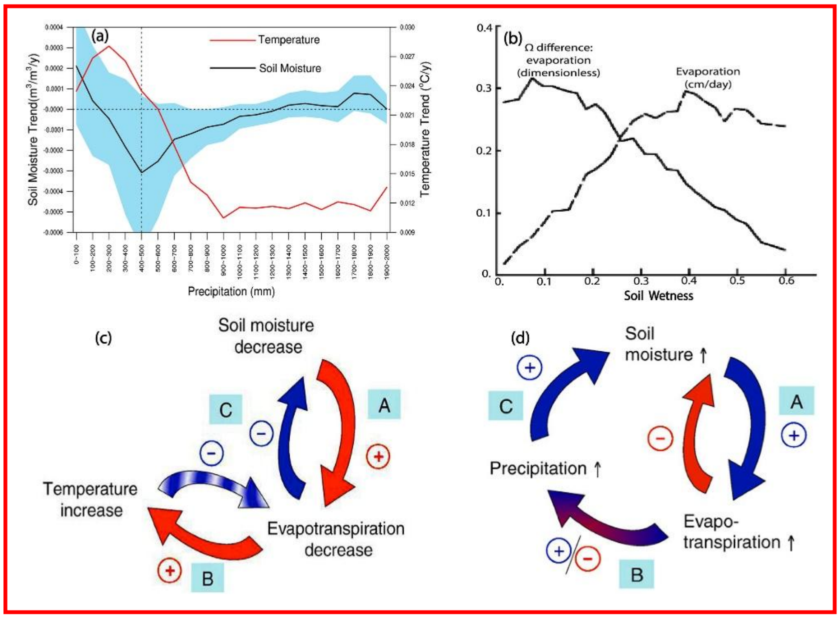


Fig. 17: Illustrates linear trends in annual-mean temperature and soil moisture as a function of climatological mean precipitation over East Asia. The black line denotes the domain average for various climatic regions, and shaded bands denote one standard deviation of the soil moisture trend. Cited from Cheng *et al.,* (2015). (b) Average relationship between soil wetness (the degree of saturation in the soil) and two separate aspects of the land-surface energy budget: the Ω difference for evaporation (a dimensionless measure of soil moisture-precipitation coupling, solid curve) and the average evaporation rate (dashed curve; in cm/d). Cited from Koster *et al.,* (2004). (c) Processes contributing to soil moisture-temperature coupling and feedback loop. Positive arrows (red) indicate processes that lead to a drying/warming in response to a negative soil moisture anomaly and blue arrows denote potential negative feedbacks. Cited from Seneviratne *et al.,* (2010). (d) Processes contributing to soil moisture-precipitation coupling and feedback loop Positive arrows (blue) indicate processes leading to a positive soil moisture-precipitation feedback (wetting for positive soil moisture anomaly, drying for negative soil moisture anomaly). The negative arrow (red) indicates negative feedback damping the original soil moisture anomaly, and the red-blue arrow denotes both positive and negative feedbacks between evapotranspiration and precipitation anomalies. A, B, and C show the different steps of the feedback loop. Cited from Seneviratne *et al.,* (2010).

Furthermore, Sheffield *et al.,* (2012) observed a mixture of wetting and drying trends because of the increase in potential evapotranspiration in 58% of the land area and a decrease of 42% in the rest area. For example, central and western Asia experienced drying trends from 1980 to 2008, whereas northern Asia became wetter Li *et al.,* (2015), El Kenawy *et al.,* (2016). Moreover, the average effects of the opposing smaller-scale trends within a region Zeng *et al.,* (2017) always counteracted the magnitude of the land-atmosphere feedback. Little change has been observed in aridity trends due to this tradeoff between regions that are experiencing wetting and regions that are witnessing drying Greve *et al.,* (2014). Regional heterogeneity of drying and wetting trends resulted in the mean weak aridity trends and the complicated interplay between climate change and vegetation activity. The pattern of drying or wetting trends of dry land subtypes (hyper-arid, arid, semi-arid, and dry sub-humid regions) with different aridity level is uncertain. Dry lands play a dominant role in determining the trends and variability of global terrestrial carbon sinks Ahlström *et al.,* 2015, Poulter *et al.,* (2014), and Smith *et al.,* (2019). The expansion of dry lands decreases carbon sequestration and exacerbates the risk of ecosystem degradation Huang *et al.,* (2015).

Aridification led to abrupt changes in plant productivity at aridity value of 0.54 to identify the systemic ecosystem changes Berdugo *et al.,* (2020). The alleviation of aridity increased vegetation growth over global dry lands He *et al.,* (2019), but the patterns varied among climate zones and biomes Xu *et al.,* (2018). Vegetation activity responds more rapidly to drying trends in arid biomes than in semi-arid or sub-humid biomes Vicente-Serrano *et al.,* (2013). Vegetation productivity is affected by aridity conditions, depending on their resistance to and resilience during long-term climate change Schwalm *et al.,* (2017). Vegetation productivity dynamics tend to exhibit nonlinear responses to hydro climate change in dry lands Berdugo *et al.,* (2020), Smith *et al.,* (2019). These are characterized in part by inconsistencies in the response of the ecosystem to climate change over periods ranging from years to decades Walker *et al.,* (2020) and by asynchronous inter-annual variability at seasonal or longer temporal resolutions Piao *et al.,* (2019). Carbon loss due to less water availability could be compensated for by the subsequent growth increase in wetter periods Jiang *et al.,* (2019), Chen *et al.,* (2020). Regional differences could be accounted for by different responses in dry lands and humid lands Huang *et al.,* (2015). Therefore, the response of vegetation growth to drying and wetting trends was constrained by the spatial aridity conditions, but the evolutionary trajectory of vegetation activity to temporo-spatial aridity variation in dry lands is not fully understood.

4. Impact of climatic changes and soil resources

FAO and ITPS, (2015), reported that soils facing the global environmental change and therefore we need to predict and know the climatic changes , vegetation, erosion and pollution, requiring better, understanding of the role of soils in the earth system, and continue to provide for humanity and the natural world Schmidt *et al.,* (2011). Soils play a fundamental role in the maintenance of a climate favorable to life. Soil processes helps to regulate climatic changes, including the thermal and moisture balance, greenhouse gases (H_2O, CO_2, CH_4 and N_2O) and particulates in the atmosphere, and can adversely influence the maintenance of air quality Fig. (18).

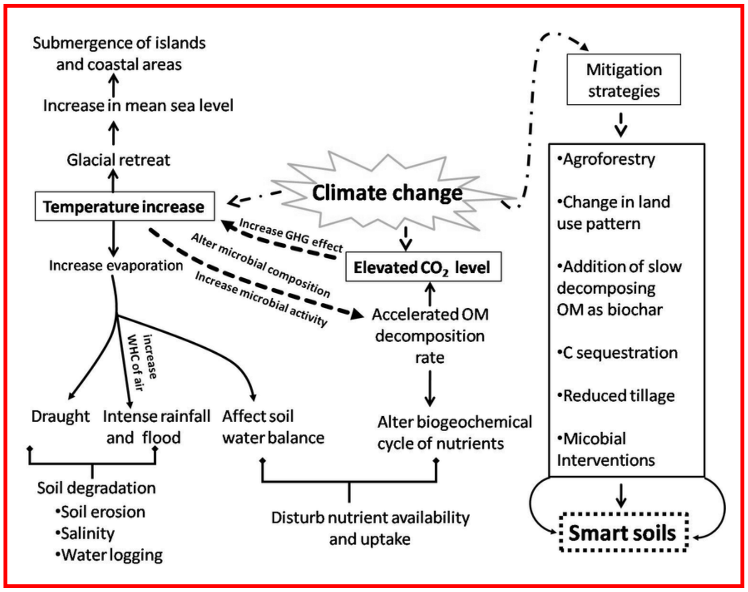


Fig. 18: Illustrates various natural processes as affected by climate change and soil-based management strategies for resilience

About 10% of all greenhouse gas emissions related to soil organic matter. FAO, (2014), stated that conservation of land use particularly, of organic soils are responsible for greenhouse gas emissions. Agricultural lands are affected by climatic changes FAO, (2014). Carbon is fixed by plants through photosynthesis and transferred to the soil, creating a substrate that soil microorganisms respire back to the atmosphere as carbon dioxide or methane depending on the availability of oxygen in the soil. The microorganism, resulting in a short residence time, gradually digests carbon compounds easily Fig. (19). However, others become stabilized in soils and have longer residence times. Soil organic carbon can also be thermally decomposed during fire events and returned to the atmosphere as carbon dioxide. Remaining charred material can persist in soils for long periods Lehmann *et al.,* (2015); soils can be a source of carbon and sink. Therefore, soils can contribute to regulate carbon cycle and effects on climate change. Changes in land use constitute the driving force that determines the soil's role as a source or as a sink of carbon. The impacts of climate change on soils are influenced by soil organic carbon.

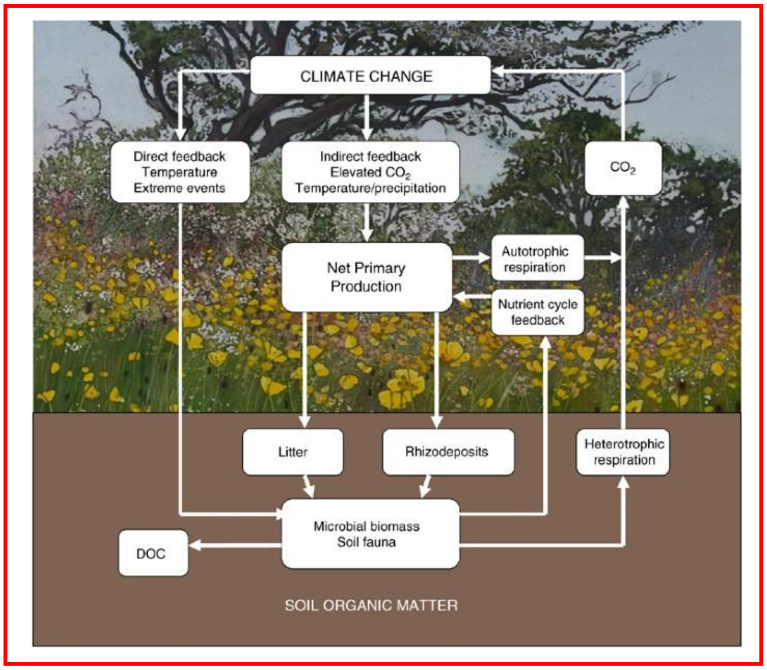


Fig. 19: Illustrates direct and indirect effects of climate change on soil microbial communities and routes of feedback to global warming through carbon dioxide production. Direct effects include the influence on soil microbes and greenhouse gas production of temperature, changing precipitation and extreme climatic events, whereas indirect effects result from climate-driven changes in plant productivity and vegetation structure which alter soil physicochemical conditions, the supply of carbon to soil and the structure and activity of microbial communities involved in decomposition processes and carbon release from soil. After: Richard *et al.,* (2008)

Tamene and Vlek, (2008) reporting that increasing of temperature may cause a higher decomposition rate of the OC, that create an increasing drought which have the opposite effect.

4.1. Soils carbon sequestration

Carbon and nitrogen are major components of soil organic matter, which are integral parts of several nutrient cycles. Brady and Weil, (2008) stated that both carbon and nitrogen are the most important from the viewpoint of soils and climate change interactions are the carbon and nitrogen cycles. Due to both carbon and nitrogen are the most important components of soil organic matter and because carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are the most important of the long-lived greenhouse gases, Hansen *et al.,* (2007). Climate change and its hydrological consequences may result in the significant modification of soil conditions. FAO and ITPS, (2015), soil health in relation to climate change should consider the impacts of a range of predicted change drivers such as increasing of atmospheric carbon dioxide (CO_2) levels, increasing temperature, altered precipitation and deposition of nitrogen, on soil chemical, physical and biological functions soil is the second largest carbon store, after the oceans Fig. (20).

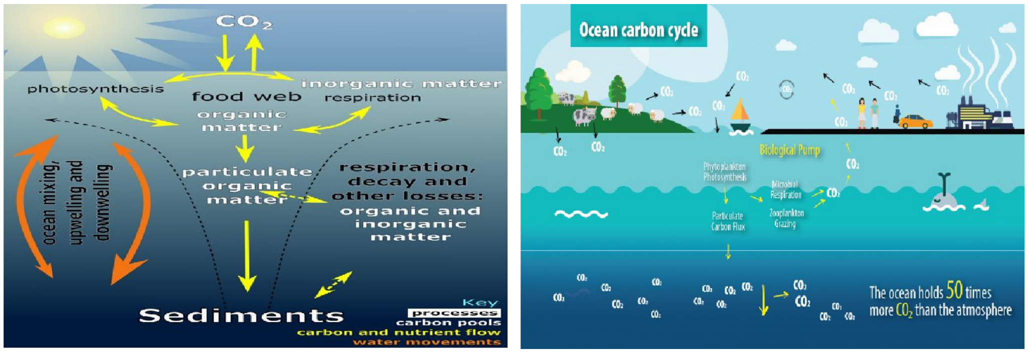


Fig. 20: Illustrates the ocean biological carbon pump, comprising photosynthesis, food web interactions and gravity, results in removal of carbon from the surface ocean and its transport through the ocean to the deep

Brinkman and Sombroek, (1996) stated that main potential changes in soil-forming factors directly resulting from global change would be in organic matter supply from biomass, soil temperature regime and soil hydrology, that shift in rainfall zones as well as changes in potential evapotranspiration. Moreover, indirect effects of climate change on soils through CO_2 induced increases in growth rates or water-use efficiencies, increasing level of sea-level rise, by climate-induced decrease or increase in vegetative cover. Change in human activities gradually impact on soils due to changes in options for the farmer, may greater than direct effects on soils of higher temperatures or greater rainfall variability and larger or smaller rainfall totals. Either increasing temperatures lead to more vegetation and more carbon stored in the soil or increasing the decomposition and mineralization of the organic matter in the soil. Organic matter can quickly break down particularly, under dry condition, resulting for carbon dioxide (CO_2) into the atmosphere. Increasing concentration of carbon dioxide in our atmosphere may cause the microbes in the soil to work faster and break down organic matter, potentially releasing even more carbon dioxide. Hättenschwiler *et al.,* (2002) reported that organic carbon has a significant influence on soil structure, soil fertility, microbial processes and populations in the soil, and other important soil properties. Increased atmospheric CO_2 would lead to increas plant productivity with increasing carbon sequestration by soil. Increasing plant growth and the soil–plant system would help offset increasing atmospheric CO_2 levels. Increased temperature 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 Gorissen *et al.,* (2004); Wan *et al.,* (2011). Brevik, (2012) stated that atmospheric CO_2 is utilized during photosynthesis and transformed into plant biomass , enters the soil and decays, some of it is transferred into soil organic matter and some returns to the atmosphere as CO_2. Soil organic matter also decays and releases CO_2 to the atmosphere, the total amount of soil organic matter increases, resulting in carbon sequestration.

4.2. Soil fauna and soil flora

Soil fauna and flora are essential components of all soils that play vital role in the retention, breakdown and incorporation of plant remains, nutrient cycling and their influence on soil structure and porosity Fig. (21). Global warming may not have a direct effect on the ecological composition because soil fauna and flora have a relatively broad temperature optimum. However, changes in ecosystems and migration of vegetation zones may seriously affect less migratory soil flora and fauna through increased temperature and rainfall changes. Significant impact of climate change on soil fauna and flora is through enhanced CO_2 levels in the atmosphere that leads to enhanced plant growth and allocation of carbon below ground rendering the microbial population to accelerate nitrogen fixation rates, nitrogen immobilization and denitrification. Similar to the findings of Jones *et al.,* (2009), increased mycorrhizal associations, increased soil aggregation and lastly increased weathering of minerals.

Fig. 21: Soil fauna and flora play a vital role in the retention, breakdown and incorporation of plant remains, nutrient cycling and their influence on soil structure and porosity

Plants accumulate nutrients from the soil solution pool, and nutrients must be in solution to be mobile in the soil. Biological transformation between organic and inorganic pools is strongly influenced by moisture and temperature, and thus, global climate change may strongly influence solution concentrations of N as well as S. Pendall *et al.,* (2004) suggested that increased CO_2 may not exert a significant direct effect on N mineralization, warming can increase N mineralization, leading to increased solution-phase N Fig. (22).

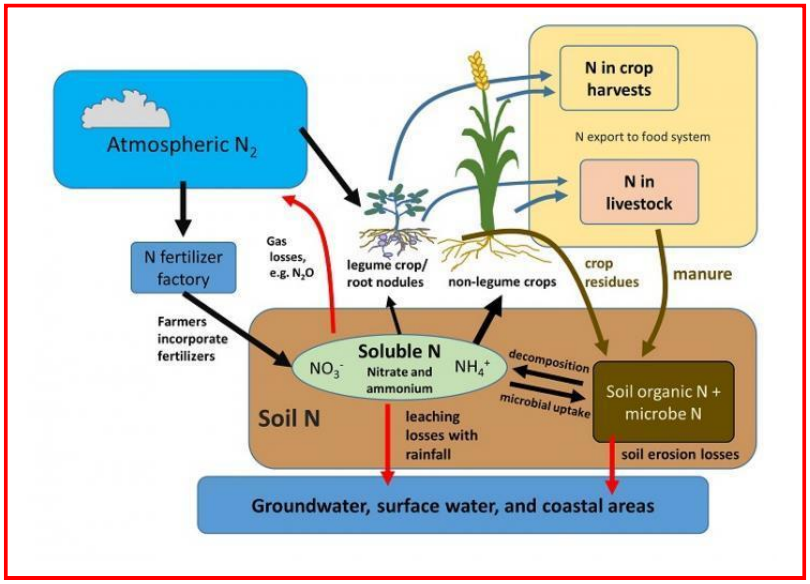
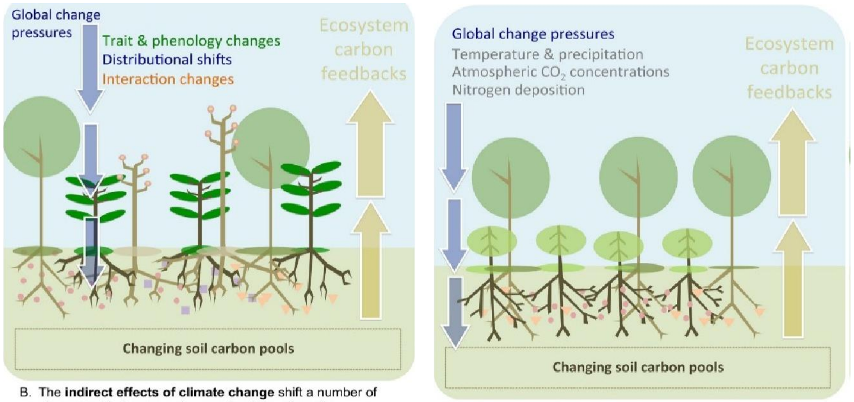


Fig. 22: Main features of nitrogen (N) cycling in food production systems. The diagram shows the multiple forms of N in soils and food production. Despite its complexity the diagram can be more simply considered in four parts: **(1)** a large atmospheric pool of N at upper left, which is used to make chemical fertilizer in factories and also by legumes to directly absorb N from the air for their own protein needs; **(2)** A soil pool which includes a predominant pool of *organic N* in large organic molecules (Soil organic matter or SOM) and microbes, as well as a fluctuating pool of *inorganic N* that is soluble in water (nitrate and ammonium ions); **(3)** The crops at the center of the diagram that are a main focus of human food production, and draw nitrogen from the pool of inorganic N in soil as well as from the atmosphere (in the case of legumes) and **(4)** Crop and livestock nitrogen exports from soil of nitrogen that then move through the food system to consumers. The very important return of crop residues and manure N to the soil N pool should also be noted (brown arrows). In addition, N can be lost from the soil in ways that are not productive (red arrows): as gases back to the atmosphere, including N_2O, a potent greenhouse gas; as leaching losses of nitrate in rainfall into waterways, and as erosion of soil particles that include soil organic N that move out of agricultural fields, eventually becoming sediments in waterways and estuaries.

Increasing temperature will enhance the reaction of adsorption/ desorption reactions, furthermore changing in soil moisture that modify reactions by altering the ionic strength of the soil solution. The balance between increasing plant growth and humification as well as decomposition of soil organic matter will be affected under a climatic change. Climate change has both direct and indirect effects on the activities of soil microbes that feedback greenhouse gases to the atmosphere and contribute to global warming. Direct effects include the influence on soil microbes and greenhouse gas production of temperature, changing precipitation and extreme climatic events. However, indirect effects resulted from climate-driven changes in plant productivity and diversity which alter soil physicochemical properties, supply of carbon to soil, structure and activity of microbial communities gradually involved in decomposition processes and carbon release from soil Bardgett *et al.,* (2008). Direct climate-microbe feedbacks is organic matter decomposition and the global warming will accelerate rates of heterotrophic microbial activity, thereby, increasing the efflux of CO_2 to the atmosphere and exports of dissolved organic carbon by hydrologic leaching Jenkinson *et al.* (1991), Davidson and Janssens (2006).

Climatic change is altering species distributions and simultaneously affecting interactions among organisms Wookey *et al.,* (2009), van der Putten (2012). Natural communities are complex and composed of organisms with very different life history traits, thermal tolerances, and dispersal ability. Further, interactions among community members can be beneficial, pathogenic, or have little to no functional impact and these interactions may change with environmental stress Vandenkoornhuyse *et al.,* (2015) Fig. (23). Numerous studies showed that shifts in species interactions in response to climate change cascade to alter biodiversity and the function of terrestrial ecosystems Walther *et al.,* (2002), Gottfried *et al.,* (2012), Langley and Hungate (2014), but fewer studies focued on soil communities Schimel *et al.,* (2007), de Vries *et al.,* (2012). Soil organisms interact with one another as well as with plants in a myriad of ways that shape and maintain ecosystem properties. In fact, soil microbial interactions, with each other as well as with plants, can shape landscape patterns of plant and animal abundance, diversity, and composition Berg *et al.,* (2010), van der Putten *et al.,* (2013).



B. The **indirect effects of climate change** shift a number of above- and belowground properties (e.g., diversity, community composition, and functional traits of plants, microbes, and other organisms) as well as the interactions among organisms, thus indirectly influencing carbon pools and feedbacks.

A. The **direct effects of climate change** act on organism process rates and inorganic resource availability to directly influence carbon pools and feedbacks to the atmosphere.

Fig. 23: The direct effects of global change on carbon feedbacks to the atmosphere have received considerable experimental attention (A); however, there has been less of a focus on understanding the magnitude of indirect effects of global change on the composition and function of ecosystems (B). The ecosystem-scale responses to the indirect effects of global change on community interactions (e.g., via changes in species distributions and/or traits) may be as large, or even larger, than the direct effects. Combined, the direct and indirect effects of global change on ecosystems may magnify, counterbalance, or reverse ecosystem carbon feedbacks to the atmosphere.

Plant-microbial interactions are considered as negative effects when the net effects of all soil organisms including pathogens, symbiotic mutualists, and decomposers reduce plant performance, however, can be positive effects when the benefits brought about by the soil community enhance plant performance such as biomass production and survival. Therefore, given their importance in defining ecosystem properties, understanding how soil microbe-microbe and soil microbe-plant interactions respond to climate change is a research priority that will shed light on important ecosystem functions such as soil carbon storage and net primary productivity Ostle *et al.,* (2009), Berg *et al.,* (2010), Fischer *et al.,* (2014), Todd-Brown *et al.,* (2012). Soils, in combination with plant biomass, hold; 2.53 more carbon than the atmosphere Singh *et al.,* (2010). Soils have the capacity to retain large amounts of carbon and their ability to sequester carbon has helped to mitigate rising atmospheric CO_2. Several factors regulate the amount of carbon, soils can sequester including climate, the parent material, the age and texture of the soil, the topography, the vegetation type, and the composition of the soil community. However, microbial decomposers ultimately regulate the rate limiting steps in the decomposition process and thus the influence of abiotic factors on decomposition. Todd-Brown *et al.,* (2012), Treseder *et al.,* (2012), and Verheijen *et al.,* (2015), reported that microbial activity will influence carbon feedbacks among plants, soil, and the atmosphere is uncertain. The activity of the soil community, such as the decomposition rate, increases relative to inputs coming from plants and animals, then the amount of carbon in soil will decrease as carbon enters the atmosphere, which can amplify carbon-climate feedbacks Zhou *et al.,* (2009), (2015) Wieder *et al.,* (2013). Moreover, microbial communities can influence important plant properties such as productivity and litter quality Harris *et al.,* (1985), van der Heijden *et al.,* (1998), properties that regulate fluxes in the carbon cycle.

Due to rates of soil respiration are thought to be more sensitive to temperature than primary production Bardgett *et al.,* (2008), it is predicted that climate warming will increase the net transfer of carbon from soil to atmosphere, thereby, creating a positive feedback on climate change Cox *et al.* (2000), Bardgett *et al.,* (2008). Such plant-mediated indirect effects of climate change on soil microbes operate through a variety of mechanisms, with differing routes of feedback to climate change but these can broadly be separated into two mechanisms. Concerning the indirect effects of increasing atmospheric concentrations of carbon dioxide on soil microbes, through increased plant photosynthesis and transfer of photosynthate carbon to fine roots and mycorrhizal fungi Johnson *et al.,* (2005), Hogberg *et al.,* (2006) and heterotrophic microbes Keel *et al.,* (2006), Zak *et al.,* (1993). It is well established that elevated carbon dioxide increases plant photosynthesis and growth, especially under nutrient-rich conditions and this in turn increases the flux of carbon to roots, their symbionts and heterotrophic microbes through root exudation of easily degradable sugars, organic acids and amino acids Diaz *et al.,* (1993), Zak *et al.,* (1993). The consequences of increased carbon flux from roots to soil for microbial communities and carbon exchange are difficult to predict, because they will vary substantially with factors such as plant identity, soil food web interactions, soil fertility and a range of other ecosystem properties Wardle, (2002). Bardgett *et al.,* (2005). However, some potential outcomes for soil microbes and carbon exchange include increases in soil carbon loss by respiration and in drainage waters as dissolved organic carbon due to stimulation of microbial abundance and activity and microbial contributions to climate change Jenkinson *et al.,* (1991).

5. Impact of climatic changes on soil parameters.

Climate is one of the most important factors affecting the formation of soil with important implications for their development, use and management perspective with reference to soil structure, stability, and topsoil water holding capacity, nutrient availability and erosion Fig. (24).

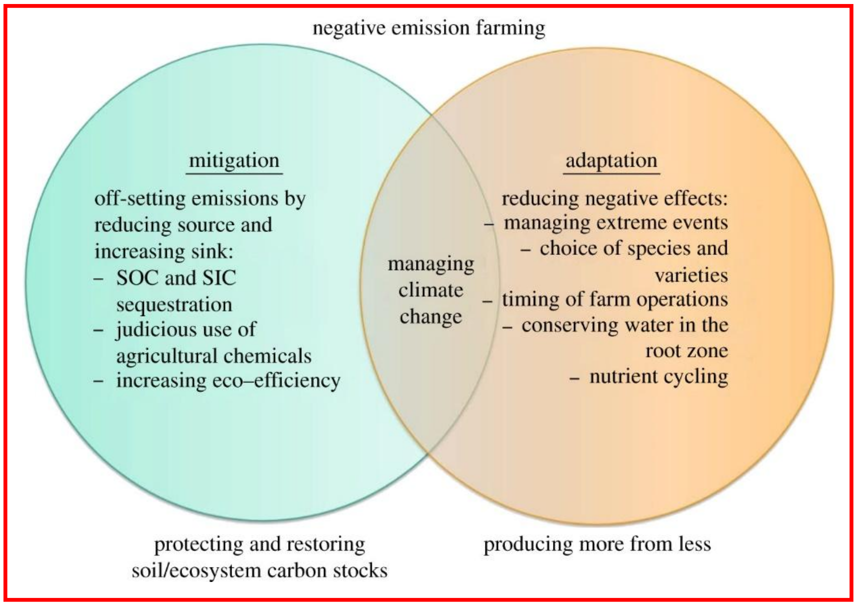


Fig. 24: Illustrates the strategies of mitigating and adapting to climate change and managing Agroecosystems as a solution through transformation of food production systems. After: Rattan *et al.,* (2021).

Soil properties that could be modified by climate change would be organic carbon content, characteristics of soil biota, moisture and temperature regimes and processes such as erosion, salinization or physical, chemical or biological fertility. The climatic parameters driving these changes would be temperature, rainfall (quantity, intensity and temporal distribution), together with atmospheric chemistry, especially carbon dioxide and nitrogen and sulphur compounds due to the increase in temperature and drought Fig. (25).

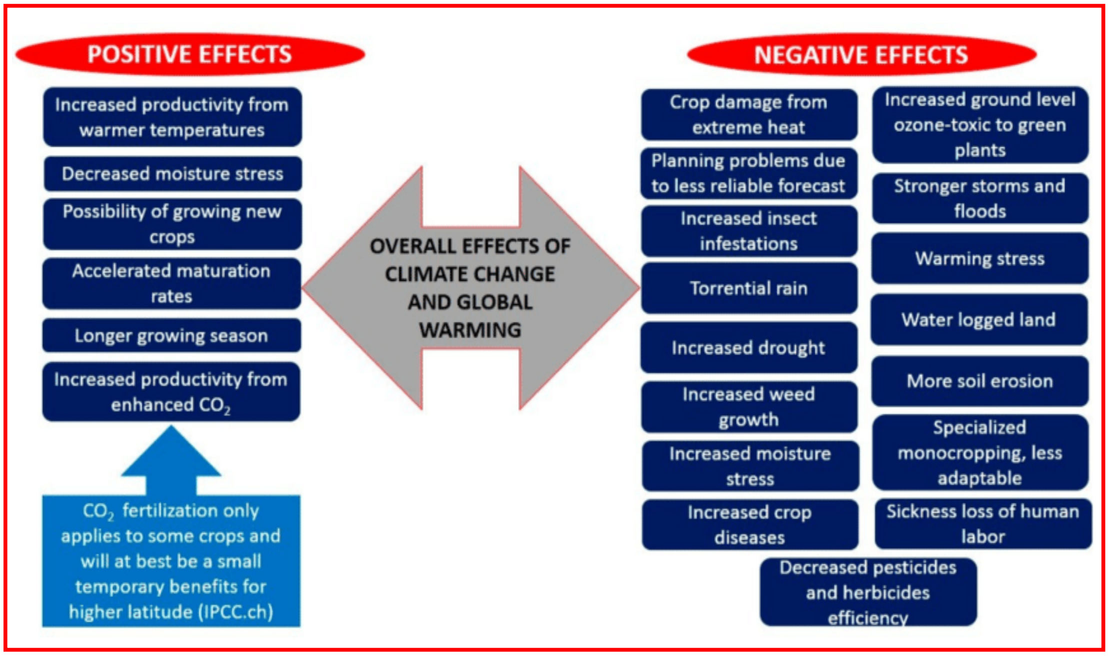


Fig. 25: Represents the overall positive and negative effects of climate change and global warming on crops and humans. After: Al-Tawaha *et al.,* (2020)

5.1. Soil Formation

Soil formation is controlled by numerous factors including climatic factors such as temperature and precipitation. These parameters influence soil formation directly by providing biomass and conditions for weathering. Main parameters of climate are sum of active temperatures and precipitation evaporation ratio Fig.(26) showed determine values of energy consumption for soil formation and water balances in soil, mechanism of organic-mineral interactions, transformation of organic and mineral substances and flows of soil solutions. Furthermore, lead to transformation of internal factors (energy, hydrological, biological).

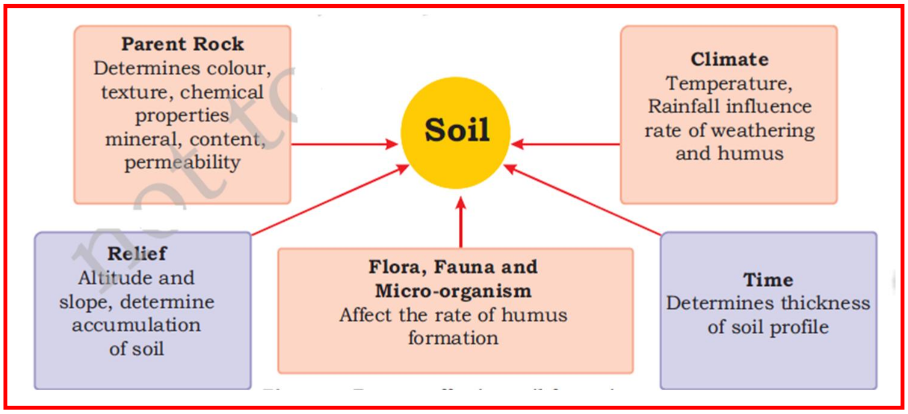


Fig. 26: Illustrates soil formation factors including climatic such as Temperature and Precipitation.

The climate change will increase energy of destruction of soil minerals resulting in simplification of mineral matrix due to accumulation of minerals tolerant to weathering. Losing of soil function for fertility maintenance and greater dependence of on mineral fertilizers Pareek, (2017). The effects of climate change on soil development may be expected through alteration in soil moisture conditions and increase in soil temperature and CO_2 levels. Among various factors controlling the process of soil development, climate plays a major role in weathering of rocks and minerals. The variables of climate change particularly, temperature and rainfall dictate various stages of weathering of rocks and minerals (parent material) resulting in chemical and mineralogical changes in soil forming rocks. Water is very essential for chemical weathering to take place and hence, an increase in rainfall accelerates weathering Pareek, (2017). The same types of primary minerals give rise to different secondary minerals when the conditions of weathering are differ. Thus, similar rock types undergoing weathering in different climatic conditions give different soil profiles, Pareek, (2017) Fig. (27), (28).

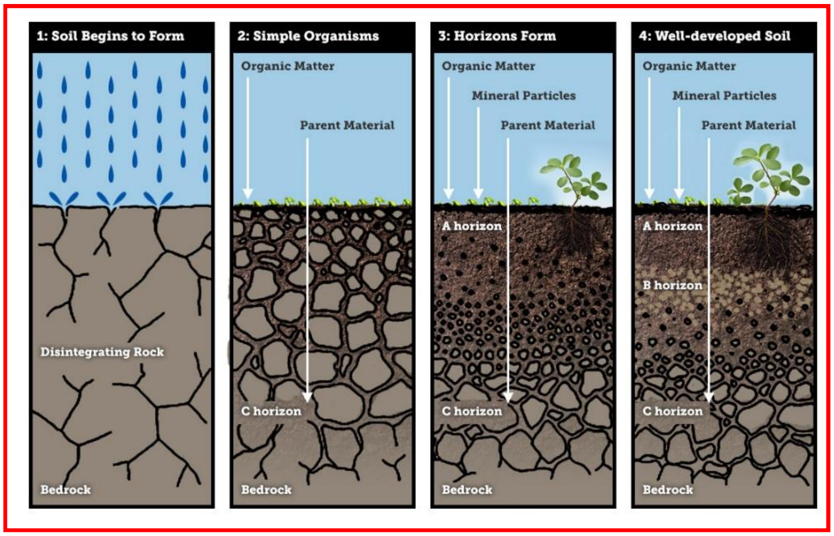


Fig. 27: Illustrates some chemical and mineralogical changes in soil forming rocks, water is important for developing soli horizons

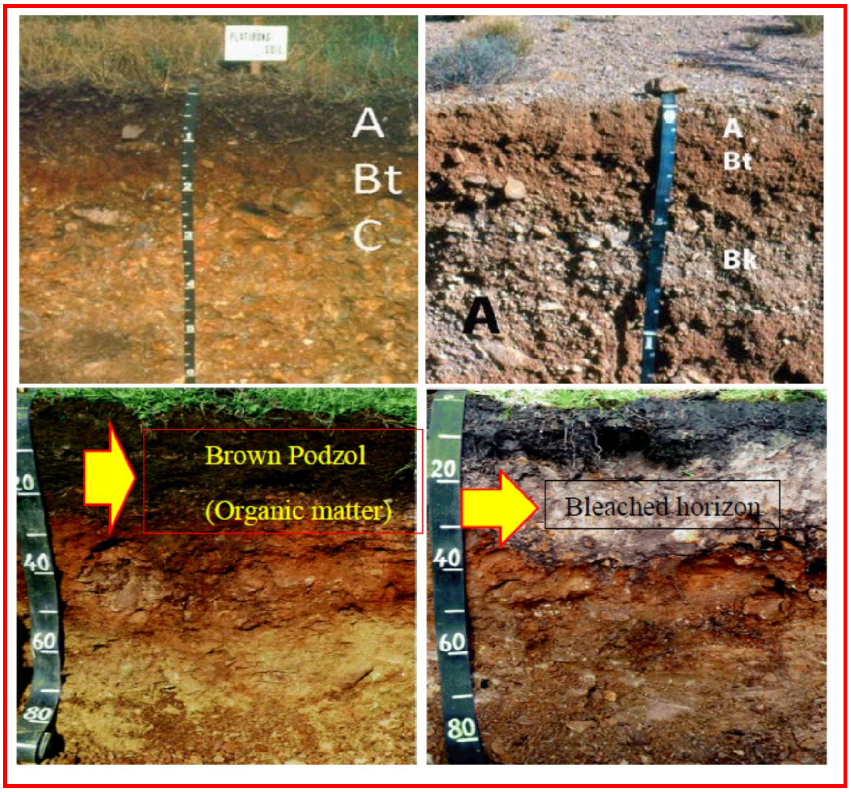


Fig. 28: Illustrates Podzol soil (showing podsolization process) (left) with acid mineral topsoil overlying a sandy bleached layer. Brown Podzol (right) with red subsoil indicating acidic conditions during soil formation with a topsoil that is rich in nutrients, potentially due to additions of lime, manure or fertilizer.

Fig. 29: Illustrates a type of weathering (physical and chemical weathering)

5.2. Soil water

Soil water can be fluctuated by a number through climate change such as precipitation causing rapid changes in soil water since the time-scale for response is usually within a few hours, temperature increase resulting in greater evapotranspiration loss of water from the soil and lastly the type of land use. The integral influence of climate-hydrology vegetation- land use changes are reflected by the field water balance and soil moisture regime Varallyay, (1990a), Varallyay, (1990b), Varallyay, and Farkas, (2008). Varallyay, (2010) Fig. (30).

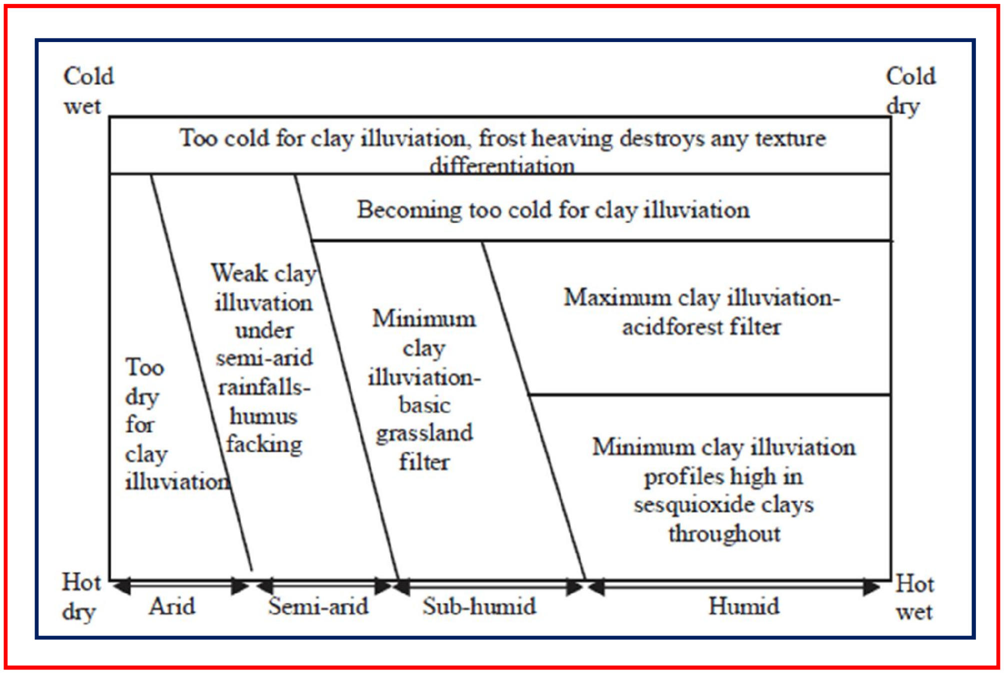


Fig. 30: Illustrates the effect of climatic changes on soil formation

Decreasing in atmospheric precipitation will result in a decrease in water infiltration (I) and water storage (S) in the soil and plants water supply; surface runoff (R) in hilly lands with undulating surfaces, consequently water erosion hazard, filtration losses and groundwater recharge (G) and will increase evaporation losses; the rate of transpiration, drought sensitivity with its physiological, ecological and environmental consequences, Varallyay, (2010). These direct influences are modified with the impact of vegetation characteristics, human intervention like land use, cropping pattern, agro technics, amelioration and other activities radically modifying the field water balance and its components. This fact offers possibilities for the elaboration of efficient measures for adaptation to the predicted climate change scenarios preventing or at least moderating their unfavorable consequences Lang, (2006), Varallyay, (2007). Several soil forming processes, including organic matter turnover, structure formation affecting the processes the following factors such as, run off, infiltration, percolation and drainage vital in the distribution of water across the landscape, weathering, podsolization processes (migration of organic matter), migration of clay (translocation and gleying) are strongly affected by soil moisture contents Fig. (31).

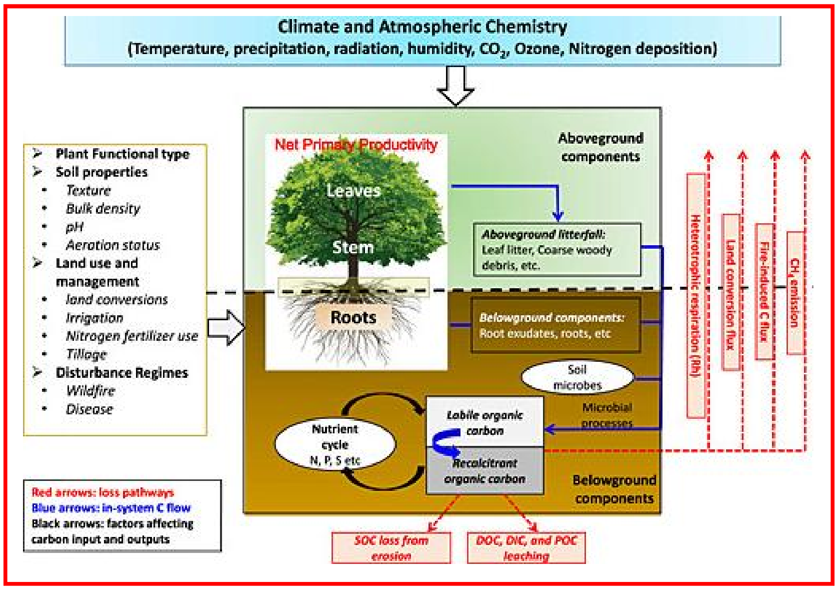


Fig. 31: Framework of major processes and controls for soil organic carbon storage and fluxes in terrestrial ecosystems.

5.3. Soil temperature

Soil temperature is important indicator of climate change, there is good relationship between air temperature and soil temperature, increasing air temperature will inevitably lead to an increase in soil temperature. Temperature regime of soil is gradually 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) studied the soil temperature trends associate with climate change in Canada where they found that warming trend in soil temperatures always associated with trends in air temperatures. 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 because of climate change or adaptation management. DEFRA. (2005).

5.4. Soil structure and texture.

Soil structure is an important indicating the soil particles combine together, it is responsible for the movement of gases, water, nutrients issue, maintenance of water quality, building foundations, soil fauna and the emergence of crops. Soil structure is strongly influenced by the quantity and quality of organic matter present, inorganic constituents of the soil matrix, cultivation methods and natural physical processes such as shrink-swell. Decreasing of soil organic matter levels gradually decrease soil aggregate stability, infiltration rates and increase susceptibility to compaction, run-off furthermore, susceptibility to erosion Fig.(32), Bot and Benites (2005). Brinkman and Brammer (1990), Scharpenseel *et al.,* (1999).

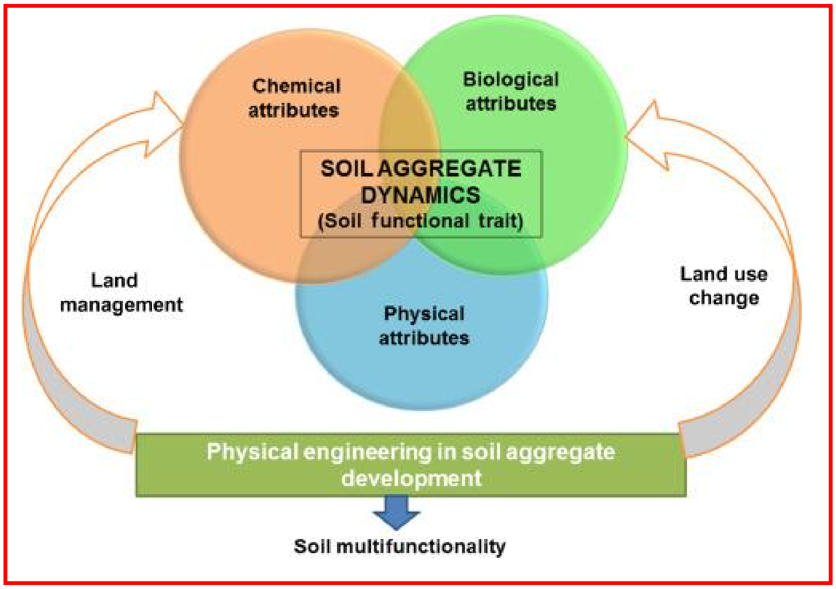


Fig. 32: Illustrates the beneficial of organic matter on soil structure which strongly influenced on infiltration rates and compaction, and soil erosion.

5.5. Wind and water erosion

Wind and water erosion are the most widespread form of degradation. In the arid and semi-arid areas, risk of wind erosion is serious. It happens whenever soil is left bare of vegetation because of cultivation and overgrazing following overstocking. Wind leads to the removal and deposition of soil particles from the top soil surface by its action. Apart from this, it can ensue extra damage by burying buildings, machinery and land with undesirable soil, Andrien (1994). Water erosion admits various processes such as splash erosion, rill and gully erosion and sheet erosion, Douglas (1994), Tate KR (1992). Splash erosion normally starts water erosion, takes place as raindrops fall onto the bare soil surface and break up the surface soil aggregates, and splashes particles into the air. Soil particles falling into the abandons between the surface aggregates reduce the amount of rainwater and can pass through into the soil and increasing runoff. Water running above the soil surface has the ability to pick up some of the soil particles released by splash erosion and besides, it also detach particles from the soil surface. This consequence may lead to removal of soil particles from the soil surface reasonably on consistent basis and is known as sheet erosion. Rill and gully erosion occurs when runoff gets concentrated into channels. Rills are small streamlets or head cuts of a size that can be checked by tilling. Gullies erode away large amounts of soil with a huge amount of rain. Gullies are similar as rills but larger. Normal tilling does not easily cease gullies Fig. (33a, 33b).

Fig. 33a: Illustrates some examples of wind, water, gullies and splash erosion.

Fig. 33b: Illustrates some examples of wind, water, gullies and splash erosion.

6. Impact of climatic changes on soil fertility and nutrient availability

Climate change may have stronger or weaker effects on soil processes. Crop yields on soils in developing countries decrease exponentially with increasing aridity, Lal, (2000). Soil moisture deficit directly affects crop productivity and also reduces yields through its influence on the availability and transport of soil nutrients. The continuously growing pressure on agricultural lands to increase food production has severely tested their capacity to produce agricultural products at an acceptable environmental cost. Estimates suggest that if current trajectories continue, 840 million people will be affected by hunger by 2030, FAO *et al.,* (2021). Moreover, some contend that by 2050-food production will need to double or more to meet the demands of a growing global population that is ever more affluent, Food Security Information Network, (FSIN) (2017). However, many lands that are already in use or have previously been used for food production are agronomically degraded. Decreased soil fertility and increased environmental sensitivity to farming due to poor soils or poor management or both have steadily reduced yields Fig. (34).

Many arable lands are now unsuitable for agriculture, and many have been abandoned from agriculture. Degraded lands often result from reduced soil fertility stemming from intensive management, poor soil conservation measures and climate change. Innumerable studies have documented the negative impacts of intensive annual crop production on the soil environment, indeed, the current resurgence of interest in regenerative agriculture Francis *et al.,* (1986); Giller *et al.,* (2021) has the restoration of soil health as a central tenet, Schreefel *et al.,* (2020) Fig. (35).

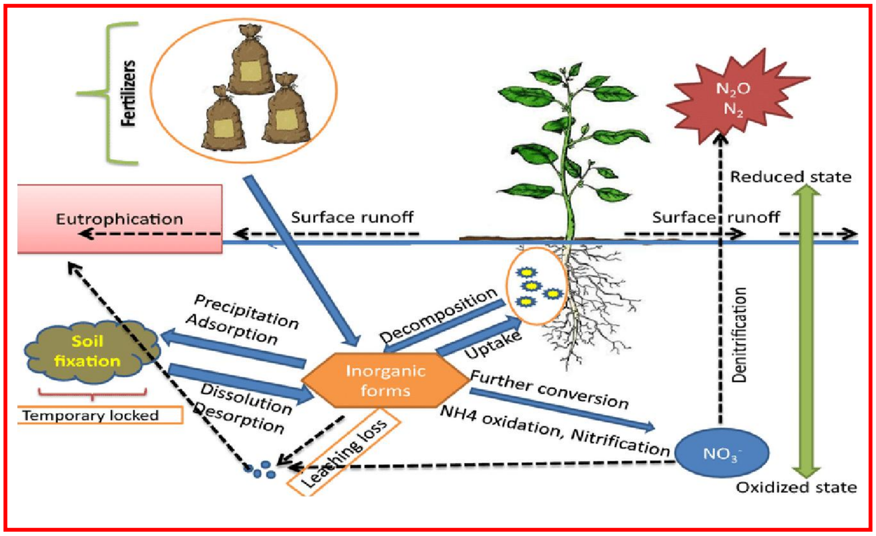


Fig. 34: Illustrates pathways of nutrients losses from the soil system. The diagram describes the multiple forms of nutrients in the soil–plant–atmosphere continuum. For simplicity, the diagram can be divided into four sections and understood as **(1)** inorganic form of nutrient either added into soil through addition of fertilizer or decomposed products of organic matter or release of fixed form of nutrients, **(2)** inorganic nutrients either taken up by the plants or microbes or **(3)** lost from the soil system through leaching, surface runoff, volatilization and denitrification or rendered unavailable to the plants temporarily due to fixation and immobilization, **(4)** lost nutrients can be potent for environmental degradation though greenhouse gases emission (N_2O), eutrophication (P and N) and ground water contamination (NO_3^-).

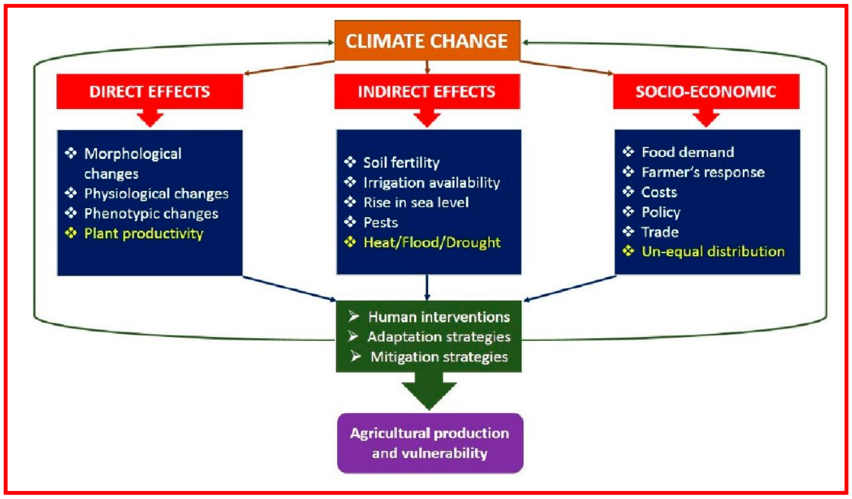


Fig. 35: Illustrates direct, indirect and socio-economic effects of climate change on agricultural production

Some specific aspects of intensive annual crop production that lead to soil degradation include frequent disturbance events such as tillage, the absence of continuous year-round plant cover, the lack of continuous deep rooting systems and crop functional diversity, and unbalanced nutrient budgets. Additionally, climate change increased warming and changing precipitation dynamics worldwide has accelerated or exacerbated soil degradation in regions where soils are increasingly subjected to flooding and drought intergovernmental panel on climate change, (IPCC) (2019). Erosion losses have been particularly severe up to 1% of topsoil is lost yearly in many places Montgomery, (2007), the result of tillage, overgrazing, and the growing incidence of extreme climate events that accelerate both wind and water erosion. The continued use of degraded lands for agricultural production requires ever-increasing management interventions to enable high-yielding food production. In this context, further land degradation represents an additional threat to agriculture's environmental integrity by exacerbating soil carbon (C), nitrogen (N), and phosphorus (P) losses. The loss of C and essential nutrients from the agricultural system results in land that struggles to produce nutritious food for human consumption FAO, (2019), and losses will only increase as management intensifies to replace lost fertility, creating a positive, downward spiraling feedback loop. Estimates of the extent of degraded lands worldwide differ markedly depending on the definition. Defined most commonly as lands with reduced productivity due to human activity, Oldeman *et al.,* (1990) leaves wide latitude to estimates of its extent, which range globally from 0.5 to more than 6 billion ha, Gibbs and Salmon, (2015). Narrowing the definition to perhaps its most severe agricultural extent former agricultural land now abandoned yields a more restricted estimate of 864 to 951 million ha, Campbell *et al.,* 2008), though still highly uncertain Gibbs and Salmon, (2015). In the United States alone, estimates based on county land use records Campbell *et al.,* (2013) and satellite observations Cai *et al.,* (2011) suggest a range of 74–99 million ha. Definition of degraded lands croplands or pastures that might, with proper management, be restored and made productive again without long-term consequences to environmental health. Such management might include biologically based practices that promote soil health and recouple C, N, and P cycles through a systems-based approach, focused on improving nutrient retention and balancing nutrient budgets, rather than, for example, fertilizer additions intended to maintain high inorganic nutrient levels in soils, Drinkwater and Snapp, (2007); International Fertilizer Industry Association, (2009). Ecological nutrient management, Drinkwater *et al.,* (2008) is intrinsic to organic, sustainable, and regenerative agriculture, Edwards *et al.,* (1983); Robertson and Harwood, (2001); Giller *et al.,* (2021) are achieved principally by improving plant diversity, including the incorporation of perennials into long rotations. We also consider restoring fertility for a newly recognized class of contemporary cropland subfield areas with consistently low and unprofitable yields. Satellite-based yield stability analyses suggest that >20% of maize (*Zea mays* L.) and soybean (*Glycine max* L. Merr) fields in the US Midwest may fit this classification Basso *et al.,* (2019). Moreover, precision farming technologies (such as identifying under-performing subfield areas and converting them to perennials) create additional potential for restoring the productive capacity of these lands with perennial cropping strategies Brandes *et al.,* (2018). Subfield variability of this sort likely occurs worldwide.

The restoration of degraded soil fertility via natural perennialization is a longstanding farming practice in place for millennia. Shifting cultivation, known by different names in different regions of the world, and in widespread use worldwide until the Eighteenth century and in the pantropic into the Twentieth century, has as a central tenet the restoration of soil fertility during a natural fallow phase after intensive cropping, Nye and Greenland, (1960); Irvine, (1989); Robertson and Harwood, (2001); Sandor *et al.,* (2007); Schmidt *et al.,* (2021). The natural fallow provides an unmanaged period during which ecological succession restores soil fertility to a point where soil can again be "mined" for agriculture. That ecological succession restores soil fertility or, in the case of primary succession, creates soil fertility is a longstanding ecological principle, Odum, (1969). In primary succession newly, lichens successively colonize exposed parent material, grasses, forbs, shrubs, and eventually trees, together with a more and more complex soil ecological community that develops as soil organic matter accumulates and N, P, and other nutrients cycle quickly enough to support accelerating primary productivity, Gorham *et al.,* (1979). Secondary succession follows a disturbance that resets the successional clock to some earlier time but does not remove soil and depending on the disturbance be it fire, extreme weather, agriculture, or some other perturbation a similar but faster sequence of recovery takes place, eventually, in the absence of continued disturbance, restoring the system to some pre-disturbance state. In one sense, annual cropping systems are caught in an early successional cycle, whereby the ecological clock is reset annually with crop harvest, Robertson and Paul, (1998); Crews *et al.,* (2016). Essential nutrients are readily lost from early successional systems and tightly conserved later, when perennial biomass is rapidly accumulating, Vitousek and Reiners, (1975), which helps to explain the contribution of perennial vegetation to nutrient retention and system-wide nutrient use efficiency. Incorporating perennials into cropping systems to restore fertility and retain nutrients thus draws on ecological theory and a long history of worldwide practice. Growing evidence suggests that degraded lands also have the potential for restoration while remaining productive, Asbjornsen *et al.,* (2013); Bell *et al.,* (2020). In almost all cases, perennialization the incorporation of perennial crops and forages in long rotations is key. Perennialization can be applied in many different systems to enhance the delivery of ecosystem services from agriculture, Syswerda and Robertson, (2014); Snapp *et al.,* (2015); Schulte *et al.,* (2017), including fertility restoration Asbjornsen *et al.,* (2013), soil C accretion, Bell *et al.,* (2020); Ledo *et al.,* (2020), N availability, Burke *et al.,* 1995; Reeder *et al.,* 1998; Tufekcioglu *et al.,* 2003), and P retention, Patty *et al.,* (1997); Crews and Brookes, 2014), all important components of ecological nutrient management.

Drought increases vulnerability to nutrient losses from the rooting zone due to low mobility as well as erosion, Gupta, (1993) Fig. (36).

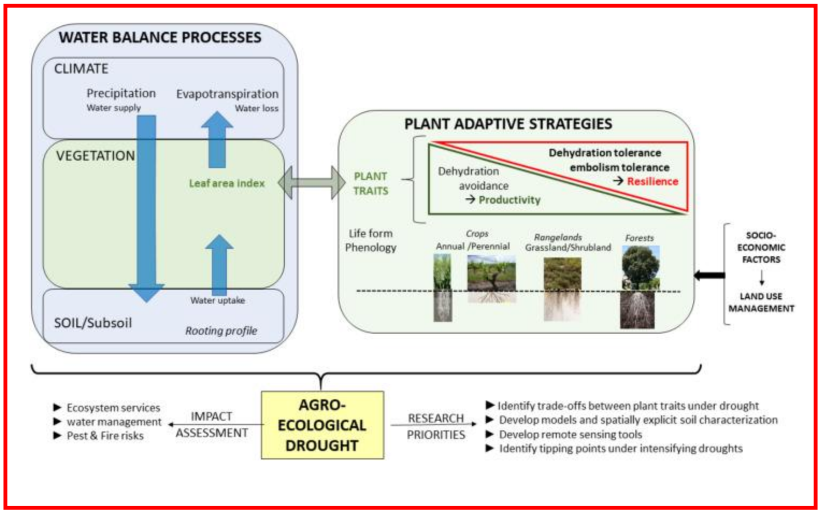


Fig. 36: Illustrates the developing agro-ecological drought indices. Improving the prediction of drought impacts entails better combining water balance models with the identification of traits involved in plant adaptive strategies under drought.

Because nutrients are carried to the roots by water, soil moisture deficit decreases nutrient diffusion over short distances and the 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 phosphorus, Lynch *et al.,* (2001). Reduction of root growth and impairment of root function under drought conditions thus reduces the nutrient acquisition capacity of root systems Fig. (37). Reductions in both carbon and oxygen fluxes and nitrogen accumulation in root nodules under drought conditions inhibit nitrogen fixation in legume crops, Gonzalez *et al.,* (2001), Ladrera *et al.,* (2007) Athar, and Ashraf, (2008).

Drought alters the composition and activity of soil microbial communities like the rediction of soil nitrifying bacteria Fig. (38). Excessive precipitation causes significant source of soil nutrient loss in developing countries, Tang *et al.* (2008) 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 the production of phytotoxic organic solutes that impair root growth and function. Hypoxia can also result in nutrient deficiency since the active transport of ions into root cells is driven by ATP synthesized through the oxygen dependent mitochondrial electron transport chain, Drew, (1988)., Atwell and Steer (1990).

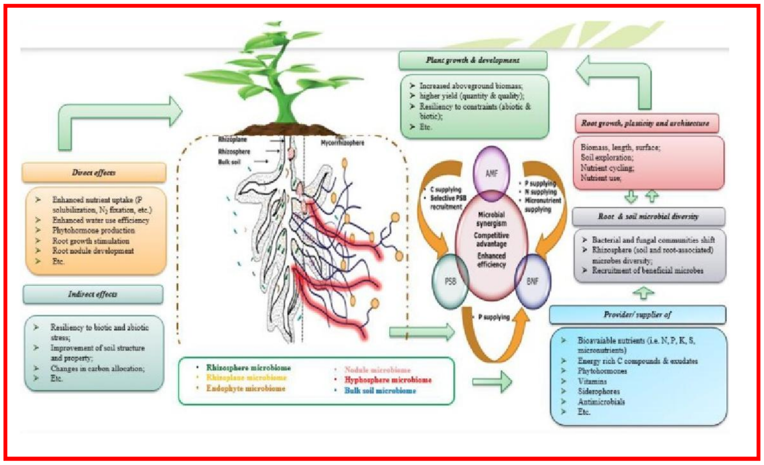


Fig. 37: Illustrates simplified of the microbial consortia concept highlighting beneficial rhizosphere PGPM and their direct (i.e., nutrients uptake via fixing N2, solubilizing P, producing plant growth promoting (PGP) substances like indole acetic acid, gibberellin, and cytokinin, etc.) and indirect effects (i.e., alleviation and/or protection against biotic and abiotic constraints) on root growth, symbiotic (rhizobial and mycorrhizal, etc.) and aboveground (plant growth, productivity, etc.) plant performance. Heterogeneity of the rhizosphere and root beneficial microbiome influences root growth and plasticity of root architecture that lead to effective exploration of soil and thus efficient nutrient uptake with positive consequences on growth and yield of the plant host.

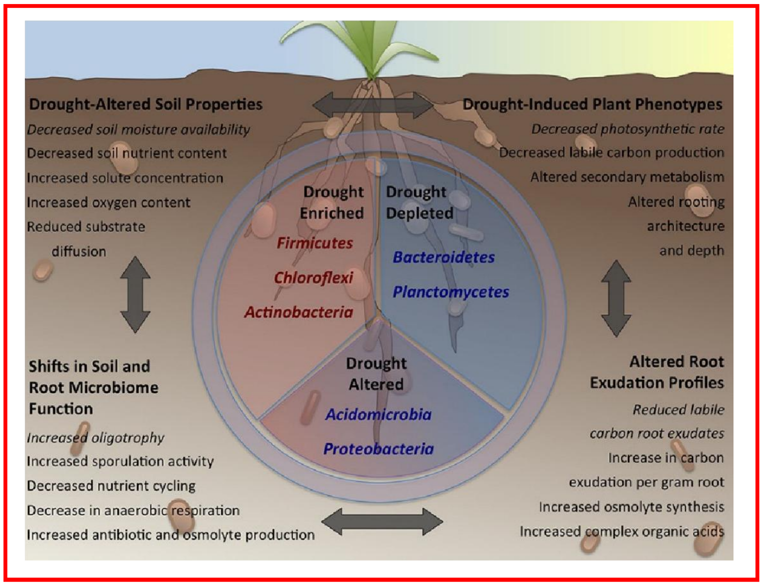


Fig. 38: Illustrates effects of drought on soils, plants and their associated bacterial communities. Drought induces shifts in soil physico chemistry (upper left), plant phenotype (upper right), root exudation (lower right) and soil and rhizosphere microbiome function (lower left). These shifts are capable of influencing one other; for instance decreases in soil moisture availability (upper left) leads to a decrease in the rate of plant photosynthesis (upper right), which in turn leads to a reduction in the rate of labile carbon exudation to the rhizosphere (lower right) and a greater prevalence in bacteria with oligotrophic life-strategies (lower left), who are less reliant on such simple carbon sources. These shifts lead to a selection for specific phyla (center panel) within the soil, rhizosphere and root microbiome, including enrichment for many Gram-positive, oligotrophic (middle left) phyla, and concurrent depletion of many Gram-negative, copiotrophic (middle right) phyla. Members of other phyla exhibit a more balanced mixture of enrichment and depletion (middle bottom). After: Dan Naylor and Devin Coleman-Derr (2018)

Naylor and Devin Coleman-Derr (2018) reported that root-associated bacterial communities play a vital role in maintaining health of the plant host. These communities exist in complex relationships, where composition and abundance of community members is dependent on a number of factors such as local soil chemistry, plant genotype and phenotype, and perturbations in the surrounding abiotic environment. One common perturbation, drought, has been shown to have drastic effects on bacterial communities, yet little is understood about the underlying causes behind observed shifts in microbial abundance. As drought may affect root bacterial communities both directly by modulating moisture availability, as well as indirectly by altering soil chemistry and plant phenotypes,

Lundberg *et al.,* (2012), stated that soils are the primary repository from which roots recruit their micro biomes; the drought-treated root microbiome is heavily dependent on the response of soil bacterial communities to moisture limitation. The term 'soil' in the context of microbiome studies may be used to refer to root zone soil, rhizosphere soil, or bulk soil, where the latter is assumed to be largely free of direct root influence and has higher diversity than rhizosphere soil. For consistency, research cited in this review concerning soil micro biomes was conducted on non-plant associated bulk soil. Furthermore, we consider only changes associated with bacteria and refrain from addressing changes in fungal communities, as by and large the effect of drought on soil or root fungal communities is small or nonexistent, Yuste *et al.,* (2011); Bouasria *et al.,* (2012); Barnard *et al.,* (2013); Fuchslueger *et al.,* (2016); thus, it should be clarified that references in this text to 'microbes' or the 'microbiome' are exclusively referring to bacterial communities Fig.(39). The observed trends in microbial biomass, diversity, composition and activity in soil microbial communities following drought treatment, and describe potential causes of these shifts, focusing first on potentially direct causes due to a loss of soil moisture, and second on indirect causes mediated through changes in soil physico chemistry. In general, total bacterial biomass has been observed to go down under drought, Hueso *et al.,* (2012); Alster *et al.,* (2013) as well as in more arid soils along a precipitation gradient, Bachar *et al.,* (2010), because of resource limitation. That being said, in certain cases soil bacterial biomass remains stable under drought Hartmann *et al.,* (2017) or goes up, Fuchslueger *et al.,* (2014), possibly due to attenuation of bacteria to repeated drought exposure, Hueso *et al.,* (2011) and/or altered functional potential to aid in resilience Bouskill *et al.,* (2016b). A confounding factor may be the methodology by which bacterial biomass is determined: one method is quantification of microbial DNA, Kassem *et al.,* (2008), whereas other studies rely on soil phospholipid fatty acid (PLFA) content, Fuchslueger *et al.,* (2014). A definitive explanation for the observed trends in soil bacterial biomass has yet to be elucidated. Community diversity represents another metric often applied in soil microbiome studies, where greater diversity is generally thought to be beneficial for the soils as a whole: increased species richness allows more metabolic activities to be present, facilitating more efficient nutrient mineralization and decomposition of organic matter, Nautiyal and Dion, (2008). Overall, drought appears to have little impact on bacterial phylogenetic diversity for soil communities, Bachar *et al.,* (2010); Acosta-Martínez *et al.,* (2014); Armstrong *et al.,* 2016; Tóth *et al.,* 2017). This trend may be dependent on drought context, as in one study where plots exposed to drought for the first time were reduced by 40% in phylogenetic alpha-diversity compared to no observed change in pre-exposed plots, Bouskill *et al.,* (2013). With respect to drought context, a confounding factor that may contribute to discrepancies described throughout the review is a lack of standardization with respect to drought treatment. Studies have imposed drought on soils through a variety of means, including exposing treatments to through fall rain exclusion for varying time periods, Bouskill *et al.,* (2013); Hartmann *et al.,* (2013); Yuste *et al.,* (2014); Tóth *et al.,* (2017), collecting samples along a precipitation gradient, Bachar *et al.,* (2010), or collecting soil samples from drought and non-drought time points, Acosta-Martínez *et al.,* (2014). In contrast to microbial diversity, community composition is significantly impacted by drought. The observed shifts in the soil microbiome under drought tend to involve changes in relative abundance, rather than outright abolition of drought susceptible taxa and concomitant appearance of tolerant ones, which helps explain the lack of change in alpha-diversity. A widely observed phenomenon is an increase in the ratio of Gram-positive to Gram-negative bacteria under drought, Acosta-Martínez *et al.,* (2014); Fuchslueger *et al.,* (2014), (2016); Chodak *et al.,* (2015). Specifically, in moisture-limited soils, commonly seen relative abundance shifts include decreases in largely Gram-negative phyla Proteobacteria, Verrucomicrobia, and Bacteroidetes, Barnard *et al.,* (2013); Bouskill *et al.*, (2013); Acosta-Martínez *et al.,* (2014); Yuste *et al.,* (2014), and increases in largely Gram-positive phyla Firmicutes and Actinobacteria, Bouskill *et al.,* (2013); Chodak *et al.,* (2015); Hartmann *et al.,* (2017). Often one or a few members of a phylum, as seen in Barnard *et al.,* drive these changes in relative abundance while relatively few groups had a large magnitude of change, most bacterial groups only had small shifts in response to drought. An experimental reduction of precipitation in German forest ecosystems provoked an increase of 300% for the family Micromonosporaceae, which was far more than its parent phylum Actinobacteria, Felsmann *et al.,* (2015); another study found increases in Actinobacteria that were mainly attributable to members of order Actinomycetales, Bouskill *et al.,* (2013). It is worth noting that these taxa-specific abundance changes in soil bacteria under drought are, to an extent, context dependent: phyla including Proteobacteria, Planctomycetes, and Acidobacteria have shown varying trends in response to water limitation. While Proteobacteria has been shown to accumulate in irrigated or non-arid soils, Bachar *et al.,* (2010); Yuste *et al.,* (2014); Hartmann *et al.,* (2017), in other studies it decreases under these conditions, Bouskill *et al.,* (2013); Acosta-Martínez *et al.,* (2014). Another example is Acidobacteria: while this phylum has, been shown to be better represented in drought roots Desgarennes *et al.,* (2014) and soils, Yuste *et al.,* (2014), it is also believed to be highly drought-sensitive Acosta-Martínez *et al.,* (2014) and decreases in abundance under soil dry down, Barnard *et al.,* (2013). Complicating matters further, Acidobacteria has been shown to have roughly equal numbers of OTUs associated with irrigated and non-irrigated soils, Hartmann *et al.,* (2017). Such discrepancies might be explained by the relative abundance of sub-phyla in each of these studies; for example, different Acidobacteria groups display contrasting abundance shifts between control and water-excluded plots, Bouskill *et al.,* (2013), possibly due to occupying disparate ecological niches with contrasting life-strategies, Hartmann *et al.,* (2017) or having distinct morphologies, such as cell membrane structure, that contribute to different tolerances to desiccation

Significant nitrogen 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 Atwell and Steer (1990) Fig. (40). Soil warming can increase nutrient uptake from 100-300% by enlarging the root surface area and increasing rates of nutrient diffusion and water influx, Prade *et al.* (1990), 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 the 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.

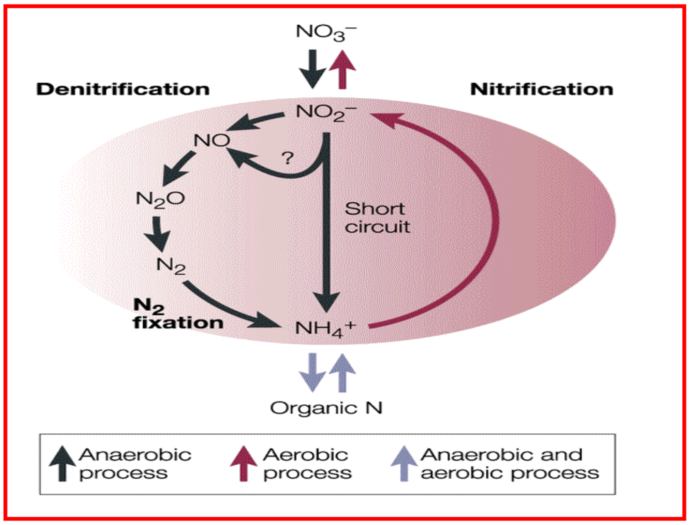


Fig. 40: Illustrates that biological nitrogen cycle. Bacteria have a dominant role in this cycle. Most commensal bacteria do not denitrify nitrate but catalyse a short-circuit in the nitrogen cycle the rapid, anaerobic reduction of nitrate via nitrite to ammonia. The question mark indicates that the mechanism of NO generation from nitrite during nitrate reduction to ammonia is uncertain.

Under dry conditions higher temperatures result in extreme vapor pressure deficits that trigger stomatal closure (reducing the water diffusion pathway in leaves), Abbate *et al.,* (2004), then nutrient acquisition driven by mass flow will decrease, Cramer *et al.* (2009). Fig. (41). 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, under dry condition, soil carbon loss decreased however, and wetter circumstances soil carbon loss increased. This could result in a positive feedback to the atmosphere leading to an additional increase of atmospheric CO_2 levels, Sabine *et al.,* (2017). Michael *et al.,* (2009) reported that transpiration is generally considered a wasteful but unavoidable consequence of photosynthesis, occurring because water is lost when stomata open for CO_2 uptake. Transpiration has been ascribed the functions of cooling leaves, driving root to shoot xylem transport and mass flow of nutrients through the soil to the rhizosphere. Consequence the link between nutrient mass flow and transpiration, nutrient availability particularly that of NO_3 partially regulates plant water flux. Nutrient regulation of transpiration may function through the concerted regulation of: (a) root hydraulic conductance through control of aquaporins by NO_3, (2) shoot stomatal conductance (gs) through NO production, and (c) pH and phytohormones regulation of gs. These mechanisms result in biphasic responses of water flux to NO_3 ‘ availability. The consequent trade-of between water and nutrient flux has important implications for understanding plant distributions, for production of water use-efficient crops and for understanding the consequences of global-change-linked CO_2 suppression of transpiration for plant nutrient acquisition.

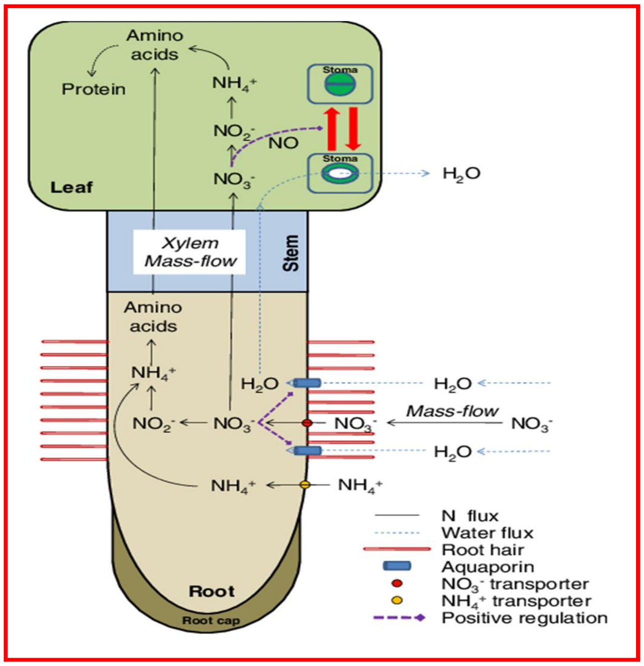


Fig. 41: Illustrates mechanism for the biphasic control of water flux by NO_3 and the lack of similar control by NH_4^+ of water flux. Uptake of NH_4^+ is shown to occur closer to the root tip than that of NO_3 Bloom *et al.,* 2003) which enters with water in the region in which root hairs occur Javot and Christophe (2002). NH_4^+ uptake and its assimilation products do not alter water flux directly, possibly resulting in aspects of the "ammoniacal syndrome". In contrast, NO_3 stimulates (positive feedback) expression/activity of root aquaporins. NO_3 uptake in excess of the capacity of root nitrate reductase (NR) for reduction is transported to the shoot where NO is produced by NR during its reduction to NO_2 Desikan *et al.,* (2002); Neill *et al.,* (2008). NO is indicated to induce stomatal closure. NO_2 is reduced to NH4 + by nitrite reductase and NH_4^+ is assimilated into amino acids through the activity of glutamine synthetase/glutamate-2-oxoglutarate amino-transferase. Details of associated pH changes, phytohormones fluxes Wilkinson *et al.,* (2007), energetic fluxes (e.g. ATP or NAD (P) H) or C fluxes have not been indicated. After: Michael *et al.* (2009)

Lambers *et al.,* (2008) stated that correlation between photosynthesis and leaf-N provides a mechanism for the trade of between WUE and NUE. The bulk of leaf N is associated with photosynthetic enzymes, particularly rubisco. This results in a strong positive correlation between *A* (adjusting the rate of photosynthesis) and leaf *–N*, Shulze *et al.,* (1994); Wright *et al.,* (2003), despite the fact that photosynthesis is a highly regulated process, under the control of multiple metabolic regulatory elements not only leaf-N and CO_2, Stitt and Krapp (1999), With higher leaf N the increased availability of photosynthetic protein is thought to increase the "draw-down" of internal CO_2, resulting from higher A at a given *g*s (shoot stomatal conductance), Patterson *et al.,* (1997); Wright *et al.,* (2003), and consequently higher WUE. Suggesting that the requirement for transpiration- driven mass flow of nutrients provides a powerful additional mechanistic reason for the trade of WUE and NUE. Nutrient regulation of water flux through plants may be through N-flux-linked signalling mechanisms, Wilkinson *et al.,* (1998), (2007); Clarkson *et al.,* (2000); Desikan *et al.,* (2002); Gloser *et al.,* (2007) that operate in both roots and shoots. Root hydraulic conductance varies on a diurnal basis Parsons and Kramer (1974); Carvajal *et al.,* (1996) due to changes in the expression of water channels. These aquaporins are plasma membrane intrinsic proteins that facilitate water flux by increasing root hydraulic conductivity, and are strongly expressed in the roots of several species, particularly in the exodermis, endodermis and vascular tissue, Maurel *et al.,* (2008). Aquaporins are gated through phosphorylation by Ca-dependent kinases, Maurel (2007) providing a potential mechanism for nutrient-mediated regulation of water flux, Chaumont *et al.,* (2005). Although the molecular and cellular mechanisms involved in regulation of aquaporins are still not fully understood, there are strong indications that aquaporin activity modifies water flux in roots, in response to nutrients. For example, deprivation of N, P, or S results in a significant inhibition of water transport associated with aquaporin functioning in whole roots or individual root cells within a few days reported by Maurel *et al.,* (2008). Conversely, increasing rhizosphere NO_3^-above deficiency has been shown to rapidly increase aquaporin-mediated root hydraulic conductivity, Carvajal *et al.,* (1996); Clarkson *et al.,* (2000); Gloser *et al.,* (2007); Gorska *et al.,* (2008). Since tungstate inhibited nitrate reductase (NR), its failure to inhibit aquaporin mediated hydraulic conductivity suggests that NO_3^- itself Fig. (41), rather than its reduction/assimilation products, is responsible for regulating aquaporin expression, Gorska *et al.,* (2008). Authors speculated that the functional significance of NO_3^--induced increases of water flux is to facilitate mass flow of NO_3^- to the roots when NO_3 ‘ was available. This may be particularly important when soil N availability is limited, but not deficient. NO_3^- has a biphasic influence on *g*s, Wilkinson *et al.,* (2007), increasing from deficiency to a maximum and decreasing with further increases in NO_3^- . Increasing NO_3^- above sufficiency rapidly (hours) elicits concentration- dependent stomatal closure, Wilkinson *et al.,* (2007), possibly mediated by changes in xylem pH, abscisic acid (ABA) signaling, Wilkinson *et al.,* (1998) and NO signaling, Desikan *et al.,* (2002); Neill *et al.,* (2008). This signaling system becomes ineffective with prolonged N deficiency resulting in decreased water flux, Radin and Parker (1979), probably in response to N starvation. The induction of root water flux by NO_3^- may at first seem inconsistent with the biphasic influence on *g*s and observed transpirational responses of plants to nutrient deficiency. Transpirational responses to nutrients, however, represent the result of complex and overlapping regulatory mechanisms that allow plants to modulate water flux in response to diverse nutritional and other environmental challenges. The site of NO_3^- reduction and subsequent assimilation of NH_4^+ in the plant varies between root and the shoot tissues, depending on species, developmental stage and nutritional environment, Wallace (1986). Above a minimum threshold, determined by the capacity of NR in the root, Andrews (1986), the proportion of NO_3^- that is reduced in the shoot increases with NO_3^- ' Oaks (1986); Wallace (1986). Below this threshold, fluxes of NO_3^- into the root are likely to result in increased root hydraulic conductivity, such as that demonstrated by Gorska *et al.,* (2008), and consequently sustained transpiration. However, NO_3^- fluxes in excess of the root NR capacity will result in NO_3^- being transported to the shoot where its conversion to NO by NR induces stomatal closure, Desikan *et al.,* (2002); Neill *et al.,* (2008) and reduced water flux. Transpiration and NR activity do co-vary Rufty *et al.,* (1987), consistent with NO_3^- regulation of NR activity and NO production from NO_3^- , suggesting that this provides a novel mechanism for the biphasic regulation of water flux in intact plants by NO_3^-concentration that was observed by Wilkinson *et al.,* (2007). Changes in loading of NO_3^- into the xylem may also result in alteration of xylem pH, Mengel *et al.,* (1994) with additional consequences for stomatal regulation through enhanced ABA transport to guard cells Wilkinson *et al.,* (2007), accounting for the synergistic effects of xylem NO_3^- and ABA on *g*s observed by Jia and Davies

(2007). The mechanism proposed here would facilitate transpiration-driven mass flow when NO_3^- supply is limited and decrease mass flow when NO_3^- is sufficient to trigger stomatal closure Fig. (41). Importantly, an N-mediated signalling mechanism would enable plants to measure inorganic N flux and increase transpiration rates to drive mass flow when soil N is limited (but not deficient). Unlike NO_3^- , NH_4^+ nutrition does not alter root hydraulic conductance or increase the expression of aquaporins in the root, Guo *et al.,* (2007a). In most species, NH_4^+ taken up by roots is assimilated into amino acids in the roots (reviewed by Miller and Cramer (2004), and NH_4^+ does not appear to elicit the closing response of stomata. Plants supplied with NH_4^+ generally have lower WUE than those supplied with NO_3^-, Raven *et al.,* (2004); Guo *et al.,* 2007a, b) and the symptoms of NH_4^+ toxicity include growth inhibition, wilting and other indications of water stress, Cramer and Lewis (1993). These changes, dubbed the ammoniacal syndrome, Chaillou and Lamaze (2001), have previously been ascribed to cation/anion imbalances reported by Miller and Cramer (2004). This water stress, however, probably additionally results from the lack of coordinated regulation of root hydraulic conductance and *g*s. High concentrations of NH_4^+ associated with agriculture are uncommon in natural ecosystems and plants may thus lack the mechanisms to respond to these conditions. The biphasic sensitivity of transpiration-driven water flow to NO_3^- also provides a mechanism for plants to sense the efficacy of mass flow to the root, since NO_3^- is readily mobilized by mass flow in many soils; in contrast, NH_4^+ cations bind to soil more readily and are less likely to be mobilized by mass flow. The mechanism proposed here Fig. (41) , provides a novel explanation for the observed disparate effects of NO_3^- or NH_4^+ nutrition on plant water relations. The complexity of soil–root interactions. NO_3^- and $NH_4{}^+$ availabilities in soil can vary by an order of magnitude over the course of a day and over the space of a few centimeters, Jackson and Bloom (1990). Altering the hydraulic properties of a small part of the root system in response to local conditions would enable effective control of the utilization of water by that portion of the root. For example, as a root depletes NO_3^- in the soil zone, the consequently reduced hydraulic conductance would potentially allow diversion of water to other portions of the soil where NO_3^- is less limiting. Root responses to NO_3^- and NH_4^+ + also differ strongly. Roots of many plants proliferate rapidly in patches of NO_3^- but not in patches of NH_4^+ reported by Miller and Cramer (2004). This differential sensitivity of root proliferation to NO_3^-، and NH_4^+ has been argued to occur because roots have evolved to use NO_3^- rather than NH_4^+ as a signal molecule owing to their differential mobility's in the soil Zhang and Forde (2000). Consistent with the lower mobility of NH_4^+ plants develop thinner and longer roots when NH_4^+ is the primary N source, Bloom *et al.,* (2003). In both rice and maize, NH_4^+absorption was higher at the root apex, whereas NO_3^- absorption was greatest in the root hair zone Colmer and Bloom (1998), where hydraulic conductivity associated with aquaporins is concentrated, Javot and Christophe (2002); Hachez *et al.,* (2006). Thus, as the root grows through the soil the tip may first take up more of the relatively immobile NH_4^+ than NO_3^- and subsequently, as the root continues to grow, the region of the root around the root hairs takes up NO_3^- transported into the rhizosphere by mass flow Fig. (34).The mass flow of nutrients other than N depends on the flux of water, the soil concentration of the nutrient and its mobility Barber (1995). Thus, N regulation of water flux provides a mechanism for N flux to regulate the mass flow of other nutrients to the rhizosphere Cramer *et al.,* (2008), (2009). It is, however, possible that nutrients other than N could also play a role in controlling water flux. At the root level, for example, relief from P deficiency rapidly increased root hydraulic conductivity, Radin and Eidenbock (1984); Carvajal *et al.,* (1996) probably due to increased aquaporin expression Clarkson *et al.,* (2000). Increased P supply has also been shown to increase WUE in several species reported by Raven *et al.,* (2004), Fig. (35), but this may be largely due to the relief of photosynthesis from P limitation, Jacob and Lawlor (1991), rather than any P induced decrease in transpiration. While there may be a role for P in regulating water flux, its effectiveness in this role may be limited by its low mobility in many high cation exchange capacity (CEC) soils Barber (1995); Kramer and Boyer (1995). However, mass flow of P can be substantial in low CEC soils, raising the possibility that mass flow could contribute to P supply to roots in such soils, Cramer and Hawkins (2009) Fig. (42).

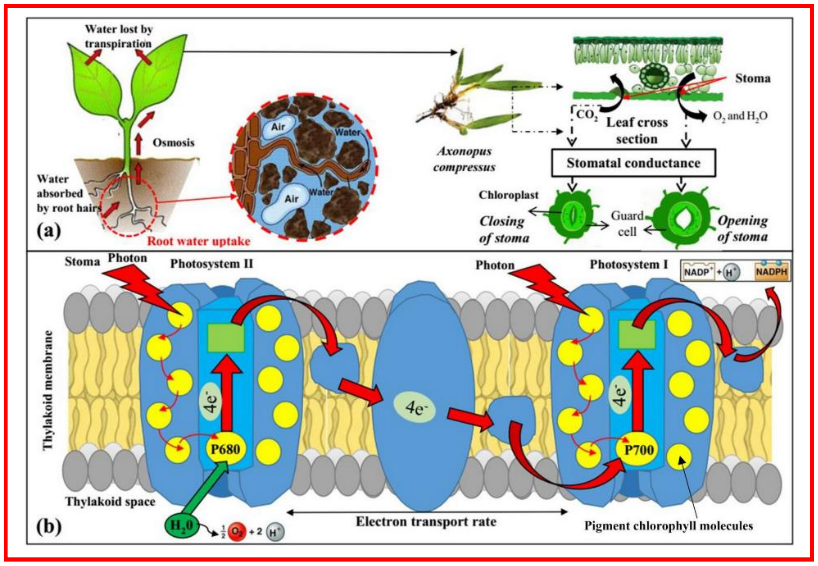


Fig. 42: Illustrates diagram depicting (a) stomatal functioning, initiated by transport of root water uptake and nutrient to plant leaf. The steps in sequence represents transpiration mechanism, indicated by loss of water via opening and closure of stomata across the leaf section; (b) light dependent photosynthesis process. Photosystems (groups of photosynthetic pigments (including chlorophyll pigment molecules) embedded within the thylakoid membrane) absorbs light energy to energize the delocalized electrons. The energized electrons are transferred to carrier molecules within the thylakoid membrane (electron transfer chain) for further ATP production (phosphorylation) and reduction of NADP+. After: Ankit Garg *et al.* (2020).

Mary Dixon *et al.,* (2020) stated that tomato (*Solanum lycopersicum* L.) is a high-value crop that has potential to enhance its P-use efficiency. While phosphorus (P) is an essential nutrient, supplies are finite and much of the P supply in agricultural soils is not bioavailable after application due to reactions such as soil adsorption, immobilization, or precipitation. Low-P bioavailability results in reduced growth, so plants may mobilize soil-bound P by altering root morphology, exuding root-derived compounds, or forming symbiosis with microorganisms. Phosphorus forms fluctuate in the soil and potential approaches to increase the bioavailable pool of P may focus on processes such as desorption, mineralization, or dissolving precipitated P-compounds. To enhance these processes, roots may alter their spatial arrangement, exude protons to acidify the rhizosphere, exude carboxylates to solubilize bound-P, exude phosphatase to mineralize organic P, or enhance symbiosis with native microbes. High PAE allows for use of accumulated soil P as opposed to relying on fertilizer application to meet crop demand.

Several strategies for enhancing *P-acquisition efficiency (PAE)* there is potential to select for high *PAE* because many genes alter expression in a P deficit. For example, approximately 29% of Arabidopsis genes micro arrayed were up- or down-regulated by a factor or two or more during a P deficit, Wu *et al.,* (2003). In yeast, 22 genes from a whole genome microarray were shown to be regulated by the PHO pathway, Ogawa *et al.,* (2000). There may be opportunities for screening genotypes effective in strategies that acquire sparingly available P including root morphological responses to low soil-P, exudation of root derived compounds, and microbial symbiosis Fig. (43).

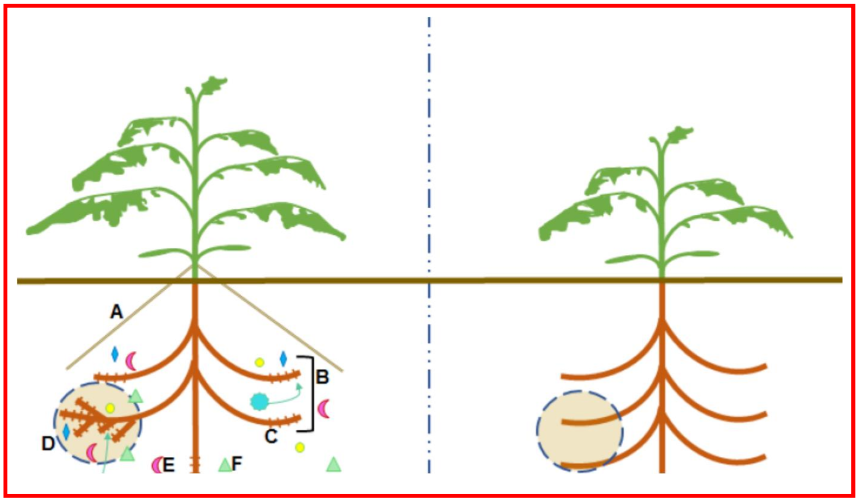


Fig. 43: A tomato plant efficient in phosphorus (P) acquisition. A hypothetical tomato adapted for P-acquisition efficiency (PAE) (left) can be compared to a hypothetical tomato inefficient in P acquisition (right). Root morphological strategies a tomato could employ to cope with a P deficit include adventitious rooting (A), topsoil foraging (B), or root hair growth (C) to better exploit a given volume of soil. Root proliferation in nutrient dense patches (D) exemplifies plasticity of an efficient root system to optimize a heterogeneous supply of soil P. Roots may exude enzymes such as phosphatase (E) to mineralize organic P sources. Roots may also exude organic acids such as citrate, malate, fumarate, or oxalate (F) to chelate bound-P. Reductants such as glucose (G) may reduce ferric iron to mobilize P. Exudation of hydrogen ions (H) acidify the rhizosphere to solubilize calcium phosphates. Rhizosphere acidification can also be achieved through excess cation uptake (I). Symbiosis with mycorrhizal fungi (J) allows for uptake of P transferred from sources unavailable to the root. There are no mechanisms illustrated for the P-inefficient representative. However, any listed strategy could be present in the root system of a P-inefficient tomato, but likely expressed to a lesser degree than a P-efficient. After. Mary Dixon *et al.* (2020)

7. Impact of climatic changes on nutrient gradient and its uptake

7.1. Moisture content and nutrient use efficiency in rhizosphere

Plant developmental processes are always controlled by internal signals, depending on the adequate nutrient supply through soil to root and translocated to the other parts of plants. Availability of plant nutrients can be a major constraint to plant growth in many environments of the world, especially, the tropics where soils are extremely low in nutrients thus limiting the crop productivity. Plants take up most of mineral nutrients through the rhizosphere where microorganisms interact with root exudates. Plant root exudates consists of a complex mixture of organic acid anions, phytosiderophores, sugars, vitamins, amino acids, purines, nucleosides, inorganic ions, Prescott *et al.,* (1999), gaseous molecules (CO_2, H_2), enzymes and root border cells which have major direct or indirect effects on the acquisition of mineral nutrients required for plant growth, Dakora and Phillips (2002) Fig (44). Hiltner (1904) described rhizosphere for the first time. It varies with the plant species and the soil, generally considered at 2 mm distance from the root surface known as rhizoplane. Hartmann *et al.,* (2008) Niu *et al.,* (2012).

Rhizosphere is a very important zone surrounding the plant roots network, Otero *et al.,* (2015); Kumar *et al.,* (2016a); Jia *et al.,* (2017) , representing the great and vital soil microbial activity, where different soil microbes are classified into three groups, namely, passive, negative and neutral microbes, Baetz (2016); Mohammadi et al. (2017). Most important and beneficial soil microbes include plant growth-promoting microbes such as Azotobacter, pseudomonads, phosphate solubilizers and AM fungi, Yazdani *et al.,* (2009); Noori and Saud (2012); Sabannavar and Lakshman (2009); Kumar *et al.,* (2016a); Verbon and Liberman (2016); Vergani *et al.,* (2017).

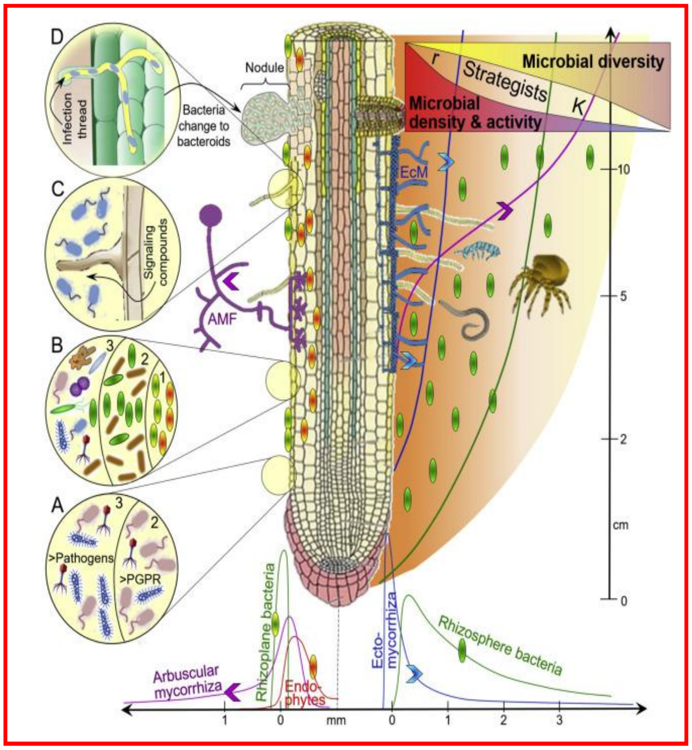


Fig. 44: Illustrates distribution of life in the rhizosphere. The abundance of various microbial groups across (X-axis at the bottom, in mm from the root surface) and along (Y-axis at the right, in cm, not proportional) the young root is presented by continuous color curves. Microbial groups include Arbuscular mycorrhiza (violet) and Ecto mycorrhiza (blue); Endophytic, Rhizoplane and Rhizosphere bacteria (green). The gradients of microbial density, activity and diversity, as well as the dominance of r and K strategists are presented at the top right. The loupes magnify various processes and microbial distribution: A: higher density of plant growth promoting rhizobacteria (PGPR) compared to pathogens in 2) the rhizosphere and 3) reverse in bulk soil; B: abundance of various microbial groups 1) on rhizoplane, 2) in the rhizosphere, 3) in bulk soil; C: infection of root hairs by rhizobia and formation of nodules; D: release of signaling compounds and attraction of rhizobia and other PGPR. The numbers in the loupes reflect: 1) rhizoplane, 2) the rhizosphere, 3) bulk soil. The schematic presentation of the abundance of individual microbial groups to the left or right of the root is made solely to avoid much overlapping of the curves. The overall life density is presented with orange shading on the right. Note that the size of (micro) organisms is not proportional to their real size. . (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article. After: Yakov Kuzyakov and Bahar Razavi (2019).

Yakov Kuzyakov and Bahar Razavi (2019) reported that soil volume affected by roots, the rhizosphere is one of the most important microbial hotspots determining the processes, dynamics and cycling of carbon (C), nutrients and water in terrestrial ecosystems. Rhizosphere visualization is necessary to understand, localize and quantify the ongoing processes and functions, but quantitative conclusions are very uncertain because of: **(a)** the continuum of the parameters between the root surface and root-free soil, i.e., there are no sharp borders, **(b)** differences in the distributions of various parameters (C, nutrients, pH, enzyme and microbial activities, gases, water etc.) across and along roots, **(c)** temporal changes of the parameters and processes with root growth as well as with water and C flows Fig.(45).

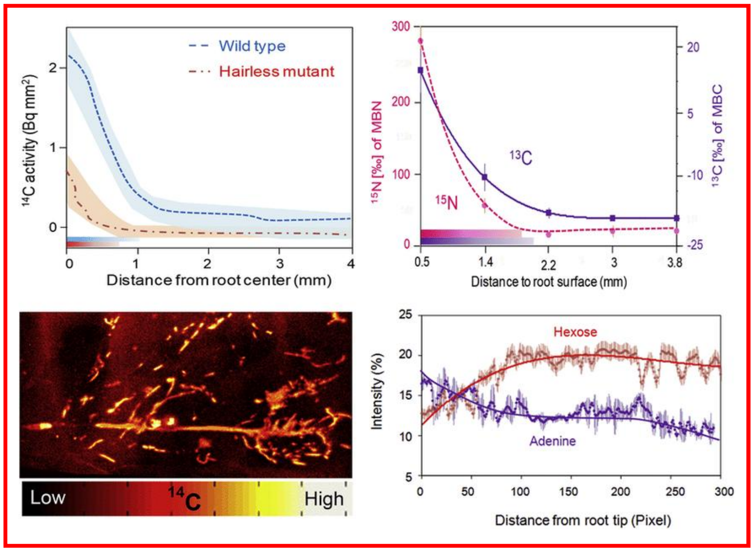


Fig. 45: Illustrates gradients of root exudates. Top left: ^{14} C profiles reflecting the exudate release by barley roots: Wild type with root hairs (blue dashed line) vs. hairless mutant (red dash-dotted line). Shading demonstrates ± SE between replicates (data from Holz *et al.,* 2018c, modified). Bottom left: ^{14} C image of lupine roots reflecting photoassimilate allocation ^{14} CO_2. After: Holz *et al.,* (2018c).

In situ techniques: planar optodes, zymography, sensitive gels, 14^{C} and neutron imaging as well as destructive approaches (thin layer slicing) have been used to analyze the rhizosphere extent and the gradients of various physico-chemical and biological characteristics: pH, CO_2, O_2, redox potential, enzyme activities, content of water, nutrients and excess elements, and organic compounds . A literature analysis allows the conclusion that: (a), the rhizosphere extent for most of the parameters assessed by non-destructive visualization techniques is 0.5–4 mm but exceeds 4mm for gases, nitrate, water and redox potential. (b), the rhizosphere extent of nutrients (N, P) is decoupled from the extent of the corresponding enzyme activities. (c), the imbalance between element flows to and uptake by roots may lead to accumulation of excess elements and formation of root carapaces (e.g. $CaCO_3$ rhizoliths, Fe plaque) ranging up to a few cm. (d), all destructive approaches show a much (3–5 times) larger rhizosphere extent compared to visualization techniques. These conclusions are crucial for a mechanistic understanding of rhizosphere properties and functioning, estimation of the nutrient stocks available to roots, and for rhizosphere modelling considering root growth and architecture, Fig. (46).

Overall, roots function as ecosystem engineers and build their environment, serving as the main factors shaping rhizosphere extent. Sharp gradients are formed within a few days for nutrients and enzymes, but more time is necessary for the establishment of specific microbial communities Fig. (47).Despite the very strong dynamics of most parameters, their stationarity is reached within a few days because the release of C and enzymes or nutrient uptake are very quickly compensated by utilization by surrounding microorganisms or/and sorption and diffusion processes.

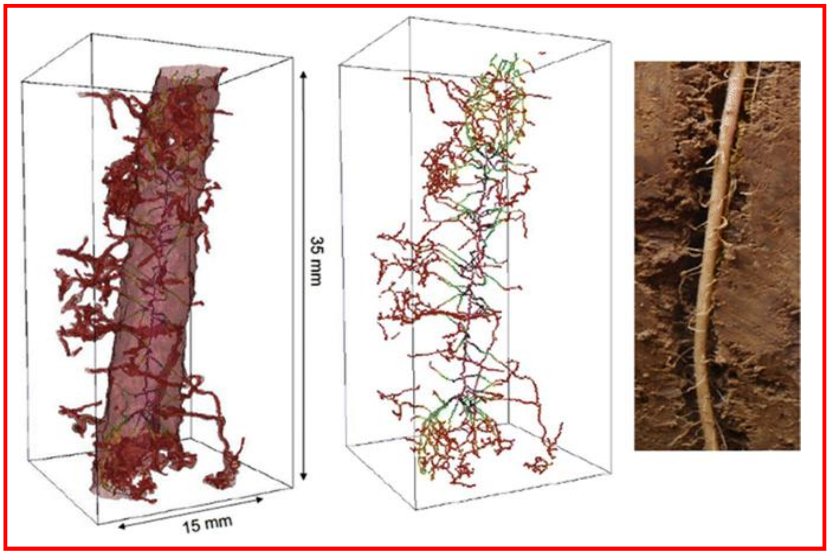


Fig. 46: Illustrates Left: Surface area of a single root induced biopore including connected lateral secondary branching channels in the rhizosphere. Left: Single root with branching secondary laterals. Middle: Pore skeleton (medial axis) of biopore network with colors indicating local channel width (burn number) from red indicating very narrow channel diameters over yellow, green, blue to purple colors corresponding to increasingly wider channels. Right: in situ sample of a single root with branching secondary laterals.

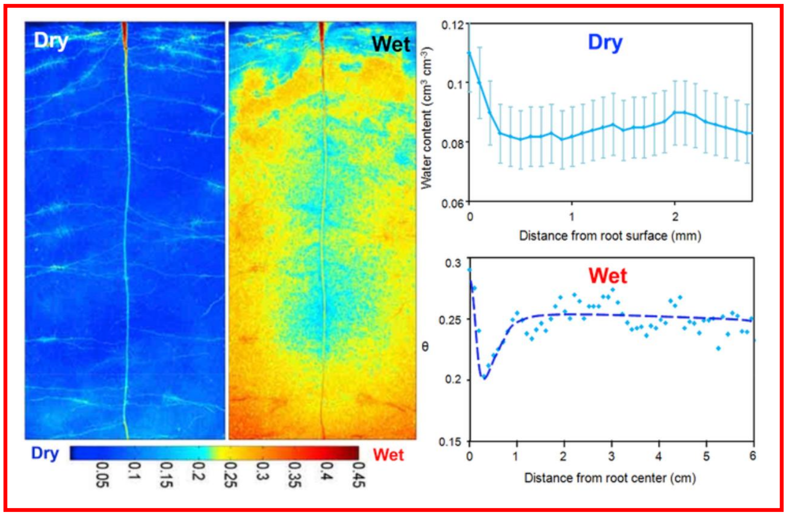


Fig. 47: Illustrates the gradients of water content in soil and rhizosphere: Water content around lupine roots when soil is dry, but rhizosphere is still wet (color left) -shortly before irrigation; and shortly after irrigation when the soil is wet, but the rhizosphere still has low water content (right). The color scale reflects the volumetric water content ($cm^3.cm^{-3}$) Carminati, (2012). Note the clear hotspots of high water content (white patches) around some roots in the left color subfigure and the same hotspots with low water content in the right sub figure. The subfigures on the left represent the water gradients from the roots calculated from the left and right color figures under dry and wet conditions, respectively. The water gradients under drought increase to the root, 2) under wet conditions -decrease to the root Carminati, (2012), Rudolph-Mohr *et al.,* (2017). The rhizosphere extent after drying is ~10 mm, but after rewetting ~0.3 mm. Note that the scales at the top subfigure are in mm and at the bottom in cm. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article). After: Yakov Kuzyakov and Bahar S. Razavi (2019).

Several investigations have been conducted about the diversity of microbial community and its beneficial aspects as well as the economic importance of agricultural crops including maize, wheat, rice, oilseeds rape, vegetables and medicinal plants, Solanki *et al.,* (2011); Kumar *et al.,* (2013); Kumar *et al.,* (2016a); Čerevková *et al.,* (2017); Chen *et al.,* (2017b); Hernández *et al.,* (2017). Due to anthropogenic activities, environmental pollution has occurred, which includes soil, Imadi *et al.,* (2016); Liu *et al.,* (2017b); Huang *et al.,* (2017b), water, Han *et al.,* (2016); Saha *et al.,* (2017); Smith *et al.,* (2017), sediment Bertrand *et al.,* (2015); Gao *et al.,* (2016); Gubelit *et al.,* (2016); Palanques *et al.,* (2017), air Achakzai *et al.,* (2017); Fu and Gu (2017); Sammarco *et al.,* (2017) . Large areas from agricultural lands around the universe have deteriorated due to soil pollution, which leads to a decline in soil biodiversity and decrease in crop productivity and poses several risks to human health Fig. (48), Lu *et al.,* (2015); Balkhair and Ashraf (2016); Zhang *et al.,* 2017d). Climate changes have direct and indirect effects on plant-soil-microbe-pollutant interactions and on the remediation of polluted soils, Abhilash *et al.,* (2013a, b); Tripathi *et al.,* (2015); Bojko and Kabala (2017), elevated CO_2 may increase the photosynthetic rate of plants thereby enhancing its productivity, the exudation of roots and rhizospheric soil microbial activity, Gömöryová *et al.,* (2013); Abhilash and Dubey (2014); Abhilash *et al.,* (2015); Duan *et al.,* (2015); Xu *et al.,* (2016); Lee and Kang (2016); Huang *et al.,* (2017a); Xue *et al.,* (2017) and also a decrease in soil pH as well as an increase in the soil content of dissolved organic matters, which will accelerate the secretion of plant root that enhances the availability of pollutants in the soil for uptake by plants as well as the degradation by soil microbes, Kim and Kang (2011); Rajkumar et al., (2013); Tripathi et al., (2015); Guarino and Sciarrillo (2017) Fig.(49).

Fig. 48: Illustrates soil pollution deteriorated agricultural lands leads to a decline soil biodiversity, decreasing in crop productivity and causing health risks

Sanjay K. Jaiswal *et al.,* (2021) noted that the symbiotic interaction between rhizobia and legumes that leads to nodule formation is a complex chemical conversation involving plant release of *nod*-gene inducing signal molecules and bacterial secretion of lipo-chitooligosaccharides nodulation factors. During this process, the rhizobia and their legume hosts can synthesize and release various phytohormones, such as IAA, lumichrome, riboflavin, lipo-chitooligosaccharides Nod factors, rhizobitoxine, gibberellins, jasmonates, brassinosteroids, ethylene, cytokinins and the enzyme 1-aminocyclopropane-1-carboxylate (ACC) deaminase that can directly or indirectly stimulate plant growth, Fig. (50).

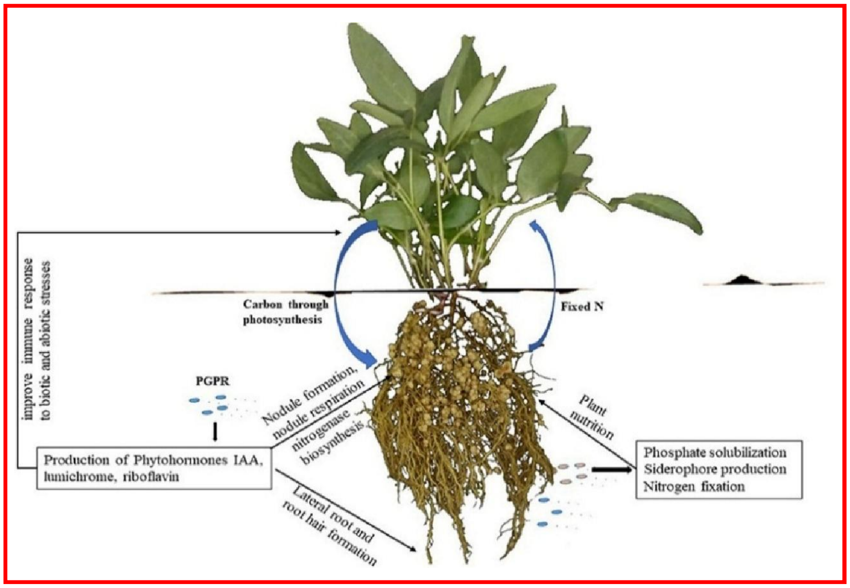


Fig. 49: Illustrates plant growth-promoting activities in the rhizosphere. Microsymbionts are activated by rhizodeposition of carbon and other signal molecules by the plant. After establishment of the PGPR in the rhizosphere, they promote plant growth by releasing growth substances and alleviating the effects of biotic stresses. After: Sanjay K. Jaiswal *et al.* (2021)

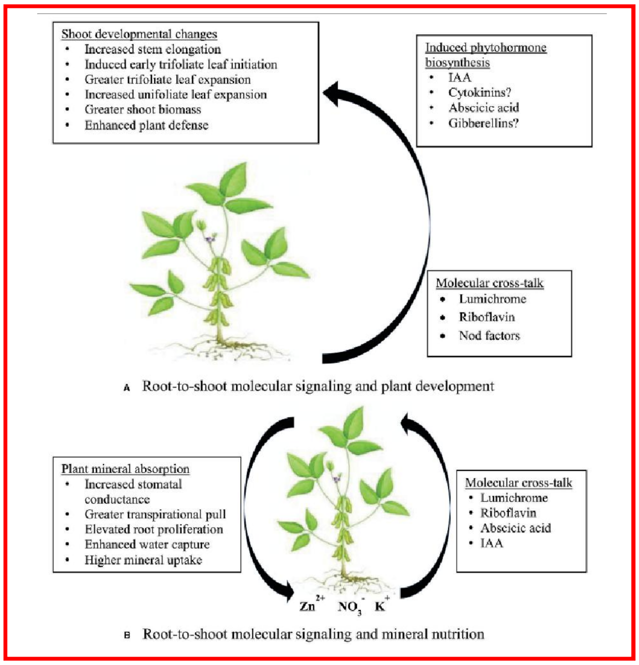


Fig. 50: Illustrates a model describing the effect of root-to-shoot signaling by rhizobial molecules on (A) shoot developmental changes, and (B) symbiosis-induced mineral uptake in the rhizosphere.

Whereas these attributes may promote plant adaptation to various edaphic-climatic stresses including the limitations in nutrient elements required for plant growth promotion, tapping their full potential requires understanding of the mechanisms involved in their action. In this regard, several N_2-fixing rhizobia have been cited for plant growth promotion by solubilizing soil-bound P in the rhizosphere via the synthesis of gluconic acid under the control of pyrroloquinoline quinone (PQQ) genes, just as others are known for the synthesis and release of siderophores for enhanced Fe nutrition in plants, the chelation of heavy metals in the reclamation of contaminated soils, and as biocontrol agents against diseases. Some of these metabolites can enhance plant growth via the suppression of the deleterious effects of other antagonistic molecules, as exemplified by the reduction in the deleterious effect of ethylene by ACC deaminase synthesized by rhizobia. Although symbiotic rhizobia are capable of triggering biological outcomes with direct and indirect effects on plant mineral nutrition, insect pest and disease resistance, a greater understanding of the mechanisms involved remains a challenge in tapping the maximum benefits of the molecules involved. Rather than the effects of individual rhizobial or plant metabolites however, a deeper understanding of their synergistic interactions may be useful in alleviating the effects of multiple plant stress factors for increased growth and productivity Therefore, further investigations are essential to understand the nexus of plant and microbe pollutants in soils under different climatic change conditions, Rajkumar *et al.,* (2013); Tripathi *et al.,* (2015); Yadav *et al.,* (2015). Therefore, the main target is to collect different links between climate changes and their impacts on the rhizosphere zone as well as soil biological processes for plant nutrition.

7.2. Rhizosphere is the effective zone for plant nutrition

The rhizosphere is a place where the most important plant–soil interactions happen including beneficial, antagonistic or neutral interactions, Baetz (2016). It is a real treasure in plant nutrition due to its significance in fate, behaviour and uptake of nutrients by plants, Kayler *et al.,* (2017); Rugova *et al.,* (2017). Several biological and ecological processes or transformations take place in the rhizosphere area that control microbial activity and plant growth as well as nutrient uptake by plants, Callesen *et al.,* (2016); Huang *et al.,* (2016). Processes in the rhizosphere definitely differ in the bulk soil, Ibekwe *et al.,* (2017), Rugova *et al.,* (2017). The rhizosphere area has very dynamic interfaces between **(a)** soil and plant roots; **(b)** plant root systems, soil and their microorganisms; and **(c)** soil, plant roots and invertebrates, Bais *et al.,* (2006); Hartmann *et al.,* (2008); Singh *et al.,* (2016); Rugova *et al.,* (2017). The fate and behavior of organic compounds, which released by the plant roots and soil microorganisms is controlled by the rhizosphere conditions, Cai *et al.,* (2017) Fig. (51).

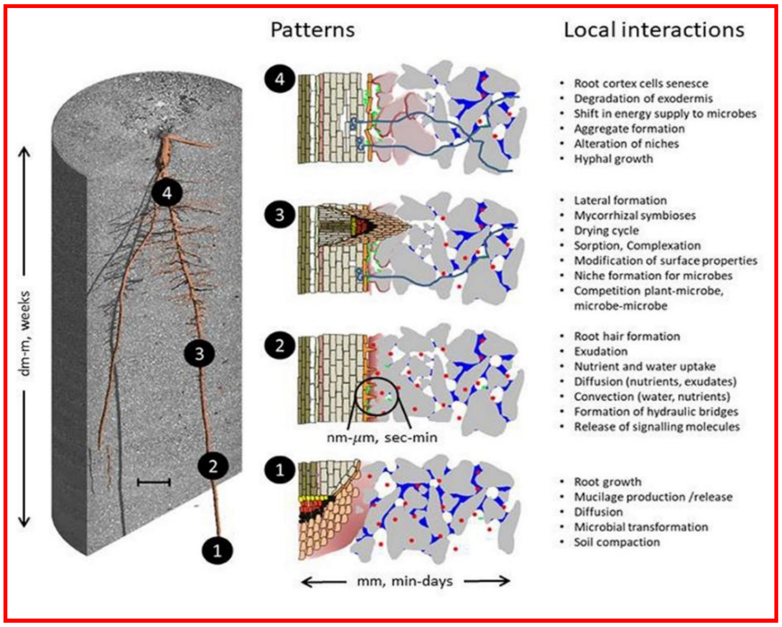


Fig. 51: Illustrates that hypothetical patterns reflecting rhizosphere self-organization based on numerous feedback loops resulting from local interaction of lower-level components. Illustrated are mucilage (rose) and water distribution (blue), compaction of soil particles (gray) and aggregate formation (gray-rose), colonies of microorganisms (green), depletion of phosphorous (red) and their potential change with root ontogeny. The latter is illustrated on the left for a 7-day old Zea mays root system growing in loam (scale bar 10 mm). Note that the patterns are not to scale. Local interactions/mechanisms are sorted according to their potential relevance at a certain developmental stage—not suggesting that they are absent at other stages. The integration of patterns for the whole root

system is expected to determine emergent properties like water and nutrient acquisition, soil structure, and carbon storage as well as plant health. After: Doris Vetterlein *et al.,* (2020)

Doris Vetterlein *et al.,* (2020) reported that resilience of soils, and their ability to maintain functions or recover after disturbance, is closely related to the root-soil interface, the soil's powerhouse. However, the key processes at the root-soil interface has so far limited. Here, we hypothesize that resilience emerges from self-organized spatiotemporal patterns that are the result of complex and dynamic between physical, chemical, and biological processes occurring in the rhizosphere. They also reported that improving our understanding of soil and rhizosphere functions, their stability under disturbances. The role for robust functioning of agricultural systems, which can informed management of agricultural systems actively considering rhizosphere processes, Fig. (52).These knowledge gaps is to link the spatial arrangement of the different interconnected components of the rhizosphere and their temporal dynamics as reported by Roose *et al.,* (2016). We propose that this challenge can be successfully tackled by applying tools and principles of self-organization.

The rhizosphere area is very rich in several compounds including low-molecular-weight root exudates and high-molecular-weight humic substances, such as mucilage or polysaccharides and proteins, Jha *et al.,* (2015). Low-molecular-weight compounds are a water-soluble fraction that include various secondary metabolites like flavonoids, glucosinolates and terpenoids, Jha *et al.,* (2015); Baetz (2016), gaseous molecules like CO_2 and H_2, inorganic ions (e.g. HCO_3 −, OH−, H+), amino acids, Zhang *et al.* (2017a), organic acid anions and carbohydrates, Haichar *et al.,* (2014); Montiel-Rozas *et al.,* (2016); Rugova *et al.,* (2017). The plant root exudates represent a wide range and complex mixture of hundreds of organic compounds, which could be classified into different categories based on their molecular weight and solubility in water, Strickland *et al.,* (2012); Huang *et al.,* (2014); Zhang *et al.,* (2014); Mommer *et al.,* (2016). Moreover, root exudates play great roles in the amelioration of plant stresses, Doornbos *et al.,* (2012); Baetz and Martinoia (2014); Nalam and Nachappa (2014); Xu *et al.,* (2015); Baetz (2016); Dubrovskaya *et al.,* (2017), in the increase of soil microbial activity, Singh and Mukerji (2006); Nannipieri *et al.,* (2008); Mommer *et al.,* (2016); Swamy *et al.,* (2016); Shcherbakova *et al.,* (2017), in the biodegradation of pollutants Liu *et al.,* (2015); Jha *et al.,* (2015); Hou *et al.,* (2016) (2016); Verbon and Liberman (2016); Dubrovskaya *et al.,* (2017). Vergani *et al.,* (2017) and in plant nutrition, Neumann (2007); Cesco *et al.,* (2010), (2012); Chen *et al.,* (2016); Meier *et al.,* (2017). Several functions in the beneficial ecological interactions with soil microbial communities in the rhizosphere, including interactions between plants and soil microorganisms, Chen *et al.,* (2016); Lareen *et al.,* (2016) and plant-plant communication Mommer *et al.,* (2016); Cai *et al.,* (2017), as well as the tripartite interactions, Haichar *et al.,* (2014); Hardoim *et al.,* (2015); Baetz (2016); Vergani *et al.,* (2017).

7.3. Climatic changes on soil microbial community in rhizosphere zone

Effects of elevated atmospheric CO_2 concentration on soil microbial community structure are often characterized by an increased mycorrhizal colonization. Due to the increased plant demand for nutrients, coupled with increased C assimilation rates CO_2 enrichment should increase mycorrhizal biomass because plant demands for N and P will increase concurrently with C assimilation rates, and plants will allocate more photosynthates belowground to the roots and mycorrhizal fungi to help satisfy this increased nutrient demand. Increasing root architecture particularly fine root mass and mycorrhizal infection promote enhanced P uptake in mycorrhizal plants grown under elevated CO_2 concentrations. It seems reasonable to expect that at elevated CO_2 levels, mycorrhizal biomass will increase as C becomes relatively less limiting and soil nutrients become more limiting to plant growth, Jones *et al.,* (2009) Fig. (53). Heike Bücking and Arjun Kafle (2015) reported that arbuscular mycorrhizal (AM) fungi play an essential role for the nutrient uptake of the majority of land plants, including many important crop species. The extraradical mycelium of the fungus takes up nutrients from the soil, transferring to the intraradical mycelium within the host root, and exchanges the nutrients against carbon from the host across a specialized plant-fungal interface.

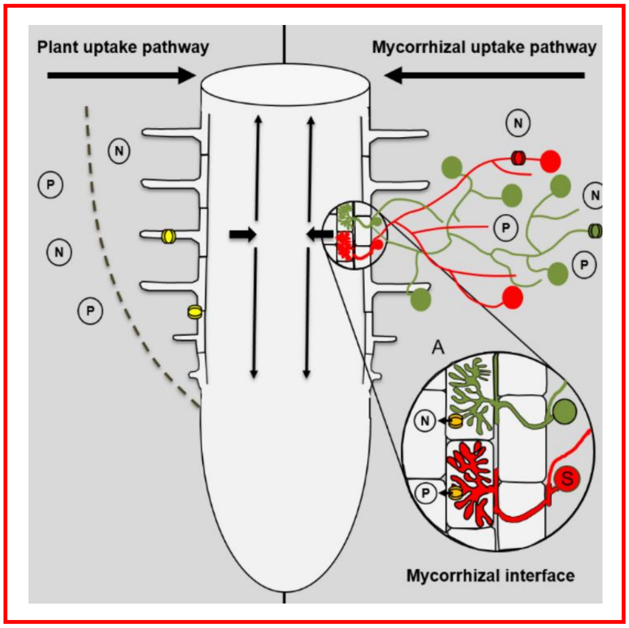


Fig. 53: Illustrates plant uptake and mycorrhizal uptake pathway. Plants can take up nutrients by transporters that are located in epidermis or root hairs (yellow symbols) or via the mycorrhizal uptake pathway that comprises the uptake of nutrients by fungal transporters in the extraradical mycelium (red or green symbols), the transport through the hyphae from the ERM to the IRM (see mycorrhizal interface), and the uptake from the mycorrhizal interface by mycorrhiza-inducible plant transporters in the peri arbuscular membrane (orange symbols). Indicated by the red and green fungal structures is the colonization of one host root by multiple fungal species that can differ in their efficiency with which they are able to take up nutrients from the soil and transfer these nutrients to their host. After: Heike Bücking and Arjun Kafle (2015).

The contribution of the AM symbiosis to the phosphate nutrition has long been known, but whether AM fungi contribute similarly to the nitrogen nutrition of their host is still controversially discussed. However, there is a growing body of evidence that demonstrates that AM fungi can actively transfer nitrogen to their host, that the host plant with its carbon supply stimulates this transport, and that the peri arbuscular membrane of the host is able to facilitate the active uptake of nitrogen from the mycorrhizal interface. They stated that nitrogen transport through the fungal hyphae and across the mycorrhizal interface. Fig. (54), illustrates that mycorrhizal roots have two uptake pathways for nutrients: the plant uptake pathway (PP) and the mycorrhizal uptake pathway The PP involves the uptake of nutrients via high- or low affinity uptake transporters in the epidermis or root hairs. Particularly for nutrients with a low mobility in the soil (phosphorous), the uptake via the PP is often limited by the development of depletion zones around the roots. By contrast, the MP involves the uptake by high affinity nutrient transporters in the ERM, followed by the translocation along the hyphae to the intraradical mycelium (IRM) in the root cortex, and the uptake from the mycorrhizal interface by mycorrhiza-inducible plant uptake transporters, Smith, and Smith, (2011). However, a plant is simultaneously colonized by communities of AM fungi that can differ in their efficiency with which their MP contributes to the total uptake of nutrients by the plant. The uptake and transport of nutrients via both pathways and their contribution to the nutrient supply of the plant has so far primarily been studied for phosphorous, Smith *et al.,* (2011), Smith, and Smith, (2011), Smith *et al.,* (2004), but both pathways also play a role in the N uptake by plants. A more or less densely arranged fungal sheath that can represent a significant apoplastic barrier and restricts the nutrient uptake of ecto mycorrhizal roots via the PP, Bücking *et al.,* (2002), Behrmann, and Heyser, (1992) encloses Ecto mycorrhizal roots. However, in contrast to ecto mycorrhizal roots, AM roots are structurally unaltered and can theoretically use both pathways for nutrient uptake. Previously, it was generally believed that the PP is not affected by the symbiosis and that both uptake pathways act additively Fig. (54).

However, information available in literature is not always consistent on this point. Mycorrhizosphere is more affected by nutrient chemistry in the soil as compared to that of bacteria of rhizosphere. Microorganism population varies in rhizospheric soil and bulk soil and contributes significant role to determine the rhizosphere effect on nutrient availability and plant uptake, Vega (2007), Gray and Williams (1971). The plant species belonging to gramineae, solanaceae and leguminoseae families had higher rhizospheric effect on soil available phosphorus (P) and biological properties than those belonging to cruciferae and compositae, Safari and Rashidi (2012). Phytosiderophores are organic substances such as nicotinamine, mugineic acids (MAs) and avenic acid etc. produced by plants, Mori and Nishizawa (1987) under iron (Fe)- deficient conditions, which can form organic complexes or chelates with Fe^{+3}, and increase the movement of iron in the soil, Ueno *et al.,* (2007). Non-proteineous, low molecular weight acids are released by the graminaceous species under the iron and Zn deficiency stress, Wallace (1991). Type of siderophore affects the plant nutrient uptake from rhizosphere. Rhizopus arrhizus has slightly higher affinity towards Fe compared to phytosiderophores. Rhizoferrin is a good Fe source for barley, probably because of the exchange of iron (Fe) from rhizoferrin to the phytosiderophores, Yehuda *et al.*, (1996) Fig. (54), (55).

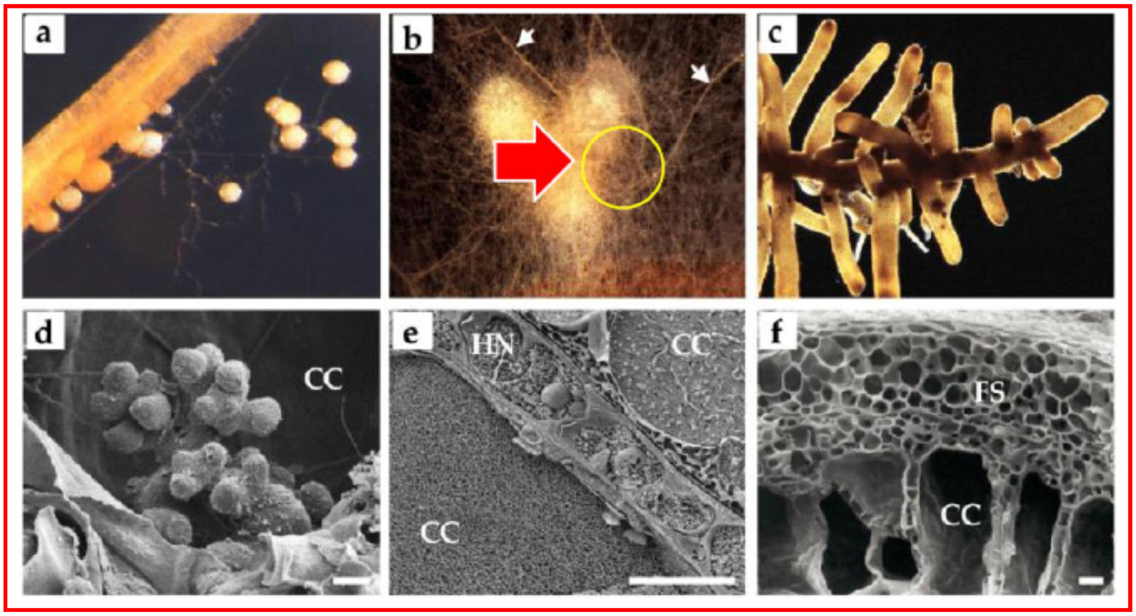


Fig. 54: Illustrates morphological characteristics of AM (a, d) and ECM (b, c, e, f) roots. Images of the outer root morphology (a-c) and scanning electron microscopically images of fungal structures within the root (d-f). (a) AM root of Daucus carota colonized with Glomus intraradices with fungal spores and ERM; (b) dichotomous ECM pine root colonized by Suillus bovinus with rhizomorphs (arrows); (c) ECM root of beech colonized by an unidentified fungus with extensive root branching; (d) arbuscule of an AM fungus within the cortical cell (CC) of an ECM root of Populus tremuloides; (e) Hartig net (HN) region and mycorrhizal interface in an ECM root of Populus tremuloides; (f) ECM root with epidermal Hartig net and radially elongated epidermis cells and fungal sheath (FS) After: Heike Bücking and Arjun Kafle (2015).

Mycorrhiza fungi (white hair are the mycorrhizal fungi)

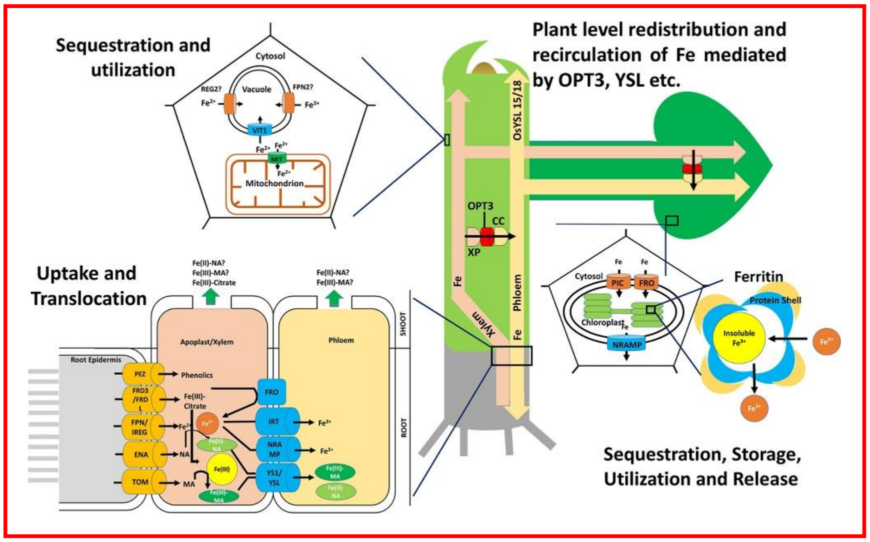


Fig. 55: Illustrates schematic representation of major iron transporters and chelate effluxers involved in Fe uptake, translocation, redistribution, circulation, sequestration and storage in plants. After Kobayashi and Nishizawa (2012); Zhai *et al.,* (2014); Connorton *et al.,* (2017). After: Tirthankar Bandyopadhyay and Manoj Prasad (2021).

Anthropogenic activities have caused the concentration of atmospheric CO_2 to increase from 280 ppm, at the beginning of the industrial revolution to over 370 ppm at present, Rouhier *et al.* (1994). Current estimates suggested that the atmospheric CO_2 concentration range will lie between 450 and 600 ppm by 2050, Kattenberg *et al.,* (1996). Microorganisms in soil regulate the dynamics of organic matter decomposition and plant nutrient availability, Paterson *et al.,* (1997) and play a key role in the responses of ecosystems to global climate changes, Sadowsky and Schortemeyer (1997). Elevated CO_2 affects soil microorganisms indirectly through increased root growth and rhizodeposition rates, Rogers *et al.,* (1994) because the CO_2 concentration in soil is much greater than the atmospheric CO_2 van Veen *et al.,* (1991) Fig. (56). Impact of elevated CO_2 in soil ecosystems focuses primarily on plants and a variety of microbial processes. The processes considered include changes in microbial biomass of C and N, soil enzyme activity, microbial community composition, organic matter decomposition, and functional groups of bacteria mediating trace gas emission in terrestrial and wetland ecosystems, Paterson *et al.,* (1997) In the present times elevated concentration of atmospheric gases like CH_4, N_2O etc. also play a significant role in global climate phenomena, Kundu *et al.,* (2013). It affects the root secretion from plant and rhizospheric microbial population, Mandal *et al.,* (2013) Studies revealed that the increased temperature accelerates the rate of microbial decomposition, thereby increasing CO_2 emitted by soil respiration producing a positive feedback to global warming, Allison *et al.,* (2010). Response of biological systems with reference to temperature is expressed as Q10 function, Prosser (1991),

$$Q10 = k2- k^{10} (T2 - T1)$$

Where Q10 is the relative change in decomposition rate with a 10-^{C} rise in temperature. k2, k1 are the rate constants for a process of interest at two observed temperatures, T2 and T1 are temperature increase in soil respiration exponentially. The concentration of heavy metal in the rhizosphere, change in the microbial population and root exudates from plants, and reduced plant nutrient uptake and crop growth, Abdousalam (2010) Leita *et al.,* (1995).

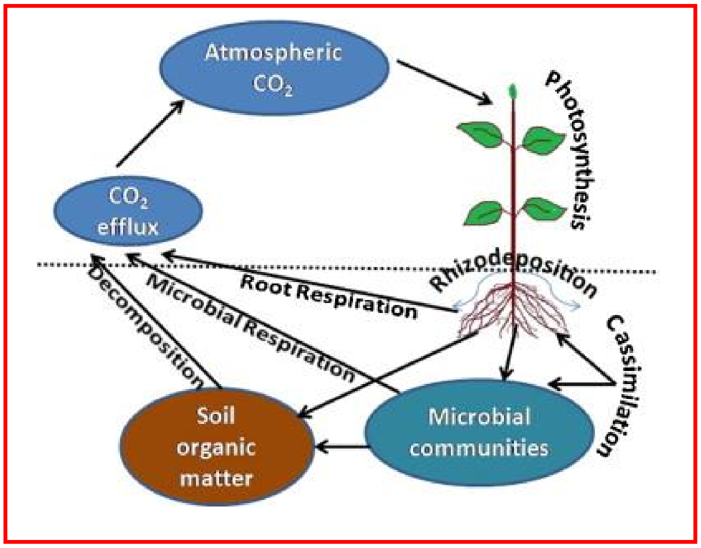


Fig. 56: Illustrates elevated CO_2 affects soil microorganisms indirectly through increased root growth and rhizodeposition rates

7.4. Root exudates and their effects on soil microbial activity

Soil microbial activity is the main source of the vital activities in soil besides plant root exudations. Populations of soil microbial in the rhizosphere have continuous flow of low as well as high molecular weight of organic substances derived from plant roots that control soil microbial activity, Nannipieri *et al.,* (2008). Soil microbial activity and its diversity in the rhizosphere have been extensively studied, Bashir *et al.,* (2016); Hakeem and Akhtar (2016); Hakeem *et al.,* (2016); Kumar *et al.,* (2016a); Swamy *et al.,* (2016); de Medeiros *et al.,* (2017), depending on the interaction between cultivated plants and rhizosphere properties Fig. (57), which include:

- Effects of applied pesticides e.g., Álvarez-Martín *et al.,* (2016); Franco-Andreu *et al.,* (2016); Lv *et al.,* (2017); Mauffret *et al.,* (2017)
- Effects of soil earthworm in presence of plants, Aghababaei *et al.,* (2014); Aghababaei and Raiesi (2015); Lv *et al.,* (2016); Zhang *et al.,* (2016a); Kim *et al.,* (2017; Liu *et al.,* (2017b)
- Effects of soil pollution including organic and inorganic pollutants, Parelho *et al.,* (2016); Hansda *et al.,* (2017); Le *et al.,* (2017); Tong *et al.,* (2017); Wang *et al.,* (2017b)
- Effects of different soil characterizations like soil organic matter, soil redox potential, etc., Khan *et al.,* (2016); Su *et al.,* (2017); Xiao *et al.,* (2017)
- Effects of climate change, Bojko and Kabala (2017); Zhang *et al.,* (2016b), (2017b)
- Effects of plant characterization, Li *et al.,* (2017); Mohammadi *et al.,* (2017); Zhang *et al.,* (2017c)
- Effects of application of soil amendments and fertilizers, Meena *et al.,* (2016); Abad-Valle *et al.,* (2017); Wang *et al.,* (2017c, d)
- Effects of applied nanomaterials, Nogueira *et al.,* (2012); Oyelami and Semple (2015); Schlich and Hund-Rinke (2015); Schlich *et al.,* (2016); Liang *et al.,* (2017)
- Effects of different stresses, Cheng *et al.,* (2016); Lee and Kang (2016); Xue *et al.,* (2017); Wu *et al.,* (2017)
- Effects of tillage and other agricultural practices, Kabiri *et al.,* (2016); Tautges *et al.,* (2016); León *et al.,* (2017); Yuan *et al.,* (2017)

- Effects of transgenic plants on microbial diversity in the rhizosphere soil, Chaudhry *et al.,* (2012); Canfora *et al.,* (2014); Sahoo *et al.,* (2015); Turrini *et al.,* (2015); Guan *et al.,* (2016); Arpaia *et al.,* (2017).

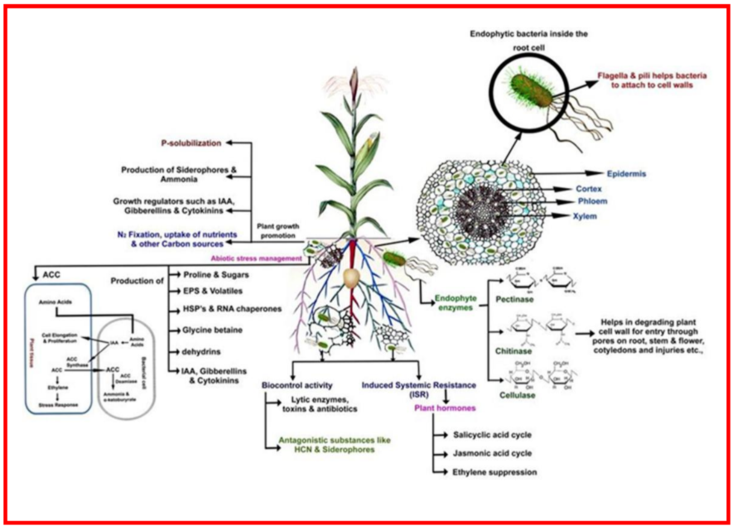


Fig. 57: Represents of possible plant-microbe interactions favoring plant growth and/or biocontrol of phytopathogens by streptomycetes as rhizosphere competent microorganisms and/or endophytes. After: Vardharajula *et al.* (2017), Sai Shiva Krishna Prasad Vurukonda *et al.* (2018)

Therefore, there is a crucial understanding for the principles of interaction among microbes–plants and microbes–microbes. The communication among microbes and plants could provide the researchers with the most important and beneficial microbial populations for agricultural. Moreover, the associated plants with microbial communities can be considered essential for both plant growth and its health, Berg *et al.,* (2014); Mueller and Sachs (2015); Cai *et al.,* (2017). A great progress has been achieved regarding different interactions between plant and soil microbes and their rhizosphere micro biomes, Berendsen *et al.,* (2012); Ofek *et al.,* (2014); Ai *et al.,* (2015); Mueller *et al.,* (2016); Cai *et al.,* (2017). These interactions could be characterized by (**a**) the competition between plants and soil microorganisms for nutrients. (**b**) Nutrients dynamics and their function in the rhizosphere. (**c**) Activity of enzymes in the rhizosphere. (d) Soil respiration and its rates and, (**e**) the biodiversity of microorganisms in the rhizosphere, Nannipieri *et al.,* (2008); Duan *et al.,* (2015); Cavagnaro *et al.,* (2016); Zhu *et al.,* (2017). Therefore, the microbial activity in the rhizosphere mainly depends on cultivated plant species because of the different compositions in plant root exudates. Rhizosphere microbes could be classified into three groups in accordance to their interactions with plants: (**A**) microbes that have negative effects on plants, e.g. phytopathogens; (**B**) microbes that have positive effects on plants, i.e. promotion of plant growth and symbiosis; and (**C**) microbes that have neutral effects or no benefits. Symbiosis represents the most important interaction between plants and rhizobia, arbuscular mycorrhizal fungi (*AMF*), plant growth-promoting rhizobacteria (*PGPR*) and plant growth-promoting endophytic fungi (*PGPF*), Fig. (58).

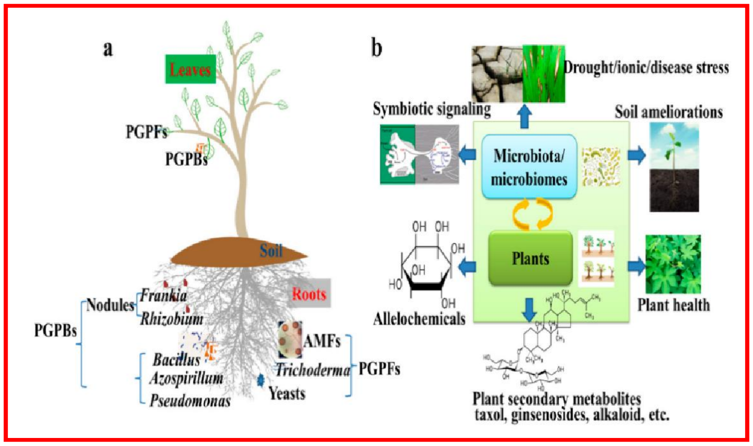


Fig. 58: Illustrates (**a**) beneficial microbes and microbiota for crop plants. Beneficial microbiota assembles in rhizosphere, phyllosphere, and endosphere. Arbuscular mycorrhizal fungi (AMFs), Frankia spp. and Rhizobium spp. act as symbionts for plant roots; (**b**) Future research trends of microbiota and micro biomes associated with crop plants. PGPBs, plant growth-promoting bacteria; PGPFs, plant growth-promoting fungi. After: Lei *et al.,* (2020)

These symbioses or beneficial microbial inoculums are mainly used in producing sustainable agri-biotechnological products including bio pesticides, biofertilizers, bioremediators and phyto-stimulators. Several environmental factors including soil pH, light intensity, soil temperature, soil aeration, soil texture, and nutrient status and soil microbes considered as the main qualitative and quantitative factors controlling the composition of root exudates.

7.5. Root exudates and their effects on plant nutrition

As mentioned before, the rhizosphere is an essential zone for plant growth and its production, and it plays a vital and significant role in the nutritional and physiological functions of crops, Kumar *et al.,* (2016a). Generally, there is close relationship between plant roots, their exudations and plant nutrition. There are direct and indirect effects of plant root exudates on plants nutrition including uptake, transformation, translocation and accumulation of different soluble compounds in the rhizosphere, Fig.(59), Neumann (2007); Nannipieri *et al.,* (2008); Doornbos *et al.,* (2012); Bashir *et al.,* (2016); Liu *et al.,* (2017c); Meier *et al.,* (2017).

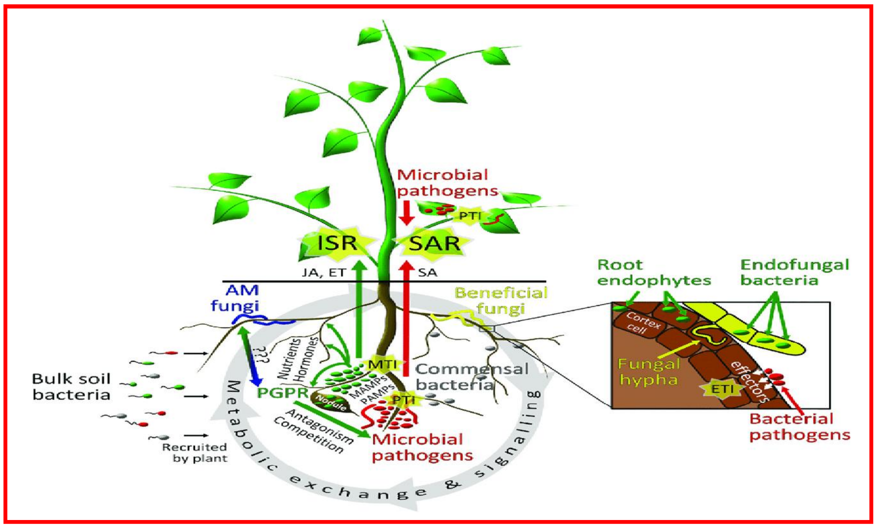


Fig. 59: Schematic epresentation of the multiple and complex interorganismal interactions taking place in the plant rhizosphere and phyllosphere. Beneficial bacteria are depicted in green, fungal and bacterial

pathogens in red, commensal bacteria in gray, arbuscular mycorrhizal fungi in blue, and other beneficial fungi in yellow. Arrows in the corresponding color indicate known interactions described in the text. Inset on the right represents a magnification of the small frame in the main image.

Moreover, the bioavailability and uptake of various nutrients in the rhizosphere are influenced by different characterizations of soil, plant root exudates and nutrient speciation as well as the microbial interactions with both soil and plants, Kumar *et al.,* (2016a); Rashid *et al.,* (2016); Nguyen *et al.,* (2017). The nutrient transfer from plant cells to microbial cells and its dynamics are mainly affected by the physiological aspects of the microbe–plant interactions, Munroe *et al.,* (2015); Callesen *et al.,* (2016); Das *et al.,* (2017), Nietfeld *et al.,* (2017). The diffusion of different nutrients and their supplements in the rhizosphere are mainly controlled by the gradient in diffusion of nutrients between soil surfaces and root surfaces, Kumar *et al.,* (2016a). Under the frame of plant nutrition, the complex interactions among plants, soils and microbes should be understood. These interactions could control the uptake, mobilization, transfer, translocation, accumulation of nutrients and their bioavailability, Lambers *et al.,* (2009); Miki (2012; Kumar *et al.,* (2016a) and biogeochemistry cycles and formation of soils in the rhizosphere or terrestrial ecosystem, Maheshwari *et al.,* (2012); Perlatti *et al.,* (2016). These interactions also include all botanical characterization, which in turn alters the growth and reproduction of plants, Miki (2012); Compant *et al.,* (2016). On the other hand, several compounds called root exudates have been identified from the rhizosphere zone, which have many roles in plant nutrition: (**a**). Acquisition of both nutrients and water through rhizosphere modification and soil with mucilage, fetchers (i.e. phytosiderophores), modifiers (i.e. rhizosphere modification with protons and reductants) and ectoenzymes (i.e. converting unusable organic forms into usable ones like phosphatases) (b). Protection against physical stress and pathogens through amelioration of the rhizosphere, modification of soil interfaces and production of both phytoalexins and antibiotics (c). Protection against toxic elements and competition through complexation of toxic elements like aluminium or sequestering like sodium as well as the root exudates that could modify the rhizosphere through phyto-actives like allelochemicals (d). Establishment of symbiotic relationships with microbes such as Rhizobium, mycorrhiza (AMF), Azotobacter/Azospirillum through nitrogen fixation and phosphorus and mineral uptake Maheshwari *et al.,* (2012). Therefore, plant root exudates are one of the most important sources for plant nutrition, which help plants directly or indirectly through promoting soil microbial activity and protecting them against pathogens. Plant nutrition processes should start from the rhizosphere and its plant root exudates.

8. Impacts of ozone on soil- microbial - plant interaction

8.1. Effects on soil microbial and plant nutrition in rhizosphere

Rapid urbanization and industrialization in the Northern Hemisphere have led to rising ground-level ozone (O_3) concentrations over the past several decades, Cooper *et al.,* (2014); Lu *et al.,* (2018). As an airborne pollutant that is highly phytotoxic, O_3 can induce changes that profoundly influence plant–soil–microbe systems by disrupting photosynthesis, antioxidant activity, and growth in plants. Production and breakdown of litter such that carbon (C) pools and nutrient cycling are adversely affected, Agathokleous *et al.,* (2020); Li *et al.,* (2017); Paoletti *et al.,* (2020); Wittig *et al.,* (2009), Fig.(60) illustrate how O_3 affects plant communities, plant-insect interactions, and PSFs and thus, plant, insect, and microbial diversity.

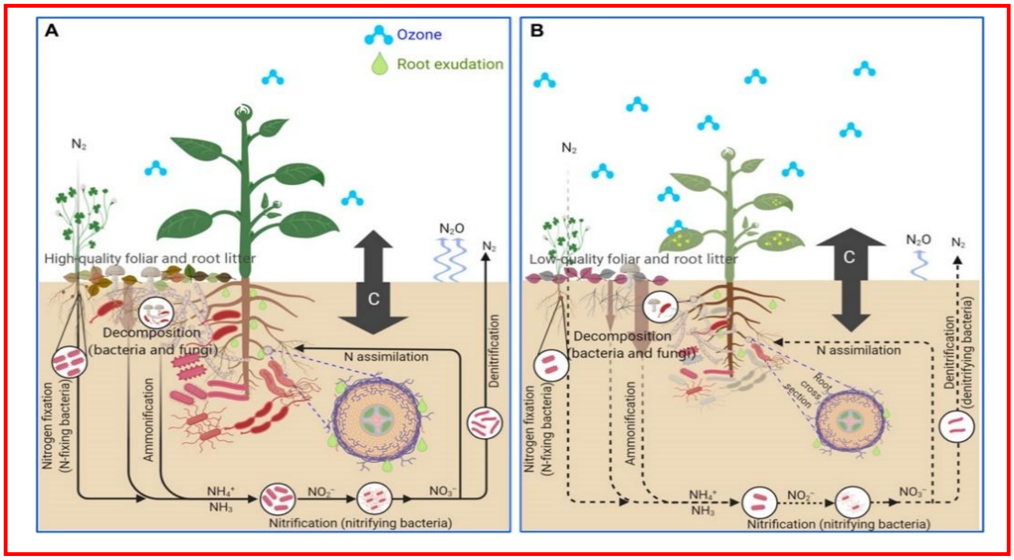


Fig. 60: PSFs under elevated ozone (O_3). A healthy holobiont in a clean atmosphere (with natural background O_3 levels), where mutually beneficial PSFs occur (A), versus a suppressed holobiont and disturbed PSFs due to O_3 (B). Gray icons represent the loss of microbial biomass but not for particular species. O_3 decreases root biomass, reduces the quantity, and affects the quality of foliar and root litter, potentially affecting litter-feeding soil macro fauna, decomposition, and cycling of nutrients. O_3 may influence the chemical composition of roots and soluble root exudates, including reduced exudation of some extracellular enzymes (e.g., β-glucosidase). The rate of decomposition can be increased or decreased species-specifically. Soil microbial biomass also decreases. O_3 alters the composition and structure of soil microbial communities, with fungi being likely more susceptible to O_3 than bacteria. Some N-fixing bacteria are promoted by O_3, but N fixation is reduced by O_3 in other studies. Some denitrifying bacteria are likewise promoted by O_3, and the abundance of some nitrifying bacteria can be either reduced or increased by O_3. The decrease in microbial biomass disturbs the rates of N and C cycling as feedback, potentially reducing N_2O and storing less C in the rhizosphere. The changes in C and N cycling in PSFs may occur in tandem with changes in the cycling of other nutrients due to poor leaf and root litter as well as affected decomposition processes. After: Evgenios Agathokleous *et al.,* (2020)

Evgenios Agathokleous *et al.,* (2020) reported that elevated, tropospheric ozone gradually affects the composition and diversity of plant communities by affecting key physiological traits, Fig. (61).

Foliar chemistry and emission of volatiles affecting plant-plant competition, plant-insect interactions, and the composition of insect communities. Moreover, plant-soil-microbe interactions and the composition of soil communities by disrupting plant litter fall and altering root. Elevated tropospheric ozone concentrations induce adverse effects in plants. The community composition of soil microbes is consequently changed, and alpha diversity is often reduced, effects always depend on the environment and vary across space and time. Above and belowground trophic interactions play pivotal roles in maintaining plant diversity. Plants respond to herbivores by various physiological mechanisms, affecting plant performance and plant-microbe interaction and potentially regulating ecosystem processes and community dynamics, Biere and Bennett (2013), Holopainen, and Blande (2013). Plant-soil feedbacks (PSFs) likewise involve interactions among plants, soil microbiota, and abiotic factors, affecting structural and functional features at different scales of biological organization, Fig. (62).

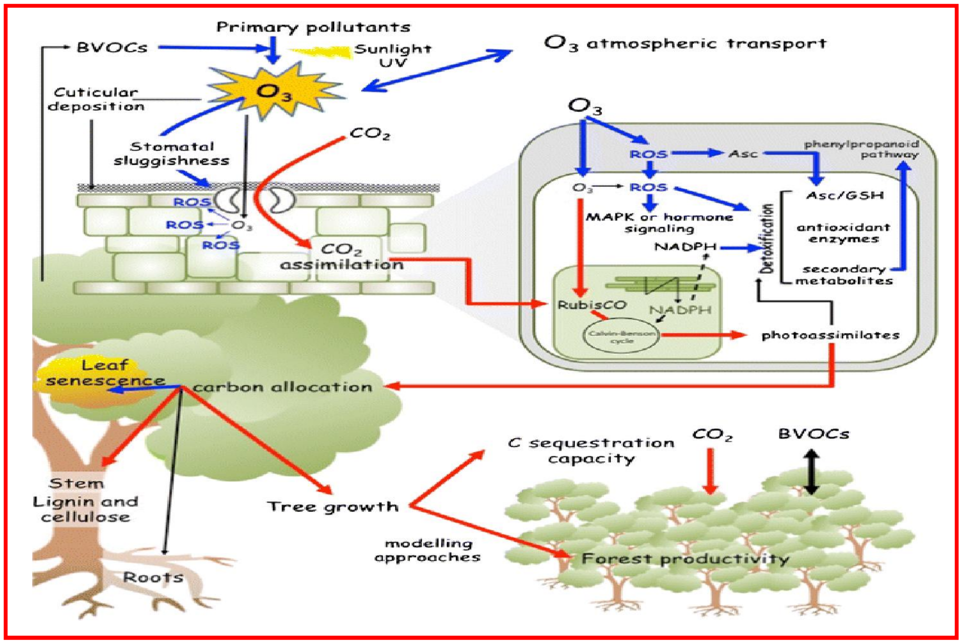


Fig. 61:. Represents O_3- effects on trees, from cell metabolism to forest ecosystem scale, highlighting (i) the perception of the pollutant at the leaf scale, (ii) the cellular responses implying detoxification and CO_2 assimilation and (iii) the carbon allocation to the various plant organs and the consequences on tree growth and on carbon sequestration at the forest level. Where arrows are present, red and blue indicate an O3-driven inhibition and stimulation, respectively. BVOCs biogenic VOCs. After: Yves Jolivet *et al.,* (2016)

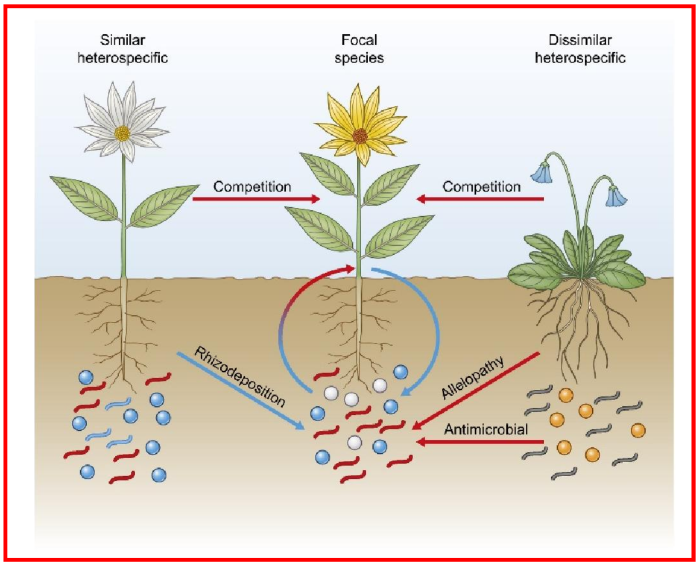


Fig. 62: Illustrates hypothesized mechanisms by which neighbor similarity affects biotic plant–soil feedback (PSF) for the focal species. Blue arrows, positive relationships; red arrows, negative relationships. Plants are expected to promote the growth of their associated soil biota (dots and lines beneath roots), which can result in either positive or negative PSF. Neighboring individuals can modify this process. Neighbors, regardless of species, may compete with the focal plant and alter PSF by modifying resource availability and reducing plant growth. Heterospecific individuals with similar characteristics are expected to share soil biota with the focal plant (blue circles and red lines), thereby increasing the abundance of soil biota affecting PSF, probably through rhizodeposition. Conspecific

neighbors should have similar effects (not shown). Heterospecific individuals with dissimilar characteristics should have distinct soil biota (orange circles and black lines), which are less likely to affect the focal plant. Recent evidence suggests, however, that soil biota may suppress each other through the production of antimicrobial compounds. This could affect the mechanisms of PSF if the antimicrobial effects are specific to certain species and functional groups. Many plant species also produce allelochemicals that can inhibit both the focal plant and its associated soil biota. If these chemicals target certain microbial groups, such as mycorrhizal fungi, this could change which mechanisms drive PSF. After: Bennett and John Klironomos. (2019).

As plants grow, they modify their soil environment, including nutrient availability and soil biota, Bennett *et al.,* (2017); Fujii *et al.,* (2018). These effects may feedback on the survival and growth of seedlings (plant–soil feedback, PSF), thus, altering plant population and community dynamics, Bennett *et al.,* (2017). PSF can range from negative to positive: negative PSF may occur through resource depletion, excretion of autotoxic compounds or accumulation of natural enemies, and positive PSF may occur if resource access increases, allelopathic chemicals accumulate or mutualists become abundant, Bennett *et al.,* (2017; Kulmatiski *et al.,* (2017); Smith- Ramesh & Reynolds, (2017) Fig.(63). These mechanisms, however, do not exist in isolation and are often interdependent. Consequently, understanding how these PSF mechanisms interact is critical to understanding PSF and its effects on plant populations and communities

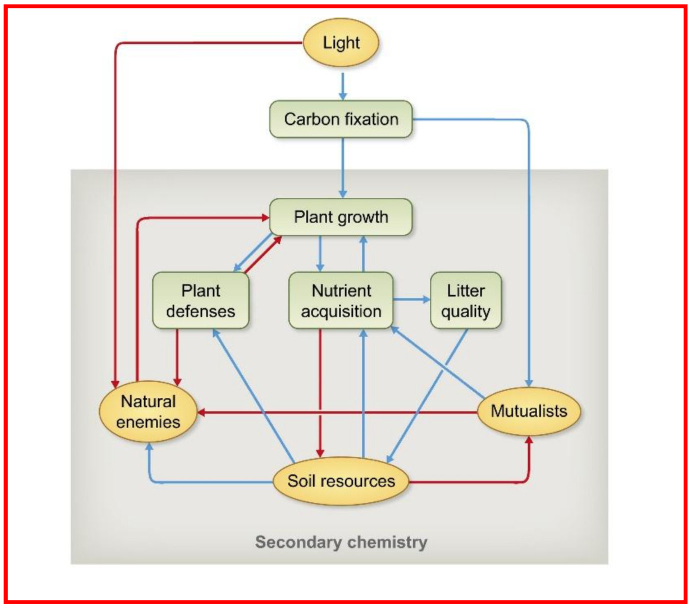


Fig. 63: Illustrates hypothesized mechanisms affecting plant–soil feedback and their dependence on resource availability. Yellow ovals represent exogenous factors and green squares show plant processes. Blue arrows show positive relationships; red arrows, negative relationships. Secondary chemistry is represented as a large gray box as it has the potential to affect multiple plant processes as well as their interaction with the exogenous factors. Detailed descriptions of each pathway can be found within the text.

As plants grow, it modifies soil environment, which include essential nutrient availability and soil biota, Bennett *et al.,* (2017); Fujii *et al.,* (2018). Such effects may feedback on the survival and growth of seedlings (plant–soil feedback, PSF), thus altering plant population and community dynamics Bennett *et al.,* (2017). PSF can range from negative to positive: negative PSF may occur through resource depletion, excretion of autotoxic compounds or accumulation of natural enemies, however, positive PSF occur when resource access increases, allelopathic chemicals accumulate or mutualists become abundant, Bennett *et al.,* (2017; Kulmatiski *et al.,* (2017); Smith- Ramesh & Reynolds, (2017). These mechanisms, however, do not exist in isolation and are often interdependent. Consequently, understanding how these PSF mechanisms interact is critical to understanding PSF and its effects on plant populations and communities.

These effects allow plants to readily respond to environmental changes and mediate ecosystem processes, Pugnaire *et al.,* (2019). Trophic interactions depend on environmental conditions, so changes in the environment may affect biodiversity and the functioning of terrestrial ecosystems, Holopainen and Blande (2013), Howard *et al.,* (2020), Bergmann *et al.,* (2017). Ground-level concentrations of ozone (O_3) increased considerably in the second half of the 20th century due to increased levels of NO_x, volatile organic compounds (VOCs), and radical precursors responsible for its production, Tarasick *et al.,* (2019), Yeung *et al.,* (2019). Suggesting that Atlantic islands in the Northern Hemisphere, the Mediterranean Basin, equatorial Africa, Ethiopia, the Indian coastline, the Himalayan region, southern Asia, and Japan have high endemic richness at high ozone risk by 2100.

Fuhrer *et al.,* (2016); Sicard *et al.,* (2017) stated that, ozone levels are forecast to remain elevated for the remainder of the 21st century, creating a risk to terrestrial ecosystems. Rhizosphere microbial communities influence the ability of plants to tolerate abiotic and biotic stressors, while also affecting biogeochemical cycling and nutrient availability through soil organic matter mineralization, Philippot *et al.,* (2013). Higher levels of O_3 more profoundly suppress resource allocation to roots relative to shoots, Grantz *et al.,* (2006); Li *et al.,* (2020), thus, disproportionately restricting the levels of nutrients available to heterotrophic microbes and thereby altering susceptible belowground microbial processes Agathokleous *et al.,* (2016); Andersen, (2003). The effects of O_3 on plant processes and aboveground communities have been increasingly well studied in recent years, Feng, Shang, Gao *et al.,* (2019); Feng, Shang, Li, *et al.,* (2019); Li *et al.,* (2017); Wittig *et al.,* (2009). Few reports to date exploring O_3-related changes in the composition of soil microbial communities associated with agricultural systems have yielded inconsistent results, both positive and negative effects on wheat and rice rhizosphere microbial communities having been reported, Bao *et al.,* (2015); Changey *et al.,* (2018); Chen *et al.,* (2010); Feng *et al.,* (2015); Li *et al.,* (2012), (2013). In some cases, O_3 was found to suppress microbial diversity, Chen *et al.,* (2019); Wang *et al.,* (2021), whereas in other cases, it altered such diversity, Ueda *et al.,* 2016) or had no effect Li *et al.,* (2013). Such phenomena might related to the species-specific effects of O_3 or to differences in the dose and duration of O_3 exposure, Agathokleous *et al.,* (2019) Fig. (64). Such variability may also be associated with the impact of other environmental factors that co-vary with O_3 levels on rhizosphere microbial community responses, Dunbar *et al.,* (2014); Kanerva *et al.,* (2008); Phillips *et al.,* 2002; Wang *et al.,* (2017) and O_3 warming interaction, Changey *et al.,* (2018). Elevated of O_3 levels and reactive nitrogen (N) deposition often co-occurs, Feng, Shang, Li, *et al.,* (2019); Zeng *et al.,* (2019), Few studies exploring the potential interactive effects of two variables on rhizosphere microbial communities. Nitrogen fertilization can profoundly alter plant growth, physiology, and productivity, all of which may shape the associated soil microbial community, Eastman *et al.,* (2021); Zhang *et al.,* (2018). Ozone- O_3 / N interactions have primarily focused on aboveground effects and have yielded contradictory results, with some authors having reported that nitrogen addition can reverse the negative impact of O_3 exposure, Handley and Grulke, (2008); Mills *et al.,* (2016), whereas others observed the opposite effect, Azuchi *et al.,* (2014); Brewster *et al.,* (2018) or detected no relationship between these variables, Feng, Shang, Li, *et al.,* (2019); Harmens *et al.,* (2017); Li *et al.,* (2020). Fang, (2008), reported that Poplar tree plantations are the second largest plantations in China and the first largest planted area in the world. As a fast-growing species, poplar has a high nitrogen demand and due to high stomatal conductance the potential to have a high uptake of O_3, Hu *et al.,* (2015). Several studies have focused on the poplar response under elevated O_3 in combination with soil nitrogen, such as leaf photosynthesis, Xu *et al.,* (2020), isoprene emission, Yuan *et al.,* (2020), and root biomass, Li *et al.,* ., (2020); however, little is known about the response of poplar rhizosphere soil microbial communities. Thus, the first goal of this analysis was to assess the interactive effects of elevated O_3 and N addition on rhizosphere soil microbial communities through an analysis of four N addition levels and five concentrations of O_3 using an O_3-sensitive poplar species, Hu *et al.,* (2015). The second goal of this analysis was to evaluate whether different levels of N altered microbial community structure and compositional responses to concentration-based or flux based O_3 doses. These two categories of indices are used to establish exposure / flux–response relationships with biomass loss, Hu *et al.,* (2015), physiological traits, Shang *et al.,* (2017), and visible leaf injury, Sicard *et al.,* (2020) for risk assessment and the estimation of critical levels of O_3 damage to poplar. Thus, we used both indices to understand the relationship between O_3 dose and microbial community composition. The third aim was to elucidate how different soil and plant variables directly and indirectly shape microbial community responses along O_3 and N gradients.

Ozone (O_3) in the troposphere is not just a greenhouse gas but also an air pollutant that is prejudicial to human health and injures vegetation, Krupa and Manning (1988), Jerrett *et al.,* (2009). Forster *et al.,* (2007) stated that tropospheric O_3 concentrations hereinafter referred to as O_3 have significantly increased by about 1–2% per year in recent decades because of accelerated industrial development and intensive combustion of fossil fuels, Forster *et al.,* (2007). Due to highly oxidizing phytotoxic pollutant, O_3 could inhibit plant growth and cause considerable reduction in crop yields and quality, Ainsworth *et al.,* (2014). Moreover, elevated O_3 may impact the C allocation to roots, Andersen (2003), alter the rhizodeposition, Kou *et al.,* (2014) change the quantity and composition of root exudate, M Crady and Andersen (2000), modify the nutrient and energy supply to soil microorganisms influence the microbial community diversity, Chen *et al.,* (2019), and accordingly, influence soil CO_2 emission flux, Hu *et al.,* (2018), Kanerva, *et al.,* (2007).

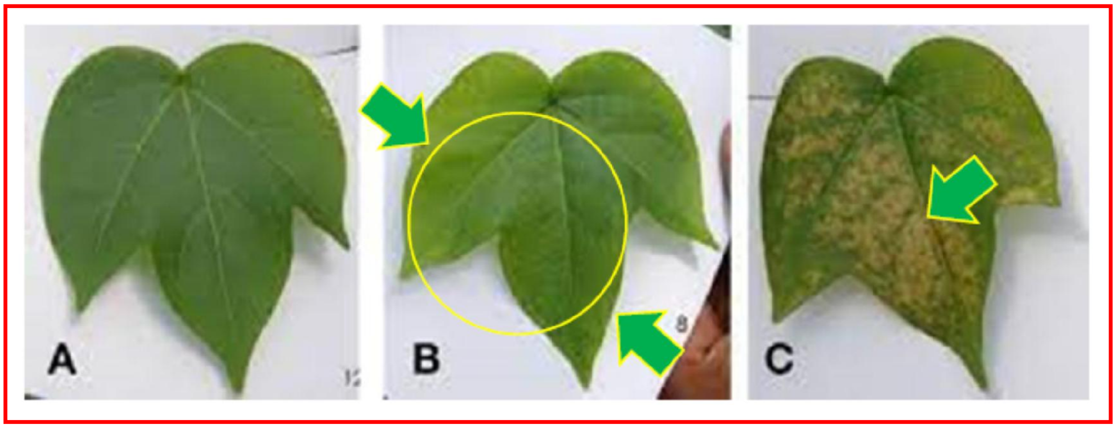


Fig. 64: Shows some examples of no to extreme O3 exposure effects in primary cotton leaves. (**A**) No exposure; (**B**) 15-min exposure to 1200 nl O3^{-}l $^{-}$1; (**C**) 15-min exposure to 2400 nl O3^{-}l $^{-}$1.Arrows in (**B**) indicate leaf margin 'burn' while arrow in (**C**) indicates lack of necrosis near the vein. Note the irregularity of the chlorosis in (**B**) and necrosis in (**C**). After: Grantz (2015).

High levels of atmospheric O_3 make it difficult to assess the future soil C source/sink function. Studies have reported by several researchers, Pregitzer *et al.,* (2008), Nikolova *et al.,* (2010), that increasing CO_2 efflux under elevated O_3 but there are also results to the contrary, Hu *et al.,* (2018), Kou *et al.,* (2018). These inconsistencies could be attributed to the variations in ecosystem, type Kou *et al.,* (2018) Chen *et al.,* (2019), O_3 exposure duration, Scagel *et al.* (1997), fumigation facility, Wang *et al.* (2019) and the complexity of soil and climate conditions, Krupa and Manning (1988). The purposes of this study were to assess the responses of soil CO_2 emission flux to elevated O_3 using meta-analytic techniques and Jerrett *et al.,* (2009) to reveal the possible sources of variation.

8.2. Influence of Ozone on plant leaf

The first standard developed for O_3 injury was visible discoloration of foliage (visible injury) Jacobson and Hill (1970); Miller *et al.,* (1996); Grulke & Lee (1997); Brace *et al.,* (1999). The level of injury (chlorosis, chlorotic mottle, bronzing, necrosis), the proportion of leaf surface area affected, where it occurred (young or older leaves, shaded or exposed surfaces) and what plant age was most responsive are recorded after a quantified exposure (leaf from a plant with little versus known, higher O_3 exposure; Fig.(65). Visible symptoms of O_3 vary genetically and among species, Heath (1980), illustrates some Ozone damages vegetation and ecosystems by inhibiting the ability of plants to open the microscopic pores on their leaves to breathe. It interferes with the photosynthesis process by reducing the amount of carbon dioxide the plants can process and release as oxygen. The U.S. Forest Service Inventory and Analysis Program (US FIA) observes visible foliar O3 assessments at forested sample plots across the United States as one measure of forest health, Smith *et al.,* (2003). For example, 12% black cherry, 15% loblolly pine (*Pinus taeda* L.) and 24% sweet gum (*Liquidambar styraciflua* L.) trees expressed foliar injury in sampled plots in the northeast and mid-Atlantic states, Coulston *et al.,* (2003).

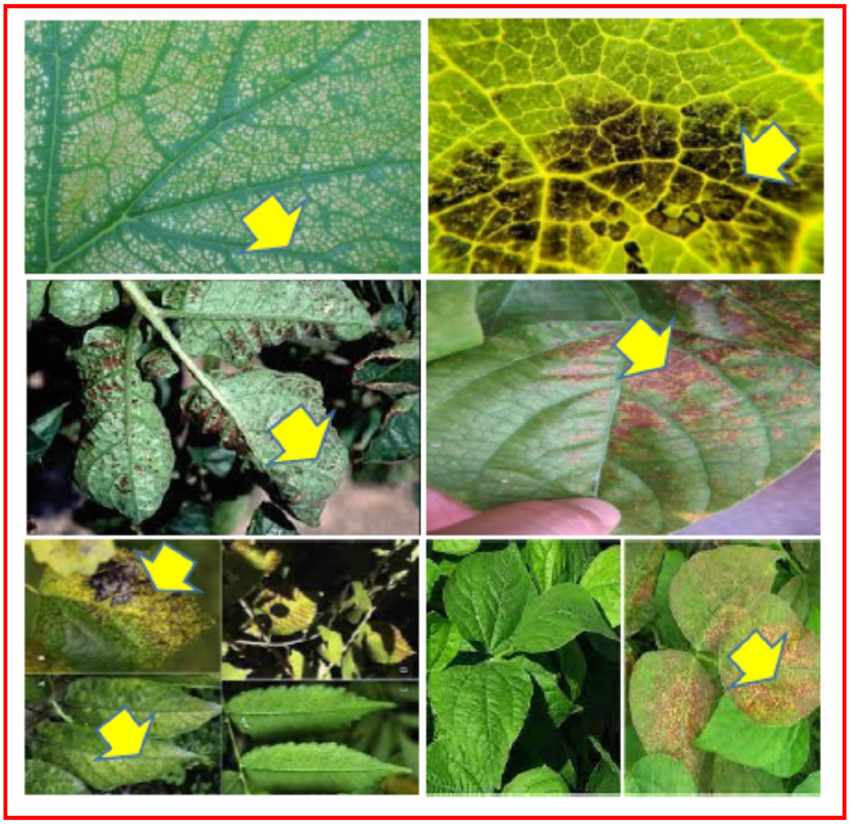


Fig. 65: Illustrates ozone damages vegetation and ecosystems by inhibiting the ability of plants to open the microscopic pores on their leaves to breathe. It interferes with the photosynthesis process by reducing the amount of carbon dioxide the plants can process and release as oxygen.

Visible symptoms are definitive for symptomatic species and can be replicated with controlled O_3 exposures, Brace *et al.,* (1999). Visible symptoms have been correlated to losses in both seed (sand blackberry, Rubus cuneifolius Pursh; Chappelka (2002) and biomass (ponderosa pine; Arbaugh *et al.,* (1998) production. However, some species have losses in production without visible symptoms white fir; Retzlaff *et al.,* (2000). In crops, 'loss' is related to the plant part that is economically important: seeds (soybean, *Glycine max* (L.) Merr; Zhang *et al.,* (2014); common bean, *Phaseolus fava*, now *Phaseolus vulgaris* L.; Burkey *et al.,* (2012), fruits (common grape vine, *Vitis vinifera* L.), leafy foliage (common lettuce, *Lactuca sativa* L.; Temple *et al.,* (1986) and roots (common beet, *Beta vulgaris* L.; Munir *et al.,* (2016); see economic assessment in Booker *et al.,* (2009). For species growing in unmanaged ecosystems, a much larger range of symptoms has been reported. These include reduced photosynthesis Patterson and Rundel (1993); Darrall and Jager (1984); Heck *et al.,* (1988), basal area increment or bole diameter in trees, Peterson *et al.,* 1987; Karnosky *et al.,* (1996); Somers *et al.,* (1998); McLaughlin *et al.,* (2007a), shifts in allocation between above-and belowground tissues or carbohydrate reserves or forms, Grulke *et al.,* (2001), foliar loss of macro- or micronutrients, reduced reproduction Luck (1980); Black *et al.,* (2000); Chappelka (2002) and competitive status (blue wild rye, Elymus glaucus Buckley, ponderosa pine; Andersen *et al.,* (2001); McDonald *et al.,* (2002) or an increase in mortality, Karnosky (1981); Karnosky *et al.,* (2001); McDonald *et al.,* (2002). Competition alters plant condition, O_3 uptake, allocation of most within-plant resources and the capacity to detoxify O_3 effects. Unfortunately, the majority of O_3 studies have been conducted on open-grown plants, often grown in pots where competition is absent both above- and belowground. It is presumptive to predict mature tree responses to O_3 from seedling response studies, Karnosky *et al.,* (2001) as: (**a**) the capacity for resource acquisition varies; (**b**) patterns of allocation among root, stem and leaf differs; (**c**) the competitive pressure differs by life stage, species composition, tree density, leaf area distribution in space and time, and these factors may change in response to O_3 enrichment (all of these factors influence gas exchange in the canopy); and (**d**) post- Reich (1987), attempts to correlate plant functional type to O_3 responses have not always been successful, Nunn *et al.,* (2006).

9. Impact of ozone on plant physiology

9.1. Carbon obtained and distribution

Chronic exposure to O_3 inhibits allocation of biomass to developing roots in Pima cotton (*Gossypium barbadense L.*; Grantz and Yang, (1996), muskmelon (*Cucumis melo* L.; Fernandez-Bayon *et al.,* (1993); and many other species Cooley and Manning, (1987); Reiling and Davison, (1992); Darrall, (1989); Rennenberg *et al.,* (1996). In cotton Grantz and Yang, (1996) and (2000) the root/shoot biomass ratio decreased and leaf area specific root hydraulic conductance declined despite reduction of leaf area. Degraded root system function may contribute to O3-induced inhibition of shoot gas exchange and carbon acquisition, Grantz *et al.,* (1999). Ozone O_3-induced reduction in photosynthetic carbon assimilation (An) , Reich, (1983); Dann and Pell, (1989); Farage *et al.,* (1991) in Pima cotton Grantz and Farrar, (1999), (2000), muskmelon Fernandez-Bayon *et al.,* (1993) and other cucurbits, Castagna *et al.,* (2001); Fernandez-Bayon *et al.,* (1993). A parallel reduction of stomatal conductance (gs) was often observed, confirming, and in some cases contributing, to the observed limitation of An. Both direct and indirect impacts of O_3 on (An) reduce the quantity of carbohydrate (CHO) available for export from source leaves to sink tissues such as fine roots. Grantz and Farrar, (1999), (2000); Darrall, (1989), reported that photosynthate may further limit CHO supply to roots.

9.2. Root architecture and respiration

Reducing allocation of carbohydrates (CHO) to roots must eventually reducing availability of substrate for root growth and their respiration, McCool and Menge, (1983) reported that in tomato, ozone - O_3 may reduce the availability of substrates and the production of root exudates, which consequently adversely affected mycorrhizal infection. O_3^- induced increases in the translocation of photosynthate to roots have also been observed, particularly with low O_3 concentrations (*Ponderosa pine*: Scagel and Andersen, (1997); *Trifolium repens*, Blum *et al.,* (1983); *Triticum aestivum*: Mc Crady and Andersen, (2000). Responses of fine root respiration (Rr) to O_3 remain unclear, with previous studies providing an array of contrasting conclusions.

Ozone-O_3 decreased the respiration (Rr) particularly in some conifers (*Pinus taeda:* Edwards, (1991); *P. armandi:* Shan *et al.,* (1996); *Pseudotsuga menziesii,* Gorisson and van Veen, (1988), and in such annual crops as *Phaseolus vulgaris* Hofstra *et al.,* (1981); Ito *et al.,* (1985). However in some cases, O_3 gradually increased root respiration (Rr) in other conifers (*Pinus ponderosa:* Scagel and Andersen, (1997) and temperate broad-leafed trees such as deciduous red oak (*Quercus rubra:* Kelting *et al.,* (1995). These conflicting observations may reflect interspecific variability, contrasting experimental conditions, or inherent variability in measured values of Rr, remains unknown. These studies report chronic O_3 exposures that may have allowed the acclimation of allometry, root system morphology, and physiological function. Such a restoration of homeostasis confounds the interpretation of primary O_3 impacts on Rr. As (Rr) may consume over half of the net primary productivity Lambers *et al.,* (1996) and up to 75% of CHO translocated to roots HoÈgberg *et al.,* (2002), the magnitude and direction of O_3 impacts on this belowground carbon sink are of considerable interest. The diversity of O_3 effects on Rr noted above has hindered the prediction of O_3 impacts on carbon sequestration as part of the overall effects of global change, and has prevented appropriate parameterization of long-term O_3 impacts on plant growth and development. O_3 effects on (Rr) could also serve as early diagnostic signals of O_3 damage to vegetation Richards, (1989); Taylor and Ferris, (1996).

9.3. Bioavailability of essential nutrients in soil

In recent decades, such anthropic activities as combustion of fossil fuels (Karlsson *et al.,* (2017) and intensive fertilization of nitrogen Wang *et al.,* (2007) always contributed to the elevated ozone (O_3) concentration in the near-ground atmosphere. The increasing O_3 levels can affect ecosystems, compromise plant growth, crop production, Sarkar, and Agrawal (2010). Thus, more attention has been directed to evaluate the effects of elevated O_3 concentration on agricultural ecosystem, Mills *et al.,* (2013), crop productivity Yi *et al.,* (2016), grain quality, Jing *et al.,* (2016) and plant physiology, Feng *et al.,* (2016). Understanding the responses of soil micronutrients bioavailability and nutrients uptake in plants to elevated O_3 level is very important, but the information is still lacking. Ozone levels can affect plant nutrient uptake and concentrations in plant tissues. Broberg *et al.,* (2015) summarized the experimental data from Asia, Europe and North America, they concluded that ozone exposure have positive effects on the concentration of mineral (K, P, Ca, Mg, Zn, Mn and Cu) in grain. Micronutrients play an important functions in plant growth, Kabata-Pendias (2011), O_3 may change micronutrient-involved plant metabolism. Besides, O_3 stress may correspond to altered plant physiology. Ozone O_3 suppress chlorophyll synthesis and leaf photosynthesis, Bakircioglu *et al.,* (2011) , disturb translocation and partitioning of carbohydrates, Zheng *et al.,* (2013). It was found that ozone alone might decrease ethanol-soluble carbohydrate contents in pine needles, Barnes *et al.,* 1990) and change the allocation of macro-and-minor nutrients in leaves, plant physiology inhibited in the presence of high O_3 level is associated with changed nutrient concentrations in plant tissues, Zhuang *et al.,* (2017). Kinose *et al.,* (2016) stated that O_3 suppression on plant biomass accumulation might be compensated by the adequate nutrient supply, the nutrient supply may mediate plant response to O_3 stress, Barnes *et al.,* (1990). Thus, it is vital to ensure adequate nutrient supply from soil to plant since soil is a major source of micronutrients for plants. Nutrient availability in soil under O_3 environment may be inhibited because of changed soil chemistry and microbiology. The bioavailability and solubility of micronutrients may indicate their availability to plants, McBride *et al.,* (2004). Micronutrients are usually associated with major components of soils, Rutkowska *et al.,* (2014). The Community Bureau of Reference (BCR) procedure is a commonly used sequential extraction that differentiates micronutrients, Bakircioglu *et al.,* (2010), in the order of decreasing bioavailability. Studies were conducted to illustrate the response of bioavailability of micronutrients under incubated in an O_3 purged OTC chamber, in order to analyse the micronutrient behavior in bulk soils as well as nutrient uptake by wheat The purposes studies were to (a) investigate the effects of elevated O_3 concentrations on bioavailability of Fe, Mn, Cu and Zn in a wheat-soil system with the BCR technique, and to (b) find out the O_3 effects on plant biomass accumulation, grain yield, and nutrient concentrations in plant tissues.

9- Summary

Climatic changes have significant impact on local, regional and global hydrologic regimes, which may in turn affect ecological, economic and social systems. Water resources are a main component of natural systems affected by climate change, such as precipitation, stream flows, and groundwater recharge that would directly affected availability of water resources particularly, under climate stress. Interactions between plant and soil may be unpredictable to natural fluctuations in climatic changes because of temperature changes, carbon-cycling processes could result in a large release of soil carbon back to the atmosphere. Precipitation patterns gradually influence on soil organic matter that affecting soil properties such as aggregate formation and stability, water-holding capacity, cation exchange capacity, and soil nutrient content. Fluctuation of Temperature as well as variations in rainfall spells are crucial indicators of environmental stresses. Relation between plant-derived carbons inputs are gradually affected by temperature on decomposition of soil organic carbon. Indirect effects of climate change on microbes through plants may be stronger than direct effects of climate on shaping microbial community and function. The rhizosphere zone is one of the hotspots in soil sciences, great interactions between plant roots and soil as well as soil microbes occur. The rhizosphere zone is the main place for plant root exudations, which are the most important source for nutrition and protection of plants and soil microbial activity, in addition, help the plant directly and/or indirectly in its nutrition through promoting soil microbial activity and protecting against some pathogens. In addition, mobility and bioavailability of various nutrients elements gradually influenced by different soil characterizations, plant root exudates and the microbial interactions with both soil and plants as well. Physiological aspects of the microbe–plant interactions enhance transfer of nutrient from plant to microbial and its dynamics. The interactions between plants, soils and microbes should be understood, particularly in the frame of plant nutrition, which could control the uptake, mobilization, transfer, translocation, accumulation of nutrients and their bioavailability -biogeochemistry cycles and formation of soils in the rhizosphere or terrestrial ecosystem. The nutrients and their supplements particularly in the rhizosphere controlled by the diffusion gradient between soil components and root surfaces. Ozone (O_3)

in the troposphere is not just a greenhouse gas but also an air pollutant that is prejudicial to human health and damage of vegetation. Tropospheric (O_3) concentrations have significantly increased by about (1–2%) per year because of accelerated industrial development and intensive combustion of fossil fuels. Ozone consider as a highly oxidizing which inhibiting plant growth and cause reduction quantity and quality in crop yields. In addition increasing (O_3) may affects the C allocation to roots, alter the rhizodeposition, change the quantity and composition of root exudate, modify the nutrient and energy supply to soil microorganisms influence microbial community diversity and accordingly, influence soil CO_2 emission flux Genetic engineering approaches have been significantly applied to develop transgenic plants with enhanced resistance against different biotic and abiotic stress.

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