Chapter 4
Soil Microbes and Climate-Smart Agriculture

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Abstract Climate-smart agriculture (CSA) includes approaches that help in reducing climatic extremities and agricultural greenhouse gas (GHG) responsible to global warming. CSA also focuses to balanced and reasonable transformations for agricultural practices. Soil is very diversified due to variations in physical and chemical properties, depending upon the quality and quantity of organic matter, redox potential, and pH status of soil, which also significantly impact the population, growth, and activity of microbes. The microorganism as an arbitrate ensures the sustainable farming by designing effective nutrient cycling strategies and pest control process and minimizing the negative impact of abiotic stress. Therefore, proper managing and development of beneficial microbes can help to achieve sustainable goals and reduce negative effects on the environment. The microbial biofertilizers, biopesticides, and plant growth-promoting rhizosphere bacteria (PGPR) will replace or at least supplement agrochemicals. Soil microbes also provide carbon sinks and help sequester carbon through various processes like the formation of recalcitrant vegetative tissues, bio-products, and different metabolic and biochemical mechanisms that capture CO_2 from the atmosphere; capacity of carbonate sedimentation; and formation of stable soil aggregates, which holds up carbon. Microbes contribute to carbon sequestration by the interactions between the amount of microbial biomass, microbial by-products, its community structure, and soil properties, like clay mineralogy, texture, pore-size distribution, and aggregate dynamics. Soil microbes play a role in climate change through decomposition of organic matter in soil. The diversity and population of soil microorganisms are indirectly influenced by changes in microclimate due to its effects on growth of plant and alignment of vegetation. Soil microbes endorse the sustainability of agriculture and effective operation of agroecosystem through precision agriculture under climate-smart agriculture.

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4.1 Introduction

Agriculture is the backbone of Pakistan economy like many other nations around globe. The world population is expecting to be more than 9 billion in 2050, and to feed this growing population, agricultural production system needs to be transformed based on sustainable land management technologies. The basic objective of this transformation would be to increase food production without depleting soil and water resources under changing climate scenarios (Branca et al. 2011). Sustainable agricultural practices lead to reduce gaseous emission and increased carbon sequestration necessary for mitigating climate change. Continuous vulnerabilities in climate, especially changes in temperature, wind, and precipitation pattern, is the cause of uncertainty, risk, and real threat to food security. The modern approach like climate-smart agriculture (CSA) can help to improve the sustainability in the production system by increasing resilience and resource use efficiency (Lipper et al. 2014). Soils are integral to the function of all terrestrial ecosystems and to food and fiber production. Soil microbes are main drivers of different ecosystem processes, and their population and functions determine the sustainable soil productivity, water resources, and gaseous emissions (Wagg et al. 2014). The change in climate, such as elevated atmospheric CO_2 concentration (eCO_2), temperature, and drought, adversely affects the soil microbial activities. The removal of nutrient-rich topsoil through dusty winds also threatens food security. Soil microbes are farmers' allies and can help in dealing the climate challenges faced by agriculture. Soil microbes play a role in fighting against this climate change challenge very effectively and can restore depleted or degraded soil. Soil microbes improve soil health, crop growth, water holding capacity, and carbon sequestration and allow for increased agricultural productivity on existing land. Soil microbes can help crops to tolerate elevated temperature and svere moisture shortage. Crops inoculated with soil microbes have a deeper root system helping to withstand drought and, consequently, accept more water effectively from drying soil. Soil microbes also minimize insect pest deleterious crop diseases and improve the overall crop growth and yield. Soil holds three times more carbon as exists in the atmosphere, and more carbon storage in the soils minimizes greenhouse gas concentrations between 50% and 80% (Paustian et al. 2016).

The terminology climate-smart agriculture (CSA) has established to portray an array of approaches that could facilitate these obstacles by enhancing toughness to climatic extremities, acclimatizing to varying climate, and reducing agricultural greenhouse gas (GHG) that causes global warming. CSA also focuses to augment balanced and reasonable transformations for agricultural practices and employments across balances, varying from small-hold owners to transnational alliances, making an essential fragment of the wider green development plan for agriculture (Braimoh 2013; Palombi and Sessa 2013). Soil is very diversified in the world due to variations in physical and chemical properties (Quesada et al. 2010). The chemical and physical properties of soil depend upon the quality and quantity of organic matter, redox potential, and pH status of soil, which also significantly impact the population, growth, and activity of microbes along with soil productivity (Lombard et al. 2011). Production of food, feed, fiber, and shelter depends upon the agricultural land (Toor and Adnan 2020). In many developing countries, agriculture offers self-employment and is vital for their economic development (Gindling and Newhouse 2014). To meet the need of food, feed, fiber, fuel, and raw material, burden on agricultural soils is increased in recent years due to the heavy increment in the human population. Although the synthetic fertilizers and pesticides are applied to increase the crop growth, they worsen the soil and environment and deteriorate soil organisms (Jacobsen and Hjelmsø 2014). Climate-smart agriculture (CSA) is an approach and addressed to mitigate the issues endeavoring to elevate agriculture production, increase adaptation, and facilitate GHG discharge drops. CSA focuses on emerging agricultural approaches not just to safeguard food security in varying climatic conditions but also to diminish GHG liberations and to ameliorate soil C sequestration (Lipper et al. 2014). Biochar (the C abundant solid produced via biomass pyrolysis) improvement in agriculture lands has been recommended as a tactic to subside climate modification by sequestering C and lessening GHG (specifically N_2O) whereas concurrently enhancing the crop productivity (Woolf et al. 2010; Jiang et al. 2020).

4.2 Soil Microbes and Sustainable Agriculture

Sustainable farming is known as a part of agriculture, which aims on the production of lasting crops and domestic animal despite causing the minimum effect on the environment. In the environment, this type of farming creates a suitable balance between food production demand and protection of ecosystem. The main standard, which ensures the sustainable farming, is the property of soil, in which the role of microorganism is very vital. The key achievements for maintaining sustainability are designing effective nutrient cycling strategies and pest control process and minimizing the negative impact of abiotic stress. Microbial services are acting as an arbitrate in such type of activities; therefore, proper managing and development of beneficial microbes can help to achieve sustainable goals and reduce negative effects on the environment. On the sustainable agriculture, the main impact of agriculture microbiology will be the replacement and addition of the fertilizers and pesticides (agrochemicals) with the microbial preparation. Some of the most common explanations for the use of microorganisms in sustainable farming are biofertilizers, biopesticides, and plant growth-promoting rhizosphere bacteria (PGPR) (Mohanty and Swain 2018).

Biofertilizers are the best tools for sustainable agriculture and considered as a gift from the latest agriculture. Moreover, biofertilizers, being used in agricultural sector, are more efficient and the best substitute to organic fertilizers and manures. Organic fertilizers consist of household wastes, compost, farmyard manure, and green manure, which can help to uphold the quality and sustainability of soil for longer period but not able to cover the instant requirements of crop. Meanwhile, manufactured chemical fertilizers influence the environment like burning of fossil fuels and emission of greenhouse gases (GHGs), which lead to the pollution of soil, air, and water. Furthermore, the constant use of chemical fertilizer for a longer period leads to nutrient imbalance in soil, which also impacts its sustainability. Microbes are also present in biofertilizers, which endorse the adequate availability of primary and secondary nutrients to their host plants and make sure to improve their physiological regulation and structural growth efficiently. In the production of biofertilizers, living microorganisms with specific functions are used to improve plant growth and reproduction. Biofertilizers are an essential element of organic agriculture and perform a key role to maintain the fertility and resilience of plants for long term. Specific microbes are identified and reproduced in vitro that have the ability to absorb nitrogen (N2) directly through the atmosphere, which can be applied in the rhizosphere to make nitrogen available to plants. Such plants or microorganisms containing such materials are knowns as biofertilizers. *Rhizobium*, *Azolla*, *Azospirillum*, *Azotobacter*, and blue-green algae are the frequently used biofertilizers in organic farming (Mohanty and Swain 2018).

Biological pesticides are made of organic components, like bacteria and plants, comprising of minerals that are commonly utilized to fight against disease-causing insects and pathogens. They are classified into microbial pesticides, crop protection agents, and biochemical pesticides. Biopesticides are made up of natural substances that fight with pests through harmless mechanisms. Microbial insecticides, such as *Bacillus thuringiensis*, release toxin A, which paralyzes the insect's midgut and prevents further food intake. Similarly, the spores of *Metarhizium anisopliae* and *Beauveria bassiana* enter the skin/cuticle of the host and releases lethal metabolites, known as destruxin and bovericin, respectively, that lead to insect death. Hence, biological pesticides are intrinsically low in toxicity, only target the relevant host pest, can easily be biodegraded, and have low exposure, because they are effective in lesser amounts. Moreover, they can solve the problem of environmental pollution (Mohanty and Swain 2018). Plant growth-promoting rhizosphere bacteria (PGPR) are found naturally in soil, which improve the productivity and immunity of plant; but these PGPRs are present in the rhizosphere, that is, a soil influenced by the roots of plant and their secretions and exudates. Because of their plant collaboration and interaction, these beneficial rhizobacteria are divided into mutually symbiotic rhizobacteria (living inside the host plant and directly exchanging nutrients and metabolites) and nonsymbiotic bacteria that live freely outside the plant roots (Gray and Smith 2005). In addition, some genera of symbiotic bacteria can physiologically incorporate with plants to make specific root structures. Depending on their working principle, beneficial bacteria are categorized as a biofertilizer, biopesticide, and plant stimulant, and certain bacteria have an overlapping application such as the adhesion of the ACC (1-aminocyclopropane 1-carboxylate) deaminase gene and the availability of phytohormones such as IAA (indoleacetic acid), siderophores on the side, intertorkinin, gibberellin, etc. In this way, they can improve the yield and growth of the plant as well as the availability and uptake of nutrients from the several types of crop plants in diverse agroecosystems. Due to multiple uses of growth-promoting bacteria, they become a pivotal part for managing sustainable agricultural systems (Mohanty and Swain 2018).

4.3 Soil Microbes and Carbon Sequestration

In broad terms, carbon sequestration is defined as the elimination, removal, or sequestration carbon dioxide from the atmosphere to moderate or reverse atmospheric CO_2 contamination and to mitigate or reverse climate change. Carbon dioxide (CO_2) is naturally captured from the atmosphere through physical, chemical, and biological processes. While in the agriculture sector, carbon sequestration is defined as the capability of forests and agriculture lands to minimize CO_2 concentration from atmosphere. The removal of CO_2 from the environment is done by its absorbance by means of photosynthesis by crops, plants, and trees and deposition of carbon in foliage, branches, roots, tree trunks, and soil (Schahczenski and Hill 2009).

In general, there are a number of technologies for sequestering carbon from the atmosphere. The main three categories are (i) ocean sequestration, (ii) geologic sequestration, and (iii) terrestrial sequestration. The world's oceans are the primary long-term sink for CO_2 emissions by the anthropogenic activities. Naturally, oceans absorb 2 giga tons of carbon annually through the chemical reactions between seawater and CO_2 in the atmosphere. As a result of these reactions, oceans become more acidic. Numerous marine bodies and ecosystems depend on the formation of sediments and carbonate skeletons, which are vulnerable to dissolution in acidic H_2O. Near the surface, most of the carbon is fixed by photosynthesis of phytoplankton, which are then eaten by sea animals (Sundquist et al. 2008). In geological sequestration, CO_2 is captured from the exhaust of fossil fuel power plants and other major sources, and then, it is supplied through pipes from 1–4 km beneath the Earth's crust layer and incorporated into the formations of porous rock. This type of sequestration is currently utilized for stocking a very lesser amounts of C per year. Many sequestrations are visualized to take advantage of the durability and capacity of geologic storage. Terrestrial sequestration/bio-sequestration is conducted by means of conserving techniques to sequester C in soil and forest that also intensify and enhance its storage (like establishing and restoring forests, wetlands, and grasslands) or reduce CO_2 emissions (like suppressing wildfires and reducing agricultural tillage). These practices are used to meet a variety of land management objectives. Carbon is released in the form of carbon dioxide into the atmosphere by different anthropogenic activities, like the burning of fossil fuels that releases carbon from its long-term geologic storage (such as coal, petroleum, and natural gas). Naturally, CO_2 is emitted through the respiration of living organisms and decomposition of plants and animals. Since the beginning of the industrial era, the amount of carbon dioxide in the atmosphere has increased due to the extensive burning of fossil fuels. CO_2, being a high potential greenhouse gas (GHG), has led to increase the normal temperature of Earth's atmosphere (Klafehn 2019). Carbon sinks are the reservoirs that store carbon and keep it from entering the Earth's atmosphere. For example, afforestation helps in sequestration and capturing of carbon from the atmosphere while C is released into atmosphere through deforestation. Naturally, carbon dioxide present in the atmosphere is sequestered through photosynthesis to the carbon sinks on Earth like plant biomass above soil or inside soils. Other than the plant's natural growth, some terrestrial mechanisms, like cropland management practices, also take part in the atmospheric carbon sequestration. It should be kept in mind that, depending upon the land use, the sequestered carbon in the above-ground vegetation and in soils can be emitted again into the atmosphere.

Microbes also provide carbon sinks and help sequester carbon through various processes like formation of recalcitrant vegetative tissues and bio-products, different metabolic and biochemical mechanisms that capture CO_2 from the atmosphere, capacity of carbonates sedimentation, and formation of stable soil aggregates, which holds up carbon. Microbes contribute to carbon sequestration by the interactions between the amount of microbial biomass, microbial by-products, its community structure, and soil properties, like clay mineralogy, texture, pore-size distribution, and aggregate dynamics. Accumulation of derived organic matter by microbes depends on the balance between decomposition and production of microbial products in the soil. Microbial growth efficiency (the efficiency with which substrates are incorporated into microbial biomass and by-products) is dependent on the (i) degree of protection of microbial biomass in soil structure and (ii) rate of decomposition of by-products by other microorganisms (Six et al. 2006). Microbes adopted different strategies for carbon sequestration like fungal and bacterial dominance (Strickland and Rousk 2010), mycorrhizal association for carbon sequestration (Wright and Upadhyaya 1998), microalgae for CO_2 capture (Buragohain 2019), etc. The bacterial and fungal soils are linked with carbon sequestration potential. If there is a greater number of fungi, then there is a greater C storage (Strickland and Rousk 2010). In the soil, where the microbial community is composed of fungi, the production of microbial biomass and by-products will be larger, because they have higher growth efficiency rates than other microbes like bacteria. Therefore, these communities will retain more carbon in biomass per unit substrate consumed and release less as carbon dioxide. Degradation of microbial-derived organic matter is slower in soils having greater proportion of fungi, as fungal products are chemically resistant to decompose, because of their interactions with clay minerals and soil aggregates (Simpson et al. 2004). The total carbon assimilation increases significantly by mycorrhizal-plant symbiosis. In this association, arbuscular mycorrhiza fungi capture carbon in soil and translocate photosynthetic metabolites present inside the associative plants to the intra-radical of arbuscular mycorrhiza fungi and succeeding extra-radical hyphae, which are then released to the soil medium (Leake et al. 2004). This mycorrhizal association could drain 4–20% of C present in the symbiotic plant to their hyphae and indirectly impact soil carbon sequestration (Graham 2000). The increasing growth and development of fungal extra-radical hyphae within the rhizospheric soil directly enhances the soil carbon sequestration. Soil carbon sequestration by arbuscular mycorrhiza relies upon the turnover time of accumulated biomass of fungal hyphae, the volume of hyphal biomass produced, and the role of fungi to stabilize the formation of soil aggregates (Zhu and Miller 2003). Hyphae produce glomalin protein, which increases the stability of aggregates; this increase in stability leads to larger amounts of protected organic carbon and thereby larger carbon sequestration (Wright and Upadhyaya 1998). Carbon dioxide fixation through microalgae is a favorable and potential technique to sequester CO_2 (Zhao and Su 2014). Microalgae fix and store carbon dioxide through photosynthesis in carbon dioxide and water are transformed into organic assimilates without consuming additional energy having no secondary pollutants. Comparing with the other C capturing and storing methods, fixation of carbon dioxide through microalgae has many benefits, like a rapid growth rate, a high photosynthesis rate (Suali and Sarbatly 2012), efficient adaptability to the environment, and less operational cost. The rate of carbon dioxide fixation through biomass and microalgae production is dependent upon the species of microalgae, soil environment (e.g., pH, light, temperature, and availability and amount of nutrients), and concentration of CO_2. In short, microbes contribute to ecosystem carbon budgets through their roles as pathogens, plant symbionts, or detritivores, thereby influencing the C turnover and modifying the nutrient availability and retention in soil. On decomposition of biomass, carbon losses from the soil due to microbial respiration, while a small proportion of the carbon is retained in the soil by the formation of stable organic matter. Carbon sequestration occurs when SOC levels increase over time as carbon inputs from photosynthesis exceed C losses through soil respiration. Terrestrial ecosystems can be manipulated through land management practices and land use for the development of distinct microbial communities that enhance C sequestration.

4.4 Agricultural Practices and Carbon Sequestration

Vegetative and root systems of grass species and forest trees can store a huge amount of carbon for an extended period; therefore, they are known as sinks for carbon. Agricultural lands can also hold an accountable amount of sequestered carbon; however, their ability to store or sequester carbon depends on climatic conditions, soil and crop or vegetation types, as well as management systems of the cropping land. The total carbon stored in the soil is also affected by the addition of dead plant and animal materials, respiration, and decomposition losses of carbon. However, the carbon losses could be reserved through farming practices through minimal soil disturbance and encouraging carbon sequestration. Overall, there are two distinct trends of the effect of nitrogen fertilization on soil organic carbon fertilizer. On the one hand, nitrogen fertilizer stimulates primary production, resulting in increased above- and below-ground biomass, which can enrich SOC reserves (Chaudhary et al. 2017). Nitrogen fertilization, on the other hand, can promote litter and soil organic matter's biodegradation (Recous et al. 1995). This results in the reduction of SOC stocks (Ladha et al. 2011). Thus, a sufficient supply may be critical for soil carbon sequestration (Van Groenigen et al. 2017). By affecting arbuscular mycorrhizal fungi, phosphorus fertilizers can influence soil carbon sequestration. In contrast to simple nitrogen fertilizers, NPK application inhibits arbuscular mycorrhizal fungi colonization, therefore limiting fungal-mediated nutrient plant absorption, which has a detrimental impact on soil carbon sequestration (Joner 2000; Liu et al. 2020).

Organic additives have numerous effects on SOC pool. Organic fertilization stimulates net primary production, allowing atmospheric carbon to be fixed through photosynthesis (Jacobs et al. 2020; Mathew et al. 2020; Sykes et al. 2020). Source of SOC provide an additional organic alterations for the prevailing pool (Maillard and Angers 2014), and organic fertilization may stimulate SOC biodegradation in the same way that mineral fertilization does (Chenu et al. 2019). When organic fertilizers are used, the outcome is predominantly translation with higher organic carbon intensities at certain sites and lower concentrations at contributing sites (Wiesmeier et al. 2020). Overall, the alternative uses of organic materials are critical, and net appropriation will happen when manures and organic fertilizers are made for a specific farmland field and when C in contemporary fertilizer will then be distributed into the atmosphere (Sykes et al. 2020). Integrating crop wastes into agronomic soils modifies soil structure, decreases bulk density, shrinks erosion, diminishes evaporation, and magnifies the infiltration ratio in soils and in supplement to cumulative SOC stocks (Bronick and Lal 2005; Lehtinen et al. 2014; Spiegel et al. 2018; Trajanov et al. 2019). Straw and hay are exploited for animal suckling or the production of thermal energy in agricultural organization systems. SOC stocks were amended by using deposits (Lehtinen et al. 2014). The carbon impounding influences a fresh equipoise, that is a constant soil organic carbon (SOC) reservoirs in top layer of soil a span after straw is unified (Wang et al. 2018). Numerous crop species and crop alternation are an important module of the natural C cycle, since plants absorb over 10% of atmospheric C production's complete photosynthesis (Raich and Potter 1995). Carbon is consumed via plants, which may be united as biomass, satisfied like root exudes or exhaled back into the atmosphere as CO_2 (Ostle et al. 2003). Maize integrates the atmospheric C more competently than C3 crops like barley, due to its C4 photosynthetic pathway and higher leaf area (Wang et al. 2012). SOC storing is prejudiced by the vegetative cover of agricultural soils and how it is accomplished. Plant biomass delivers the mainstream of organic matter contribution in the topsoil, which reductions as soil depth upsurges (Kaiser and Kalbitz 2012). Varied agricultural spins with several primary crops, cover crops, perennial crops, and forages provide suggestively greater soil organic stocks (SOC) than single cropping systems of monoculture with cereals or maize (Jarecki and Lal 2003; Poeplau and Don 2015). Crop rotational assortment, organic fertilizer/alteration use, and/or perennial farming patterns, all of these can be possible to accrue higher soil organic carbon (SOC) than traditional mono-cropping systems (Don et al. 2018; Minasny et al. 2017).

Root exudations (e.g., organic acids, amino acids, and sugars) from deep delving species and cultivars of crop can transport C into the soil subsurface, where there is a high carbon impounding potential (Sokol et al. 2019), particularly if organic compounds are endangered in organo-mineral aggregates (Paustian et al. 2016). Sunflower (*Helianthus annuus*), alfalfa (*Medicago sativa*), or perennial crops like grass clover, grass, legume, and alfalfa grass amalgamations have deep rooting systems. After the primary crops (e.g., cereals) have been harvested, catch crops are grown or they are undersown in/with the main crops. This consequences in a perpetual vegetative cover on arable land as well as a supplementary period of carbon fascination (Chahal et al. 2020). Traditional tillage practices like plowing eliminate soil aggregates from topsoil, revealing previously endangered SOM to microbial deprivation (Dignac et al. 2017). It also stimulates soil erosion and in lowering SOC stages (De Clercq et al. 2015; Six et al. 2000; Veloso et al. 2019). SOC satisfied in the topsoil (0–10 cm) was originated to be higher in fields refined with no- or reduced-tillage performs than in fields refined with conservative tillage, such as moldboard plowing (Beniston et al. 2015; Francaviglia et al. 2019; Mazzoncini et al. 2016). However, no consequence of tillage practices on SOC accretion was seen as soil depth (>10 cm) increased (Mazzoncini et al. 2016). Soil erosion was allied to the SOC sufferers caused by tillage (Beniston et al. 2015). Besides, lowering mechanical instabilities improves soil health by increasing combined constancy, which decreases erosion (Abid and Lal 2009; Mikha and Rice 2004). By evaluating the complete soil profile (from 0 cm to 60 cm), the impacts of minimal and no-tillage practices on C sequestration are imperfect and inconsequential (Haddaway et al. 2017; Luo et al. 2010; Minasny et al. 2017; Powlson et al. 2014; Sanderman et al. 2009; Spiegel 2012). Biochar is completed by a thermal process of burning organic materials (animal or plant-based) at high temperatures prodigious 350 °C and with a low oxygen source called pyrolysis (Meena et al. 2020). Biochar delivers a long-term carbon sink in soils due to its strong resistance. Biochar treatment is said to boost SOC stocks in agricultural areas (Liu et al. 2016a, b; Maestrini et al. 2015) by cumulative primary output, (Lorenz and Lal 2014) rebellious fractions of SOC, and subsurface SOC pools (Lorenz and Lal 2014; Mao et al. 2012; Rumpel and Kögel-Knabner 2011; Solomon et al. 2012). Moreover, it also can advance soil water retaining, collective stability, soil erosion discount, and soil biota action (Liang et al. 2014; Palansooriya et al. 2019; Schmidt et al. 2014). Agroforestry is the combination of woody perennials like shrubs and trees with grasslands or an agricultural crop. Agroforestry, in all-purpose, assists various roles at the same time, comprising environmental (like better soil fertility and maximized SOC pools) and socioeconomic aids (e.g., increased crop efficiency and to deliver fodder, crops, or timber) (Shi et al. 2018; Sun et al. 2018; Wiesmeier et al. 2020). Deforestation is the loss of forest land for other purposes, such as agricultural crops, growth, or mining processes around the world. Deforestation has impaired the natural ecosystems, the biodiversity, and the climate and has been amplified by human activity since 1960 (Allen and Barnes 1985). Substantial amounts of carbon are stored in forests. As trees and other plants grow, they take carbon dioxide from the atmosphere. This is altered to carbon, which the plant stores in its leaves, trunks, branches, roots, and soil (Gorte and Sheikh 2010). When forests are expurgated or scorched, the carbon that has been deposited is released into the atmosphere, mostly as carbon dioxide. Because trees absorb and store CO_2 throughout their life, deforestation has an important impact on climate change. According to the World Wildlife Fund, tropical forests store more than 210 gigatons of carbon. What's more regarding is that the exclusion of these trees has two major negative consequences (Shukla et al. 1990). To begin with, chopping down trees results in CO_2 emissions into the atmosphere. Additionally, with a smaller number of trees, the general aptitude of planet to capture and sequester CO_2 is abridged. These both processes aggravate the greenhouse gas emission, which contribute to global warming and climate change (Moutinho and Schwartzman 2005).

4.5 Climate Change and Soil Health Indicators

Soil quality consists of active and inherent constituents. Inherent soil qualities, e.g., types of clay, depth to bedrock, and consistency, are difficult to change and take over thousands of years to form as a result of climate changes, such as topography, time, biota, and parent material (Wienhold and Awada 2013). On the other side, dynamic properties of soil quality are established due to human activities and human management practices and can be changed over a brief period. Soil quality comprises physical, chemical, and biological features required to nurture agricultural sustainability and environmental health (Cardoso et al. 2013). Soil is more complex than air and water because it is module part of solid, liquid, and gaseous phases and used in substantial number of variety of determinations assessed for natural ecosystems and efficiency having major focus is on the management biodiversity and environmental quality includes human activities, cultural and geographic heritance. Reaction of soil in comeback to the management practices is slow; thus, it is complex to understand the changes caused in the soil before nonreversible changes. The most significant part for evaluating soil health is the credit of diplomatic soil features that proves the job of soil to work and can be measured as the indicator of soil quality (Nortcliff 2002). The chemical indicators for soil quality evaluation are pH, available phosphorous, and available potassium. The physical indicators include aggregate stability and available water capacity. Biological indicators are represented by organic matter content and active carbon content. Indicators can be restrained from the composite sample of patent sites (Rashidi et al. 2010).

In recent views, soil health assessment is progressively integrated with land evaluation, because its policies are using multiple aspects and for a variety of designs involving sustainable land management. Common management are dependent on long lived land potential conditional on climate, topography and inherent soil properties and can be altered with respect to weather conditions and dynamic soil properties (Herrick et al. 2016). There are three soil indicators, and these are (i) soil physical indicators, (ii) soil chemical indicators, and (iii) soil biological indicators. Physical soil indicators include aggregate stability, porosity, bulk density and texture, and matchup with hydrological processes counting erosion, aeration, runoff, infiltration rate, and water holding capacity. Physical indicators of soil health overall comprise easy, quick, and low budget methods. A soil is reviewed poor in physical aspects when appears having low rates of root density, low aeration, water infiltration, difficulty of mechanization, enhanced surface runoff, and poor cohesion

(Dexter 2004). Soil particles with a size of less than 0.2 micron meter are assembled to make aggregates of 20–250 micron meter that are considered as microaggregates, and when these microaggregates cling together, they form macroaggregates. A substantial portion of soil organic matter is composed of carbohydrates that contribute up to 5–25% and is responsible for the stabilization of soil aggregates. Microaggregates have a low organic matter content and are very less disturbed by the microorganisms and more Fe and Al content responsible for the encouragement of microaggregation and, due to micro mass quality, are less disturbed by management practices (Cardoso et al. 2013) Plus, soil organic carbon in microaggregates is less responsive to changes (Zhou et al. 2020) than macro aggregates, which are more vulnerable to management practices and land use and specifically linked to the of the soil organic matter variations. Microbial activity in soil is understood indication toward more organic matter content also dispersion of soil aggregates following land use management practices is low intensive in soils. However, as the organic matter decreased, the accompanying aggregate dispersion lowers soil oxygenation and macroporosity and reduces the interpretation of microbiota causing decomposition and approach to the organic material. Air and water exist in the macro- and micropores of soil particles (Easton and Bock 2016), and soil texture plays a vital role in balancing between water and gases, which become substantial with time and management practices. However, the total porosity and bulk density can demonstrate the consequences of land management and usage on air and water relationships in a better way. Low bulk density of the soil particles are thought to be responsible for boosting up the structure of soil under low anthropogenic assumptions like local forests (Bini et al. 2013). The good amount of the SOM (soil organic matter) is also allowed to play a key role in boosting up the soil structure. In return, it improves soil macroporosity for plant roots, air, and water. The total soil porosity have relationship with texture (proportion of soil particles), and structure (biopores and macrostructure). The structure can easily get damaged by maximum use of land and plowing techniques, due to which distinctive soil water retention curve based on structural pores may change. Cropping methods and intensive management practice alert the structure, which is described as the arrangement of main soil particles (sand, silt, and clay) (Dexter 2004). Organic matter in soil imposes beneficial impact on soil structure in contrast to physical properties, including water infiltration, water retention, bulk density, porosity, and aeration; these are less responsive toward organic matter content. Soil aggregates regulate nutrient cycling, controls aeration and permeability, and acts as a home for soil microbes; as a result, the soil microbes, including microorganisms (bacteria, fungi, and virus), plants, and fauna, affect the soil aggregates. Organic matter (OM) and biological phase are the basic source of water and nutrient supply in soil; as a result, these factors allocate the physical structure of soil and hydrological processes (i.e., erosion, drainage, runoff, and infiltration). As a result, losses of soil function such as synthesis and mineralization of the soil organic matter, as well as consequences on biochemical cycles, may result from the reduction of the soil microbial activity owing to water limits (Bini et al. 2013). Different soil microbes act different on the restriction of water in soil. In the dry soil, water film is more strongly connected with the soil particles due to the restricted movement of bacteria, but, on the other side, in the dry soil, hyphae of fungi can travel in soil pores, which are filled with the air. Availability of the water depends on biological, chemical, and physical characteristics, but these characteristics are influenced by organic matter.

Chemical indicators of soil strength are coordinated with measurement of supplying the nutrients to plants and keeping of chemical elements that cause damages to the ecosystem. The chemical indicators pertaining toward soil strength evaluations are soil CEC, soil OM, soil pH, and nutrients availability (Kelly et al. 2009). Electrical conductivity (EC) and available nutrients in turn favor good crop production, nutrients availability, and microbial activity. Electrical conductivity is defined as the measurement of salt concentration; one of the chemical indicators for measuring soil health can easily be measured due to its very delicate and one-step conductivity measuring instrument. While soil pH is used to detect impact on soil by land use and plowing techniques and eventually climate change will impact on nutrient cycling, organic matter content, carbon cycling, water availability and plant productivity. Although a high amount of OM content also shows adverse impact on the health of soil by reducing the efficiency of pesticides. Electrical conductivity (EC) lets us know the current scenario in biological activity, crop performance, nutrient cycling, and salinity/sodicity in the soil (Arnold et al. 2005). CEC and sorption abilities of soil are important regarding assessment of soil chemical quality the retention of major nutrient cations calcium, magnesium, potassium, and immobilization of potentially toxic cations aluminum, and manganese. These characteristics reveal important signs of soil health, such as the soil ability to absorb nutrients and the presence of pesticides and pollutants (Ross et al. 2008). Due to the hot temperature, decomposition and loss of the soil organic matter will be increased, as a result, the CEC loss of coarse textured/sandy and clay soils with low biological activity, which results in low cation exchange capacity, and soils with low CEC causes poor holding of nutrients and leads to the leaching of nutrients in high rainfall and heavy irrigation applying areas. Nitrogen cycling closely associated with soil organic carbon cycling, consequently operators of change in climate, e.g., hot temperatures, irregular precipitation, and decomposition of atmospheric N cause effect on N cycling and changes the cycling of other plant-available nutrients like phosphorus and sulfur, from direction and exact magnitude of change in plant-available nutrients must be examined in detail. Heavy metals are collected in the soil through chemical and metallurgical industries (Pantelica et al. 2008), and that type of soil will eventually affect plant growth and human health, including adverse effect on soil ecology and agricultural existence of heavy metals in production quality and ground water quality. Concentrations of free metal ions in soil solution are significant to govern because these impact on bio availability to plants which in outcome are achieved by the metal ion speciation in the soil. The free metal ion concentration depends on the total metal content and metal species present in the soil. Irrigation with wastewater increases the amount of heavy metal adulteration in soil, and as there are large amount of heavy metal contaminants in the soil, plants will uptake more heavy metals, depending on the soil types. Other sources of heavy metal gathering are industrial production, mining, transportation, chemical industries, iron, steel industries, agriculture, and domestic activities responsible for the addition of excessive amounts of heavy metals into the water, including both surface and ground water; soils; and the atmosphere. Heavy metal growth in plants is of considerable responsibility because of the chances of food pollution through the soil-root interface. Some heavy metals, like Ni, Cd, and Pb, are not important for plant growth, and they are taken up and accumulated by plants in toxic forms. Soil chemical indicators are directly correlated with the crop production and soil health for higher plants production and sustainability and are quickly interpreted and improved by using fertilizers (Bini et al. 2013). The soil organic carbon is the basic chemical gauge for soil health and yield, as it affects the major functional operations in the soil like the storage of nutrients nitrogen, water holding capacity, stability of aggregates, and microbial activity. The applications of organic alterations in the soil are helpful even in the chemical maintenance of mine soil and the impact of microbial populations present in the adjustments on soil native microbial communities. Sheep and paper supplements are effective at raising the soil pH and decreasing the metal bioavailability and phytotoxicity, whereas poultry and cow dung resulted in greater soil microbial property values, including respiration and functional diversity. Beneficial effects reported under poultry at the start of the research because of the existence of easily degradable organic matter (microbial and chemical) and phytotoxicity to definitively diagnose bottlenecks during amendment selection for chemical stabilization in combination with low metal bioavailability and improved soil health (Galende et al. 2014). N is a required essential in the soil so that plants can accept to fulfill their required needs and is available in different chemical forms like mineral N (especially nitrate) and organic N stored in the soil organic matter. The use of nitrogen for the soil health indicating parameter put through the factors including climatic conditions, turning insufficient the analysis of the real availability for plants, based on soil chemical analysis. After N, phosphorus (P) is also a chief nutrient for crop growth and is essential in defining soil quality that limits the agricultural yields in tropical soils, particularly in highly weathered, oxidic soils, where the main part of the total soil P is fixed in clay minerals and oxides. The available P in the soil solution is found as orthophosphates, but the microbial P and organic P are also stocks that can rapidly become available (Bini et al. 2013).

Soil health pointers concerning biological indicators all needs sufficiently of soil bacteria, fungi and actinomycetes, earthworms, nematodes, protozoa, soil biomass carbon and N and biomass nitrogen. Soil biological indicators call attention to some actions and performances of microorganisms in the soil (Russo et al. 2012). Favorable activities of microorganisms present in the soil include the following: plant nutrients are unconfined from inexplicable inorganic substances; organic residues are decomposed and nutrients are released; beneficial soil humus is composed by breaking down residues that are organic in nature and application of fresh compounds; compounds that increase plant growth are produced; and nutrition of plant is enhanced symbiotically, which leads to the convert nitrogen from atmosphere into the form available to plants. Increasing surface area of roots for absorption of phosphorous; improving soil accumulation by the obligatory agent's production like glomalin and polysaccharides from mycorrhizal fungi and bacteria, respectively;

refining aeration of soil and infiltration of water; having toxic effect against pests and insects and against pathogens of plants weeds; and supporting degradation of pesticides and bioremediation. Soil organic matter indicators turned out to be used in long-time soil conduct experiment for the evaluation of change in climate; however, the reaction of soil organic matter toward elevated temperature is scientifically debatable. It is understood that the increasing temperature improves the decomposition rate of OM, increases the productivity of plant and supply of soil organic matter, as well as improves warmth and precipitation. Carbon dioxide fertilization and deposition of atmospheric nitrogen may promote productivity of plant and supply of organic matter to soil and hence enrich the soil organic matter. According to Kuzyakov and Gavrichkova (2010), the reason for soil organic matter loss is the availability of SOM to microorganisms, despite the rate modification in climate influence like temperature. The microbial biomass of soil is produced by the living portion of the SOM made by the living organisms, including bacteria, algae, fungi, and protozoa, which are the vital source of micronutrients and can be certainly cycled to fulfill the plants' demand. Soil microbial variety performs essential purposes in the sustainability for soil health, considering nutrient and carbon cycles. Microbial indicators are more responsive toward adjustments imposed to the land use and management (Masto et al. 2009). Not only microbial biomass but also soil exhalation has been used on a large scale in agricultural soils as bioindicator of soil health. Modifications in vegetation, including deforestation, reduces the microbial respiration for a long time, because of the low level of organic carbon inputs into the soil through land outer layer or rhizosphere. The less influencing management methods causes higher microbial activity (Babujia et al. 2010). The OM regulates the activity of microorganisms for the source of carbon, nutrients, and energy, which lead to the availability of CO_2 and mineralization, and the rate of mineralization relies on the quantity and quality of SOM. Balance between demands of farmer and needs of community can be fulfilled by healthy soils. Due to the deterioration in soil qualities, soil health is comprised of the complex network functioning as biological, chemical, and physical indicators. Soil organic matter supports to stimulate the soil health, maintain inactivate compounds that are toxic, and destroy pathogens and its implicit interactions between the internal and external soil elements to sustain agriculture. The soil has an ample variety of microbes. Concerning the global expertise of soil microbial dynamics, its function is enhancing rapidly, and the knowledge of rhizosphere complex is constrained to a limit, excluding its value in regulation soil plant systems (Sahu et al. 2017). Soil enzymes including dehydrogenase, urease, protease, phosphatase, and β-glycosidase (Mohammadi 2011) and enzymatic activity work as an indicator to variations occur in the soil plant system as it is nearly mention to the nutrients cycling and biology of soil, can be measured, combine information on the physicochemical status of soil and microbial level and show quick reaction to changes in management of soil (García-Ruiz et al. 2009). By modifying the quality and quantity of underground C input by plants, microbial enzyme activities may be stimulated by elevated CO_2, C change, and plenty of microbial enzymes affecting the function of microbial community in soil on a level. Plus, possibly soil aggregate size has the long-term effect on stimulation of microbial enzyme activities (Dorodnikov et al. 2009). Atmospheric N deposition causes impact on enzymes (extracellular), which are concerned in the processes of soil organic carbon decomposition and nutrient cycling. Soil faunae include the invertebrate community that may live their whole life or half of their life cycle in the soil, as soil fauna has become an important soil health indicator since recent years. Important in processes related to structure of terrestrial ecosystem, disintegration of residues of plants and creating relationships at different degrees with microorganisms. So, their active participation in processes causes effects on the soil properties, considered as great indicators of changes in the soil. OM is decomposed and transformed into various available forms of nutrients, which are conducted by the microorganism and microbial activities. Microbes will work more effectively as the organic matter quantity available to them at large and soil organic matter will be more shattered and spread out along the soil profile. Also, increasing the surface area of contact, earthworms enhance the distribution of organic material in the soil layers vertically or horizontally (Kostina et al. 2011). Higher permanence of soil accumulation has been seen in soil with elevated biomasses of microbes and earthworm. Further, the fauna actions combine particles of soil and generate blocks, tunnels, pores, and other biological chambers that make the movement of water and air, promote the microbial activity, and hence make the soil more accessible for agricultural creations and enhance plant harvests. On the other hand, soils having less activity of fauna reveals more compaction in soil fragments which makes complicated for plant roots for saturation have low accessible water content and less air in the soil triggers poor agricultural construction and have low variety of microbes. Soil fauna can be categorized by the food which they choose to eat, by flexibility, by diversity in their functions, and primarily by size. The most distinctive organisms examined as soil health indicators are members of mesofauna in soil that are present in places between soil macropores and in the soil, litter maintain feeding on organic matter and fungal hyphae and thus take part in process of nutrient cycling and soil accumulation. Some of the experiments have revealed that some species of springtail are good gauges of soil health. The macrofauna comprise bigger soil organisms, consisting of nematodes, proturans, and sauropods feeding on soil microorganisms, decaying plants, and animal materials, which intermittently are active in the soil ecosystem.. Differences in the environment may have different impacts on family, species, or functional group arrangement of the soil faunae. Practical groups as bioindicators have been preferred to use even though of the variety of total species because of the role which they are producing in biological performs. As some species of earthworm are distinct, the organic material accrued on the soil outside, and for that purpose, the activity of the species (individually) was deemed considered restrictive. In fact, in the presence of other functional groups of organisms, they are incompetent to change the role earlier performed by the earthworm species. But the existence or deficiency of some species may be constraining for an ecosystem operating directly influence on the vitality index is considered in evaluations of soil condition.

4.6 Soil Microbe Mitigating Climate Variability

The activity and growth of microorganisms is highly dependent upon the environmental factors, like moisture, temperature, and substrate disposal, and therefore the microbial responses and processes are influenced by climate change. The interests and growth of soil microorganisms may be directly and indirectly influenced by change in climate. The direct effects include change in precipitation pattern, temperature effects, and harsh climatic results, whereas ancillary effects comprise variants due to climate that amends the plant productivity and physicochemical estates of soil. Soil microbes play a key role in climate change through decomposition of organic matter in soil, and ratios of heterotrophic microscopic action stimulate the CO_2 effluence to the atmosphere that will improve global warming. The variety or diversity and population of soil microorganisms are indirectly influenced by changes in microclimate due to its effects on growth of plant and alignment of vegetation. On the first hand, the soil microorganisms are affected indirectly by increasing concentrations of CO_2 in the atmosphere, and in the second phase, there is enhanced photosynthesis and transport of carbon (photosynthate) to mycorrhizal fungi roots (Bardgett et al. 2008; Zak et al. 1993) and microbes that are heterotrophic in nature (Högberg and Read 2006). Because of excess concentration of CO_2, photosynthesis process in plant rises and plant growth may be doubled (Curtis and Wang 1998) that in return encourages the carbon flux in plant roots and microorganisms that are heterotrophic in nature through root exudation of sugars, which degrades it easily (Diaz et al. 1993; Zak et al. 1993). Soil microorganisms may be applied to support adaptation to change in climate by development and growth promotion and improving resistance against various abiotic and biotic stresses. Soil microorganisms take part in the formation of soil; maintain its properties; regulate its fertility, breakdown, and remediation of toxic contaminants; increase sustainable production; and eventually enhance ecosystem sustainability and resilience. Microbes are applied for management of soil health and resilience of ecosystem to lower the demand for production and transportation of synthetic fertilizers. Novel microbes and organic regulating agents can be applied to diminish the damaging influences of novel and advancing pests and pathogens in climate change setting. Frequently found natural managing agents comprise rust fungus *Maravalia cryptostegiae*, applied in country Australia for managing the weed rubber vine and *Neozygites fresenii* (parasitoid) applied for controlling the pest of cotton *Aphis gossypii*. The bacterium *Bacillus thuringiensis* is cast off at field condition, because it produces crystalline toxins, which demolish the *Diptera* and *Lepidoptera larvae*. Beneficial microorganism plant relations can efficiently enhance the growth of plant and increase their resistance to abiotic stresses and deteriorating diseases. Bacteria that are beneficial for plants help in the acquisition of nutrient, secrete PGP (plant growth promoting) hormones, and modify biochemical and physiological characters of the host plant and, so in this way, protect the plant roots from soil-borne deleterious pathogens. Bacterial genera like *Serratia*, *Bacillus*, *Azospirillum*, *Streptomyces*, *Rhizobium*, and *Pseudomonas* reduction in this class. These plant-growth indorsing useful bacteria can be applied for increased growth of plant and improved resistance against disease in altering conditions of climate. According to researches, right strains of mycorrhizal fungi, when inoculated with C4 plant, help against raised levels of CO_2 (Tang et al. 2009). Novel species of *Rhizobia* affiliated with *Medicago sativa* holds the potential to work under several circumstances (abiotic) like high or low pH or temperature, or low concentrations of SOM. The vast unmapped reservoirs of genetic and metabolic diversity of microorganisms offer a marvelous opportunity for the identification of novel genes to control the pest, biodegradation, and N_2-fixation with the help of the latest improved tools like metagenomics.

Soil microorganisms and their metabolism can impact the atmosphere-land carbon exchange cycles in several ways, which can be categorized into diverse groups like those which influence the ecosystem by CO_2 and methane uptake and which also affect the loss of carbon from the soil by respiration. Methane-oxidizing bacteria (MOB) or methanotrophs found in aerobic soils can function as effective biological sink to minimize emissions of methane to the atmosphere. They depend upon CH_4 for energy and carbon. About 15% of the total worldwide CH_4 is contributed by MOBs. They are sensitive to environmental calamities and hard to isolate because of their fixed attachment to soil particles and slow growth rate. A bacterial specie *Methylokorus infernorum*, which is present in geothermal zones in hot and acidic locations, exploits methane CH_4 gas. These bacteria have the ability to use a high amount of methane, which is up to 11 kg year^{-1} and can also be used to reduce emissions of methane from CH_4-producing areas and factories. Moreover, *Methylobacillus* utilize carbon-containing compounds, like methanol, methylated amines, and methane. Additionally, there exist some natural microorganisms, which transform CO_2 into calcium carbonate ($CaCO_3$). Some species of microbes (denitrifying) are accountable to transform nitrous oxide (NO) into nitrogen (N_2) gas. The microorganisms have the propensity to reduce and mitigate emissions of GHGs. The microbial nutrients, gasses, and climate change pathway are explained in Fig. 4.1.

Soil microorganisms improved productivity, influencing the greenhouse gas budget in sense of discharges of greenhouse gas per part food fabrication. The advantage acquired by using the beneficial microorganisms in case of productivity can be thought as a role of microorganism to mitigate the change in climate. The world of microorganisms is very large, and only a very little portion <10% is characterized and identified so far (Bhattacharyya and Jha 2012). Soil microbes sense the biochemical created stimuli and releases the chemicals from their body, which can trigger complex mechanisms of plant defenses (Glick 2012). They effectively contribute in utilizing the greenhouse gases like N_2O, CH_4, CO_2, and nitric oxide (Bardgett et al. 2008). Microbes are essential for crop protection by promoting the capacity of disease resistance in plants opposed to the damaging pathogens and exposing destructive structures or auxiliary as biological elicitors against several biological and ecological influences. The fungi among microorganisms have the ability to colonize the external parts of plants and offer protection from several living and nonliving agents like pathogens, pests and insects attack, heat, and drought (Singh et al. 2011). Usage of microbial biofertilizer in agriculture system is

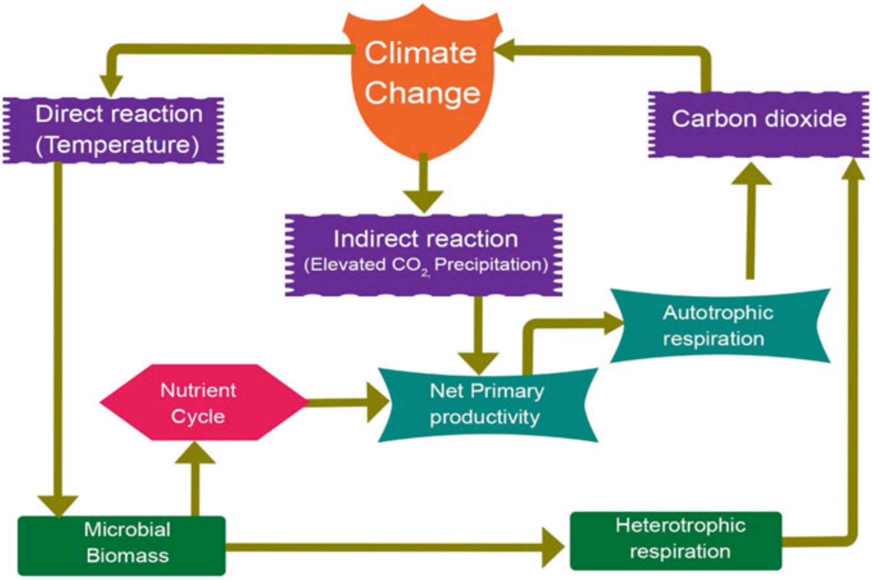

Fig. 4.1 The microbial nutrients, gasses, and climate change pathway. (Dutta and Dutta 2016)

not yet so common because of the problems of identification and tracking of inoculated strains and uncertainty of results. Nowadays, the application of microbial biotechnology is very important in sustainable agricultural development. Conserving the microorganism diversity is vital to maintain the species variety of higher living organisms and strategies for nutrient management and disease of plants (Colwell and Munneke 1997). Changes in climate encourage modification processes in the micro-organisms and plants (Grover et al. 2011) and therefore alter the efficiency of microbe-plant linkages. The concept of microclimate difference-microbe response and potential negative and encouraging position of microorganisms in worldwide environment difference is important to use them for changes in climate improvement and variation.

The three main factors affecting climate modification consist of natural, human, and atmospheric influence. The sun radiates solar energy that affects the planet and raises temperature; and rising temperatures cause global warming (Lean 1991). Improved amounts of human-generated glasshouse gases reason much more warming than current fluctuations in solar action. Satellites have been observing the sun's energy harvest for more than 40 years, and it has oscillated by less than 0.1%. The life on Earth exists due to the sun, which keeps its temperature warm and makes the conditions favorable for the survival of humans. It also influences Earth's atmosphere. However, the contemporary warming has been far too swift to be credited to the changes in Earth's orbit and far too huge to be caused by the solar endeavor (Assessment 2018). In a single solar cycle, which is of 11 years, the sun never brightens the same way it brightens and dims slightly. The sun undergoes various changes in activity and looks over each cycle. The level of the radiations coming from the sun changes, as does the quantity of material discharged into space by the sun, as well as the volume or size and number of solar flares and sunspots. Long- and short-term disparities in solar activity play only a minor effect on Earth's climate. Warming caused by the rising amounts of human-produced greenhouse gases is many times more commanding than any effects caused by the recent vagaries in solar activity. Satellites have been tracing the sun's energy output for more than 40 years, and it has been altered by less than 0.1% over that time. Since 1750, the warming produced by greenhouse gases unconfined by human use of fossil fuels has been more than 50 times more than the small extra warming caused by the sun (Birat 2021). Global climate change has been linked to huge volcanic explosions (Altman et al. 2021). Volcanic explosions have two major effects on the climate. First, they radiate the greenhouse gas carbon dioxide, which promotes global warming. However, the influence is negligible. Volcanic emissions have been projected to be at least 100 times lower than those from fossil fuel incineration since 1750 (Wilson 2021). Climate change is influenced by volcanoes. Massive quantity of volcanic gas, drips of aerosol, and ash are inserted into the stratosphere layer during a huge explosive outbreak. Although volcanic gases such as SO_2 can provide a cooling effect globally, on the other hand, volcanic gas like carbon dioxide, which is a greenhouse gas, has the ability to raise the temperature of the globe (Sigurdsson et al. 2015).

Climate alteration and air pollution have an intricate relationship. Pollutants, such as ozone O_3 and black carbon, raise the Earth temperature by entrapping the heat in the atmosphere, while others like SO_2 that form light-indicating elements cool the temperature (Stern 1977). Sustained decrease in air pollution and GHG emissions are dangerous because they cause significant health and ecological hazards around the world. Air property and climate lineups can be an advantage to one another: change in climate vindication enterprises can help decrease pollution of air, while policies related to clean air can help reduce greenhouse gas emissions, resulting in lower global warming. If decrease in a specific emission of pollutant results in increased atmospheric temperature rather than cooling, there may be trade-offs (Seinfeld and Pandis 2016). All through complex interactions in the environment, difference in climate, and pollution in air influence each other. raising levels of greenhouse gases interrupt the balance of energy between the atmosphere and the surface of Earth, which results in temperature changes that alter the atmosphere's chemical makeup. This balance of energy can also be influenced by direct emissions of air pollutants, for example, black carbon or those pollutants formed from emissions like sulfate and ozone. As a result, climate change and air pollution organizations have common impacts (Paoletti et al. 2007). The less gasoline we burn up, the better we are at decreasing air pollution and the dangerous effects of climate change. Make wise shipping verdicts. Walk, ride a bike, or operate public transportation wherever possible. Buying food in the vicinity decreases the quantity of fossil fuels need to transport or fly food across the country and possibly most prominently, “Support leaders who promoter for clean air and water, as well as accountable climate change action” (Mackenzie 2016). Water vaporization is the most plentiful GHG, but it also functions as a climate response. As the temperature of Earth increases, degree of water vapors increases, but, as a result, chances of clouds and rainfall also increase, making these two response mechanisms important to the greenhouse effect. CO_2 levels in the atmosphere raised from 280 ppm to 414 ppm in the last 150 years, due to the industries that underlie our modern society. Generated greenhouse gases, such as carbon dioxide, methane, and nitrous oxide, are produced by humans, likely to be responsible for much of the rise in Earth’s temperature during the past 50 years (Oreskes 2004; Karl et al. 2009). Increase temperatures result in higher evaporation costs, since the amount of energy required for evaporation decreases as the temperature rises. In a sunny, warm weather, water loss is increased due the high evaporation as compared to depressing and cool weather. As a result, when the weather is bright, hot, dry, and windy, evaporation rates are higher. Due to the water vapor functioning as a greenhouse gas in the atmosphere, evaporation might have a warm effect on the global climate. Increases in the evaporation intensity tend to induce clouds to develop low in the atmosphere, which function as a signal that the sun’s warming rays are being reflected back into the space (Spracklen et al. 2018).

The emissions of greenhouse gas have a wide range of environmental and physical condition inferences. They contribute to respirational ailments due to air pollution and smog, along with triggering environmental difference through confining the heat up. Other consequences of climate change produced by greenhouse gases include extreme weather, food supply shortages, and more wildfires (Nunez 2019). Carbon dioxide is a minor but vital component of the environment. Ecological practices like respiration and volcano explosions emit carbon dioxide, as do human endeavors like deforestation, land use changes, and fossil fuels burning are only a few examples. Human has raised CO_2 level in the atmosphere by 47% since the beginning of the industrial revolution, which is the most significant long-term “forcing” of climate change (Fig. 4.2).

4.7 Climate-Smart Agriculture

Soil health is indispensable for creating more climate flexible agricultural systems, and it may be enhanced through an assortment of climate-smart agriculture (CSA) advances. Climate-smart agriculture (CSA) has been suggested as a general attempt to establishing agricultural practices to ensure long-term food insurance in the face of climate alteration (Palombi and Sessa 2013). One of CSA’s pivotal goals is to minimize the emission of greenhouse gases while also enhancing the soil carbon appropriation and soil physical condition (Campbell et al. 2014; Lipper et al. 2014). Increasing the carbon consequences while lowering the carbon outputs is the key to distinguish more carbon in soils. Adding cover crops to the crop rotation, utilizing biochar to soils, and decreasing soil tillage are all often recommended ways for SOC

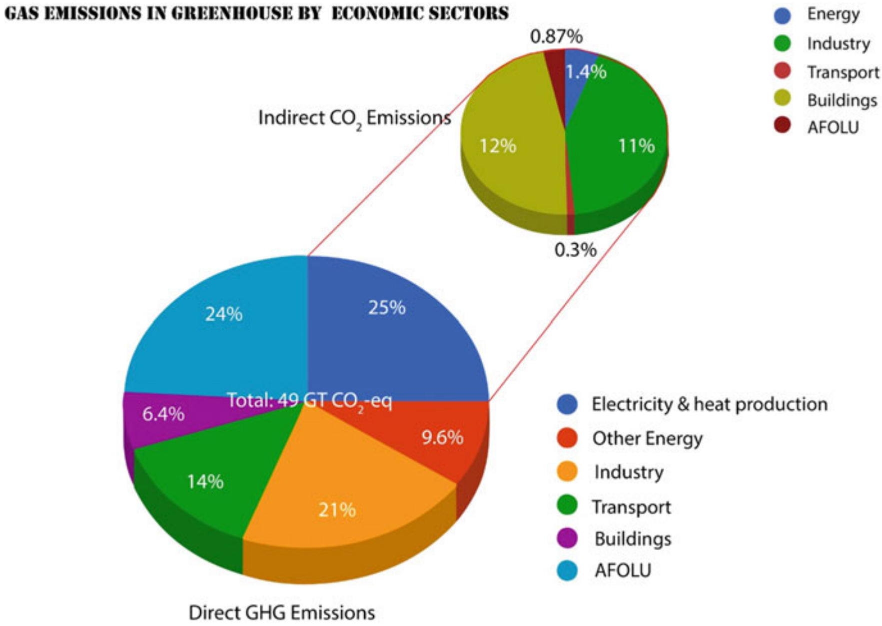

Fig. 4.2 The greenhouse gasses that affect climate change. (FAOSTAT 2022)

sequestration (i.e., conservation tillage). These administration tactics have been used in important agricultural zones around the world in the latest decades, developing in an enormous number of examinations and statistics (Chen et al. 2009; Clark et al. 2017). Encouraging effects of CSA regulating methods on SOC appropriation have been described by several processes. Conservation tillage, for instance, minimizes the organic matter rate in the soil and also minimizes the soil disturbance (Salinas-Garcia et al. 1997) and stimulates earthworm and mycological biomass (Fragoso et al. 1999; Briones and Schmidt 2017), thereby advancing SOC stability (Wang et al. 2021). Cover crop boosts carbon and nitrogen inputs, improving the agroecosystem biodiversity, and offers extra biomass inputs from above- and below-ground (Blanco-Canqui et al. 2011) (Lal 2004). Furthermore, cover crop can increase soil aggregation and structure (Sainju et al. 2003), reducing carbon loss from soil erosion indirectly (De Baets et al. 2011). Biochar alterations prejudiced the soil organic carbon diminuendos 2 ways: (1) enhancing soil combination and physical protection of aggregate related with soil organic matter from microorganisms attack; and (2) increasing the pool of intractable organic material, resultant in a low soil organic matter putrefaction amount and significant adverse priming (Du et al. 2017; Weng et al. 2017; Zhang et al. 2012). Even though these climate-smart agriculture governing techniques have been commonly utilized to improve the soil physical condition (Denef et al. 2007; Fungo et al. 2017; Thomsen and Christensen 2004; Weng et al. 2017), their effects on CO_2 sequestration change over time and are highly dependent on experiment design and site-specific factors, including climate and soil condition (Abdalla et al. 2016; Liu et al. 2016a, b; Paustian et al. 2016; Vickers 2017). The aptitude of CSA methods to sequester soil carbon differs widely. Some research has also claimed that CSA management techniques have a negative impact on SOC (Liang et al. 2007) (Tian et al. 2005). Most mathematical exploration intensive on the impacts of a single climate-smart agriculture practice on soil organic carbon (Abdalla et al. 2016; Liu et al. 2016a, b; Vickers 2017) and very few studies estimated the joint effects of varied CSA and conventional management practices. A combination of cover harvest and preharvest tillage, according to several recent research, may dramatically improve SOC when compared to a single management strategy. When no-tillage and cover crop practice were combined, soil carbon sequestration increased by 0.267 Mg C ha^{-1} $year^{-1}$, with the latter being a varied culture of hairy vetch (*Vicia villoma*) and rye (*Secale cereale*); when only no tillage was used, soil carbon sequestration decreased by 0.967 Mg C ha^{-1} $year^{-1}$ (Ashworth et al. 2014; Blanco-Canqui et al. 2013; Duval et al. 2016; Sheehy et al. 2015). When biochar was added to conservation tillage, Agegnehu et al. (2016) found that 1.58% and 0.25% more of SOC were sequestered in the midway and end season, respectively, under conservation tillage.

Climate-smart agriculture (CSA) is emerging progressively more popular as a solution in many nations. CSA is a comprehensive approach to landscape organization that improves productivity, improves flexibility, and lowers greenhouse gas emissions. The World Bank, as one of the major agricultural financiers, assists countries in their attempts to scale-up climate-smart agriculture. Climate-smart agriculture (CSA) is a management strategy for farmers in the face of climate change. The CSA wants to advance internationally relevant agriculture management practices for food security. The concept was initially introduced in 2009, and it has since grown based on feedback and interactions from a variety of stakeholders. The CSA strategy was established in response to arguments and disputes in environmental change and agricultural policies for long-term development (Lipper et al. 2017). Enhancement in mitigation by decreasing GHGs is an important CSA goal and a key to long-term efficient climate change adaptation; therefore, it comprises inventions and implementation of cultural techniques, varieties of crop, managing techniques, and organizations that will speed up improvement. Transitioning to no- or small tillage methods has already been recognized as a significant resource of carbon sequestration, and implementing more varieties of yields and conservation practices that decrease agriculture's land, ecological, and nonrenewable fuel resources is an additional significant reduction policy (Lal 2011; McCarthy et al. 2012). Climate-smart agriculture may work as an agent for developing resistance, better modification, and adaptation approaches within sociobiological structure (Steenwerth et al. 2014) (Fig. 4.3).

Precision agriculture is one such implement that is useful in making an agriculture more "climate savvy" by minimizing its environmental influence. Thus, precision agriculture is an intensive system that entails the usage of a world aligning system, several instruments for observing soil moisture content, nutrients availability, and geo reference map for various soil characteristics, but when implemented on a huge scale, it can support to increase productivity, reduce resource ingesting, and reduce ecological impact. Precision agriculture is a contemporary day climate-smart

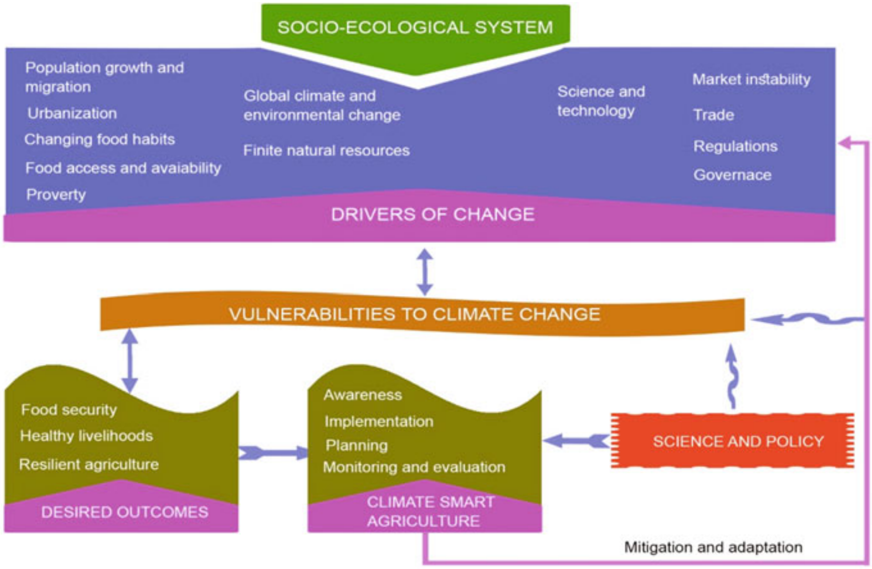

Fig. 4.3 Climate-smart agriculture for improving resilience, better mitigation, and adaptation. (Steenwerth et al. 2014)

agricultural technique that has the potential to address the food problems insecurity in poor nations and combine as a strong instrument and solution to the agriculture sector's numerous challenges (Roy 2020). The practice of "no-till farming," which avoids soil manipulation for crop production, is one approach to sequester carbon. No-till farming has numerous potential benefits for gardeners, farmers, and the environment when combined with cover cropping. The combination of no-till farming and cover cropping is always found suitable for increasing organic matter. Through this way, a shield is created over the soil to protect it during the driest times as well as a sponge in the soil to protect it during heavy rains. So, while the two activities combined generate organic matter and store carbon in the soil, they also offer additional advantages. Because all that organic waste is now decomposing, they give nutrients to the food. There are numerous environmental advantages to no-till farming. It increases carbon sequestration in the soil and reduces fossil fuel use in farm activities. The quantity of nutrients that the soil can contain increases as soil organic carbon levels rise, implying less petroleum-based fertilizers and runoff into nearby water bodies. Farmers would benefit from the method in the event of harsh weather, such as drought, because soil rich in soil organic matter absorbs water better than tilled ground. Agricultural practices in poor nations frequently result in poor soil quality. Climate change-related extreme weather may exacerbate the problem, unless better agronomic techniques are implemented. The goal of soil and land management must be to enhance yield while preserving soil and water resources. It also intends to sequester carbon. Organic fertilization, least soil disruption, residue absorption, terraces, water gathering, preservation, and agroforestry are all illustrations of this administration (Branca et al. 2013), but there are several

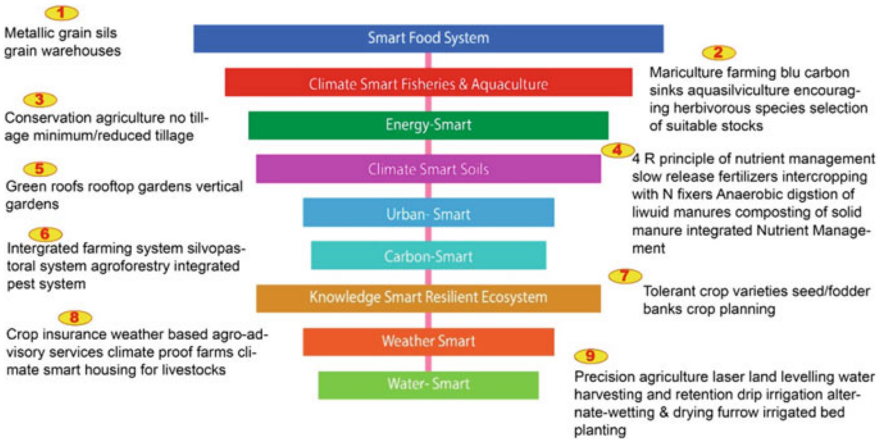

Fig. 4.4 Climate-smart agriculture technologies. (Adopted from Source: Khatri-Chhetri et al. 2017)

prospects for improving new management methods and improving existing ones to adjust spatial and climatic erraticism.

All agroecosystems require climate-smart agriculture (CSA) equipment, methods, and help. These approaches can help to improve agriculture, protect it from climate change, and ensure food security. The biophysical environment, farmer socioeconomic traits, and the benefits of CSA technology all play a role in CSA adoption (Khatri-Chhetri et al. 2017) (Fig. 4.4).

For countries that rely on agriculture for subsistence, CSA technologies provide at least two benefits in terms of production, resilience, and mitigation, with productivity being the most important. Metrics nested under these broad CSA categories can be used to track progress against a realistic baseline. For example, improved productivity could be assessed in terms of yields, income, or internal rate of return. CSA aspires to maximize synergies and minimize trade-offs across all of its pillars (Rosenstock et al. 2016). While boosting food security, CSA technologies manage climate- or weather-related risk. Extreme occurrences (such as floods) as well as slow-onset threats may be considered (such as delayed onset of seasonal rains). CSA technology should assist in mitigating the effects of these risks in the short term (by increasing the amount of production per farm, hectare, season, etc.) as well as in the long run (by increasing the amount of production per farm, hectare, season, and so on and decreasing the variability in production over time, despite climate change).

4.8 Soil Microbes and Global Agriculture

Food security becomes a major challenge in the twenty-first century in response to the increase in demand of sufficient food with respect to population rate. Nowadays, the other main factor influencing food security is climate change (Alamgir et al.

2020; Borrill et al. 2019). The alteration in environment, such as extreme temperatures and fluctuation in rainfall intensity, becomes a global aspect that concerns agricultural production (Abberton et al. 2016; Milus et al. 2009). These alterations have high impact on soil, microbiota, agricultural output, and global food security (Adger et al. 2009; Hill et al. 2009; Nelson et al. 2009; Campbell et al. 2016; Durán et al. 2016). As per contemplates, the normal world temperature has risen, and freshwater supplies will be fundamentally decreased before the end of the twenty-first century. Varieties in snowfall and territorial precipitation have additionally been noticed, and these variations are required to deteriorate in the coming days (Misra 2014; Reidsma and Ewert 2008; Reidsma et al. 2010; Stocker et al. 2013). Climate is fundamentally affected by farming. Farming emanates enormous volume of ozone-harming substances, i.e., GHGs like CO_2, CH_4, N_2O, and corona carbons into the environment, where they assume a critical part in ingest sun-powered energy (Valizadeh et al. 2014). Farming is responsible for an expected 17–32% of all worldwide greenhouse gas emanations (Cotter and Tirado 2008). Agribusiness can lessen GHG discharges and ease environmental change. While certain harvests may profit with environmental change in certain areas, expanding temperatures may in the long run lower rural yields on a worldwide scale, especially in dry and hot areas (Smith and Gregory 2013; Valizadeh et al. 2014). Moreover, extreme temperatures have increased weed and creepy crawly attacks, bringing about lower farming yields (Nelson et al. 2009; Reidsma and Ewert 2008). Without a debate, the combined impacts of environmental change on agribusiness are negative, representing a risk to worldwide horticultural creation and, thus, imperiling sanitation (Glenn et al. 2013; Malhotra 2017).

Farming usefulness is associated with conditions both straightforwardly and by implication, through giving and related cycles; environmental change will put a strain on this fragile equilibrium (Altieri et al. 2015; Smith and Gregory 2013). In spite of the fact that environmental change will impact our overall ability to get food, it is plausible that underestimated individuals in nonindustrial countries would be the most exceedingly awful hit (Sanchez and Stern 2016). It is clear that future requirements for food and environment administrations will require more extreme changes underway, utilizations, and strategies (Davidson 2016). CO_2 and other fellow gases are growing, and these additions will in the end affect the world's environment (Ortiz-Bobea 2021). Plant constructions and thus crop productions are prejudiced by various organic parts, and these components similar to suddenness and temperature may act either synergistically or ridiculously with various variable quantities in selecting yields (Yevessé 2021). Controlled field preludes can make information on how the yield of a specific gather arrangement responds to a given lift, like water or fertilizer. Nevertheless, by their disposition, such controlled tests consider only a confined extent of biological factors (Jiang et al. 2021). An elective method to manage and check out crop yield (changes) is the use of gather biophysical diversion models that introduce limits drawn from crop tests (Gurgel et al. 2021). Since natural change is likely to cut across a huge gathering of living components, such collect proliferation models give the most quantitative examinations of changes in ecology impacts on crop yields (Manzoor et al. 2021). However, the usage of gather reenactment models makes the examination of climate impacts over an area of yields logical; these kinds of models furthermore have limits, counting the separation from the grouping of components and state that impact creation in the field (Lal 2021). feasible ecological circumstances that changes, consolidate increased temperatures, variations in rainfall or snowfall, and increased air CO_2 obsessions. Regardless of the way that temperature additions can have both positive and antagonistic outcomes on crop yields, with everything taken into account, temperature increases have been found to diminish yields and nature of various harvests (Avagyan 2021).

A climate with greater CO_2 intensity would achieve higher net photosynthetic values (Horton et al. 2021). Higher centers may equally reduce arising (water disaster) as plants decline their stomata holes, the little cavities in the leaves through which CO_2 and water seethe are replaced with the air (Ortiz et al. 2021). The net change in crop yields is limited by the affability between these negative and positive direct ramifications for plant improvement and progress and by deceitful effects that can impact creation. These inadvertent effects have been usually disregarded in the examination of ecological change impacts (Zougmoré et al. 2021). Typical effects may rise up out of changes in the event and course of vermin and microorganisms, extended speeds of soil crashing down and defilement, and increased troposphere ozone levels in view of rising temperatures (Kehler et al. 2021). Extra deceitful effects may rise up out of changes in overflow and groundwater re-invigorate rates, which impact water supplies, and changes in capital or mechanical supplies, for instance, surface water accumulating and water support practices (Koutsoyiannis 2021) (Fig. 4.5).

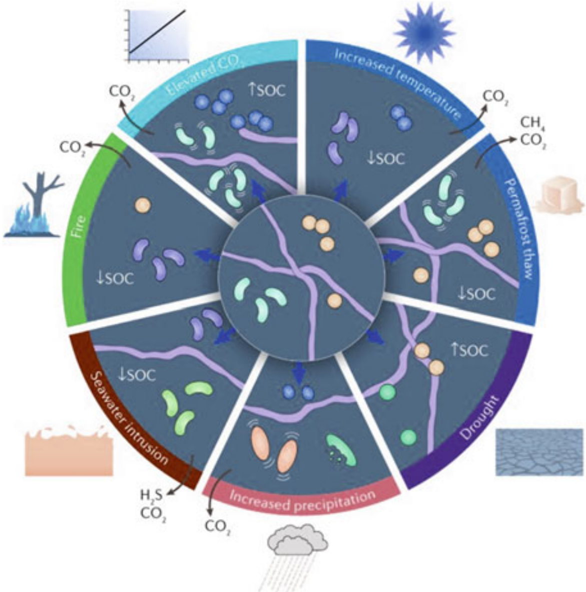

Fig. 4.5 Soil microbial response to climate change. (Jansson and Hofmockel 2020)

Naturally, more than 90 billion bacteria are preset in one-gram soil that promotes the plat growth by making the unavailable nutrients in the available form for plant uptake. Nowadays, the biotic stress is a big challenge for agriculture due to day-by-day increase in the world population, which causes increase in food demands. The use of chemical means of nutrients increases the crop production, but it also deteriorates the environment causing a reduction in soil fertility and plan growth (Armstrong and Taylor 2014). For agricultural production, the health of soil is very important, which depends on different reactions, such as chemical, biological, and physical, collaborated by microorganisms. The beneficial microorganisms are group of naturally occurring microorganisms, like plant growth-promoting rhizobacteria, fermenting fungi, actinomycetes, yeast, lactic acid bacteria, etc. These microorganisms play a very important role in improving the soil structure and soil fertility, suppressing soil-borne pathogen, fixing nitrogen, increasing the decomposition of organic matter, and enhancing the level of nutrients and of plant strength and ultimately crop yield (Joshi et al. 2019).

Soil microorganism is involved in different biogeochemical cycling of all major (N, P, K, S, etc.) and minor nutrients (Fe, Mn, Co, B, Zn, etc.) required for crop growth and other life (Jansson and Hofmockel 2020). The impact of climate change on soil microbes in different climate-sensitive soil ecosystem is illustrated in Fig. 4.1 (Dutaa and Dutta 2016). Mycorrhizal fungi and bacteria that live near the roots offer numerous advantages to the host plant, including faster growth, enhanced nutrition, better drought resistance, and defense against pathogens. Mycorrhizal fungi are broadly characterized into two groups. The first one is vesicular arbuscular mycorrhizas (VAM or AM) and the second is eco-mycorrhizas (EM), which differ extensively in structure and function. The structures produce by VAM within the roots of plants are known as arbuscules and vesicles, which participate in the transfer process of nutrients. This symbiotic relation benefits the host plants directly, through the solubilization of phosphate and other mineral nutrients from the soil by the fungus, while the fungus obtains a carbon source from the host plants. The symbiosis also improves the resistance of plants to biotic and abiotic stresses. Ectomycorrhizas (EM) frequently produce large aboveground fruiting bodies like that of a mushroom and toadstool as well as a hyphal net around the root of plant. Vesicles and arbuscules are absent, and the hyphal penetration of the root is incomplete. EM fungi are amenable to axenic culture. Potential inoculum can also be produced in the field from mycelium (Harrier 2001; Thomson et al. 1994). The soil microorganisms play a vital role in soil health and sustainability. The density and diversity of microorganisms' population indirectly depend on the level of organic matter, because it provides energy for soil microorganisms and improves the structure, stability, and moisture of the soil and plant nutrient availability and stops the occurrence of soil-borne disease (Zhang et al. 2007).

4.9 Microbial Contribution in Climate-Smart Agriculture

Worldwide, agriculture participate in and is an agriculture both promotes to and is endangered by climate change over. Corresponding to the account of IPCC, agriculture brings part in 58% and 47% of the total anthropogenetic constructions of N_2O and CH_4, respectively. Agriculture is previously facing the severe impacts of climate adjustment (Lobell et al. 2011), and consequently, the food production is also being affected directly and indirectly by it. Fluctuations in rainfall pattern, upsurge in mean temperature, and intensification in occurrence of intense climatic effects, like scarcity, floods, and cyclones, will highly affect the agriculture (Lee 2007). The growth of population in the world is forecasted up to one third by 2050, and most of the people (about 2 billion). The world's residents are expected to improve by one third by 2050, and most of the added two billion people will survive in improving states (Boettcher et al. 2015). With the aim to fulfill the constraints of food and feeding, agricultural production is predicted to grow by 60%. It is a big challenge for the upcoming food security, as the resources required to maintain the present agricultural growth are already being endangered. Furthermore, worldwide agriculture is already being harmfully impacted by global climate change, and climatic hazards to livestock, fisheries, and cropping are predicted to rise in the coming years. In the period of such rapid change in climate, alteration and redirection of agricultural production led to the strategy of climate-smart agriculture (CSA). Microorganisms are vital members of the soil-plant ecosystem, and simply no food production is possible without them. Microorganisms perform a vital role in the cycling of plant nutrients in the system of microbe plant soil and atmosphere. Microbes are crucial to nitrogen and carbon cycles and take part in the consumption and production of greenhouse gases (GHGs), like nitrous oxide, methane, and carbon dioxide. A vast diversity of microorganisms offers an unexploited way to improve the quality and quantity of agricultural products, leading to adaptation and mitigation of changing climate outcomes, thus helping to attain the target of climate-smart agriculture. The microbes that cause diseases to insect pest and weeds are utilized as biopesticides. There are many microbes in the soil, which promote plant growth through various biocontrol mechanisms. The free-living soil microbes help to maintain the soil structure, carbon sequestration, and nutrient storage and availability (Das et al. 2019).

Microbe variety in soil enhances the numerous mechanisms that are a vital part of biogeochemical cycles and henceforward promotes and maintains a lot of agroecosystem's biochemical reactions, such as decomposition of organic matter, nutrient availability to plants, and overall productivity of plant and soil. Many times, the microorganisms make associations, and many limiting resources are made available to plants by them. Furthermore, the host-specific microorganisms like mycorrhiza and N_2 fixers also make available limited and fixed plant nutrients to enhance plant growth. Consequently, microbes endorse the sustainability of agriculture and effective operation of agroecosystem (Das et al. 2019) (Fig. 4.6).

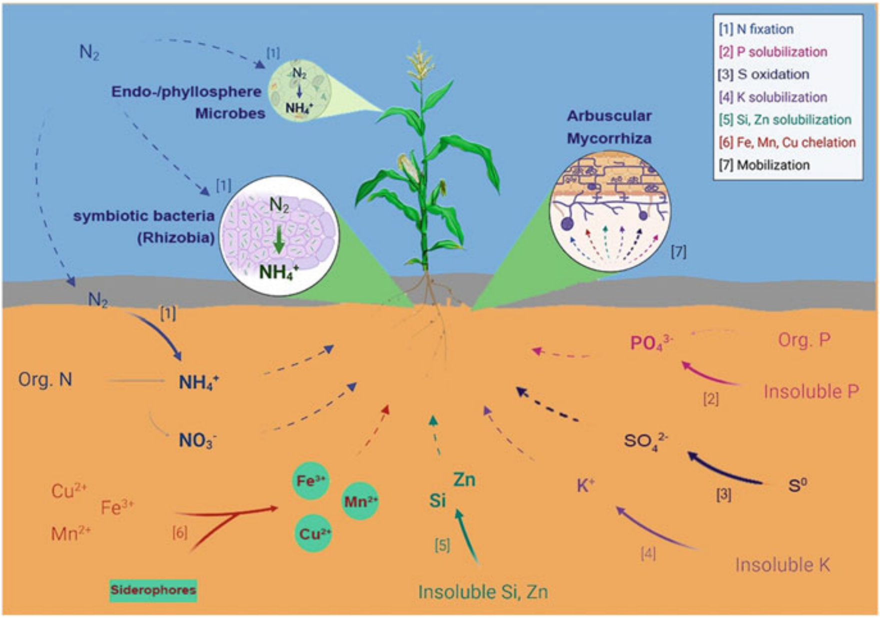

Fig. 4.6 Microbial-mediated nutrient transformation pathway. (Mitter et al. 2021)

The process in which complex organic biopolymers present in the dead remains, and residues of animals and plants are broken down into simpler inorganic and organic monomers through various biochemical reactions, referred to as organic matter decomposition (Juma 1998). During this microbial process of organic matter decomposition, nutrients and energy are recycled, and the surplus plant nutrients, like N, S, and P, are added to the soil in the plant-available form; this transformation is known as mineralization. Hence, in this way, microbes are crucial for the availability of essential plant nutrients and necessary inorganic compounds in the soil through the processes of nutrient recycling, by decomposing the plant residues and dead bodies of animals (Das et al. 2019). Fixation of atmospheric elemental nitrogen (N2) into plant-available forms is one of the most important biochemical reactions that is highly essential and beneficial for global agricultural sustainability and efficient ecosystem functioning. Worldwide, the annual incorporation of the fixed nitrogen through symbiosis between rhizobia and legume is assessed to be 18.5 million tones and 2.95 million tones for oilseed legumes and pulses, respectively (Howieson et al. 2005). However, the symbiotic bacteria nodulating the legume crops belong to the genera *Brady rhizobium*, *Ensifer*, *Rhizobium*, and *Mesorhizobium* that are conscientious of about 80% N accumulation in grains, causing high nutrition and profit. The bacteria, which live freely and do not form a symbiotic relation with the host crop, are known as free-living N2-fixing bacteria. Some of them are *Azospirillum*, present in temperate region cereal-growing soils; Beijerinckia, associated with sugarcane in tropical areas; and *Azotobacter*, prominent for N2 fixation in rice growing soil and also used as a biofertilizer for tobacco, tea, coffee, coconuts beetroot, sunflowers, oat, barley, maize, and wheat crops. Moreover, the species that belongs to the genera *Herbaspirillum*, *Gluconacetobacter*, and *Azospirillum* are endophytes of sugarcane and provide nitrogen to the crop. *Azorhizobium* strains that fix the N2 are isolated from the rhizosphere of wheat crop, while *Bradyrhizobium* and *Rhizobium* are from the roots of paddy. Additionally, there are specific diazotrophic bacteria that form a true beneficial mutualism (symbiosis) with some host plants by forming the nodules with its roots (García-Fraile et al. 2015). Phosphorus solubilizing microorganisms (PSMs) release the plant unavailable inorganic and organic soil phosphorus through mechanisms like solubilization and mineralization and make P available to crop plants, thus playing a vital role in soil fertility (Sharma et al. 2013; Walpola and Yoon 2012). In the P-deficient soils, a diversified variety of PSMs like fungi (*Penicillium* and *Aspergillus*) and bacteria (*Bacillus*, *Pseudomonas*, and *Actinomycetes*) can be inoculated in the soil to increase the P availability, through their mineralizing and solubilizing capability (Gyaneshwar et al. 2002). P solubilization by bacteria is more efficient than fungi (Sharma et al. 2013). *Penicillium bilaii* is also a beneficial P-solubilizing bacterium that effectively takes part in the phosphate solubilization in native soils. Secretion of organic acid by fungi solubilizes the phosphate reservoirs in soil, making P easily available to plant roots. Potential phosphate-solubilizing bacterial genera in the soil include *Pseudomonas*, *Rhizobium*, endosymbiotic rhizobia, and ectorhizospheric strains of *Enterobacter* and *Bacilli* (Khan et al. 2009). A mutual exchange of nutrients and carbon occurs between mycorrhizal symbiosis of arbuscular mycorrhizal fungi (AMF) and host plant. The host plant acquires nutrients, e.g., phosphate and nitrogen, from fungus, which promotes plant's resistance against abiotic and biotic stress, and, in response, fungi get 4–20% C fixed by photosynthesis. Mycorrhizal symbiosis is quite common, and its symbiotic functions depends upon the variations between the soil properties, host plants, and AMF species. Generally, the AMF symbiotic linkages are thought to be nonspecific and diffused due to their several linkages by many species to different plants (Selosse et al. 2006). AMF symbiosis is an important biological mechanism to remediate polluted soils and mining spots (S. E. Smith and Read 2010). The microbes that benefit the health when consumed are known as probiotics. The concept of probiotics was given by the Nobel Scientist Élie Metchnikoff, who recommended that food requirement by intestinal microorganisms helps to exchange the detrimental microorganisms by beneficial microbes and to follow measures to adapt the microbial flora in our bodies. Soil probiotics are normally thought as soil-based organisms (SBOs), since they are advantageous bacteria which live in the soil. As the plants do not genetically acclimatize in the rapidly changing environment, i.e., drought, limited nutrients, and toxins, therefore, they may utilize the microorganisms to build the capacity for fast growth in the fluctuating environmental conditions for shorter life period. Hence, in this way, plants show the same mechanism as humans using probiotics to progress their health. Stimulation of plant-specific microbial species in their rhizosphere region tells us that plants can support and stimulate tactically to certain microbes, which have the ability to produce antibiotics that defend the plants against diseases causing soil pathogenic organisms (Weller et al. 2002). The bacterial species of the genus *Pseudomonas* are universal in many soils and participate in a lot of reactions, like bioremediation, nitrogen (N2) fixation, nutrient cycling, control, and inhibition of diseases, therefore promoting the plant growth. Pseudomonads work as a potential biocontrol agent against oomycete and fungi pathogens over the last two decades (de Souza 2002). Their most frequent property is antibiosis that is responsible for their reactions against the disease-causing plant pathogens, and a variety of antipathogenic compounds are also recognized, e.g., biosurfactant, hydrogen cyanide (HCN), pyoluteorin, pyrrolnitrin, phenazines, and 2,4-diacetylphloroglucinol (2,4-DAPG) (Picard and Bosco 2008). Their quick response capability to variations in nutritional, carbon, chemical, and physical conditions in the soil is very highly beneficial in agriculture, environment, and ecosystem functioning.

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