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Review Article

SCOPE OF MICROBIAL INTERVENTIONS FOR DEVELOPING CLIMATE RESILIENT AGRICULTURE

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Abstract- Climate change includes slow rate of crop growth, and unavailability of moisture, due to the variation and changes in water use for irrigation purpose and other agricultural chemicals use. The present review updates the impact of climate change on agriculture, adaptations to climate change and role of microbes in climate resilient agriculture.

Keywords- *Climate change, Environment factors, Crop diversity, Agricultural productivity, Microbes, Microbial interventions*

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Introduction

Increased in anthropogenic activities such as industrialization, urbanization, deforestation, change in land use patterns etc leads to emission of greenhouse gases due to which the rate of climate change is much faster. Because of these increased rates of climate change factors there is much concern about future changes in climate which may lead to their direct and indirect effect on agriculture [1-3]. Extreme weather conditions, such as droughts, floods, heat, cold waves, flash floods, cyclones and hailstorms are direct hazards to crops Climate may have indirect and possibly lagged influences, the increase in minimum temperatures increases maintenance respiration requirement of the crops and thus further reduces net growth [2,4]. Modification in environmental factors is due to climate change that is seriously a matter of concern. Not even the environmental stress, soil stress is also a matter of concern due to which flowering, pollination and other factors also get affected. There will be urgent need of drought tolerant varieties to cope up with the soil stress. At the end extreme evaporation leads to salt accumulation in soil [5]. Temperature and extreme precipitation affect the water availability for irrigation demand [6]. Strong gradients of temperature and pressure lead to higher rainfall. This in turn leads to soil erosion [7]. Various levels and types of technological and socioeconomic adaptations to climate change are possible. The extent of these adaptations depends on the affordability of such measures. Adaptation is about building resilience and reducing vulnerability. As for vulnerability, resilience can be considered in various dimensions-biophysical, economic and social and at various scales [8].

Adaptations to Climate Change

Agricultural sector is especially adaptable given that technological, resources, and management changes can be undertaken relatively quickly [9] It is also apparent from the empirical literature that while adaptation options are numerous, they must be site and sector specific and must reflect numerous decision rules. Discussion of adaptation options is based on measures that are appropriate for the short and long term [10]

Short Term Adaptations

Some types of adaptations are easier to address short term concerns. In case of temperature and moisture stresses diversification are an alternative process to increase the overall productivity [11, 12]. Seed genetic diversity and composition diversity has been recognized as an effective defence against disease and pests, outbreak and climate hazards. Other options include changes in the timing and intensity of production. To reduce the soil erosion and to increase the soil moisture retention location of land use has to change [13,14]. To reduce the risks from climate change in farm production alteration in the fertilizer use and application of other chemicals is necessary [15]. Farmers adaptations may also involve changing the timing of irrigation or use of other inputs such as fertilizers [16]. In addition, several adaptations measure for livestock and rangeland management that have emerged to offset climate impacts. The option also includes grazing management grazing management that is timing, duration and location or in mix of grazers or browsers; varying supplemental feeding; changing the location of watering points; altering the breeding management program; modifying operation production strategies as well as changing market strategies [12]. In warmer climates, adverse climatic conditions such as heat stress can be moderated by the use of sprinklers [16,17]. Increased carbon dioxide levels and higher temperatures are likely to induce a need for increased plant protection in light of likely pest and disease outbreaks [14,18,19]. Implementing improved nutrients management techniques to maintain soil fertility and prevent erosion. Changing land topography through land contouring, terracing, construction of reservoirs and water storage can help reduce vulnerability by reducing runoff, erosion and promoting nutrient restocking in soil [20]. The impact of temporary migration on agricultural productivity has received some attention. Migration is an important form of risk diversification [21]. Migration is treated as transient phenomenon, or as a permanent feature that is necessary for achieving long term well-being [22,23]. Workers migrates seasonally and undertake off or non-farm activities in part of the year and return during harvest time includes in temporary migration [24, 25]. Agriculturally engaged households need insurance mechanisms to cope with income risks has long been recognized. Agricultural sectors faced four types of risks due to climate variation, including productions risk due to crop disease and other causalities; ecological risks from climate change, pollution and natural resource management; market risks, which depend on input and output price variability; and regulatory and institutional risks due to state intervention in agriculture [26]. Insurance may improve the adaptations strategies [27].

Major problem that plagues the system of credit and insurance in India is the inadequacy of crop insurance premiums [28]. Perverse incentives are also one of the major difficulties in providing insurance for adaptation. That is the reason that the farmer adapt is directly affected by the insurance scheme programs [29].

Long Term Adaptations

Farmers must withstand and minimize the adverse impacts of short term climate variability; a long-term adaptation phenomenon should entail a comprehensive long-term response strategy at the national or local level (World bank, 2000). Limited knowledge of the options in addition to other priorities, limited resources, or economic or institutional constraints are likely to make the requisite decision-making process [30]. To cope with various climatic conditions technological innovation and research in crop and animal productivity and have been fundamental to the growth and development of agriculture in both industrial and developing countries [31]. Two basic types of technological options, mechanical and biological, that are important for agriculture were identified [31,22]. A wide range of adaptation measures for improving water management have been highlighted, including improving water distribution strategies, improved water resource management; changing crop and irrigation schedule top use rainfall effectively; water cycling and conjunctive use of groundwater; rehabilitation and modernization, improving farm level managerial capacity. Among all these options irrigations has become the primary tool to increase and utilize agricultural production in the face of uncertainties associated with rainfall frequency and drought [33]. An alternative strategy includes improved irrigation practices through better water management plan and unsafe of technological innovations. Current technological advances in irrigation, such as the use of centre pivot irrigation, dormant season irrigation, drip irrigation, gravity irrigation, and pipe sprinkle irrigation, make this possible [14]. Second form of migration referred as 'frontier agriculture migration [23]. This encompasses permanent migration in the form of the movement of migrants into new economic areas, possibly due to governed policies or permanent changes in their previous environment. Long lasting climate pressure increases the vulnerability of migratory groups to climate change [34].

Microbes for Climate Resilient Agriculture

Role of microbes in developing crop resilience to climate change induced stress, is especially applicable in context of a changing climate. Plant microbe symbiosis is especially important and essential for plants living in high stress environments [35]. Soil microbes are reliant on plants to survive stressful environments [36]. Climate change leads to unprecedented environmental impacts, due to which microorganisms will respond, adapt and evolve in their surroundings. Because they have generation times as short as a few hours, they will do so as higher rates than most other organisms. this makes microbes ideal sentinels for understanding the effects of climate change on biological systems and the global biogeochemical cycles that microbes mediate. Soil environment directly affect the type of microbial population as well as the rates of processes they perform. For example, according to Rivest, et al., (2015) [37] In context to present agriculture, external inputs like chemical fertilizers are heavily used worldwide to ensure security of food. These synthetic and inorganic inputs generally lead to degradation of soil quality by harming the soil microbial populations [38]. Apart from it the injudicious use of pesticides results into suppression/smothering of beneficial soil microorganism which are involved in retention and recycling of nutrients. It also leads to deterioration of nutrient pools, thereby decreasing the soil fertility [39]. Crop microbiome, microbes playing role in nutrient cycling, endophytic microorganisms, mycorrhizae, and antagonists of pests and disease contributed to durable and sustainable farming systems. Microbes thrive in extreme environmental conditions, from hot to cold places, from very acidic to very alkaline sites, or those with high salt concentrations, high pressure, or any other environment that might not look favourable and normal to humans. Microbes are involved in many processes, such as the carbon and nitrogen cycles, and are responsible for both the production and consumption of greenhouse gases such as carbon dioxide and methane. Also, it is certain that human activities have helped to increase the production of greenhouse gases [40,41].

Phytomicrobiome in Crop Resilience to Stress

The plant microbiome or phytomicrobiome is generally composed of a variety of diverse niche environments such as on leaves (Phyllosphere), stems (Caulosphere), flowers (Anthosphere), fruit (carposphere), within the plant (endosphere), on the roots (episphere) and adjacent soil under the influence of root exudates. (rhizosphere). The distribution and composition of microbial communities on above ground plant parts is thought to be determined more by the environment than the host plant [42]. Application of plant microbiome to improve crop productivity is especially appealing in context to climate change because it offers a low input approach that can be implemented much more quickly than plant breeding or genetic engineering. Host plants and associated microbes in the Phyto microbiome often work in concern to respond to wide variety of stresses [43]. The beneficial effects of plant symbiotic microbes are often most apparent under stressful conditions [44]. Symbiotic microorganism can promote plant growth through a variety of mechanisms including improving nutrient availability, biological nitrogen fixation, production of plant hormones, stimulating plant immunity and antagonism involved toward phytopathogens [45]. Plant microbe symbioses are especially important and sometimes essential for plants living in high stress environments [46]. Members of phytomicrobiomes from stressful environments have adapted together to survive extreme and persistent biotic and abiotic stresses [47]. The microbiomes of plants native to stressful environments such as plants growing in geothermal soil, alpine mosses, lichens, primroses and agave have been identified as potential sources of microorganism that may help plants survive extreme environments [47,48]. Importance of the microbiome in plant health and resilience are showing that natural adaptations of the phytomicrobiome to environmental pressures can be exploited to increase agricultural production under adverse conditions, much in the same way genetic adaptations in individual organism are used for traditional breeding or genetic engineering [43]. Genetic engineering is nominally faster and presents a wider array of genetic possibilities; however, strict regulations often render this form of crop improvement prohibitively expensive [49]. Manipulations of the plant microbiome can be carried out quickly, may work on multiple crops and multiple stresses simultaneously, and are only limited by the vast genetic pool of the plant associated microorganisms [43].

Microbes as Biofertilizers

Microbial formulation containing substances are known as bio fertilizers [50]. Microbial formulation do not contain any harmful compound [51]. Native microorganisms are usually exploited to develop biofertilizers to assist plant growth promotion. The concept of biofertilizers was developed with the discovery of nitrogen fixing *Azospirillum* by [52] and phosphate solubilizers by Dobereiner, et al., (1976) [53]. Scientific preparation of microbial based fertilizers and application of microbial formulation is important while developing the agriculture in sustainable way.

Plant Growth Promoting Activity by Biofertilizers

Several soil microorganisms including nitrogen fixers and phosphate solubilizers are known to produce plant growth promoting substances (PGPS). The beneficial effect of bioinoculants is attributed to increase the nitrogen input from biological nitrogen fixation, higher phosphate solubilization, production of plant growth promoting hormones like auxins, gibberellins and cytokinin's and reduction of plant diseases and nematode infection. The phytohormones induce plant growth as well as dry matter production. Inoculation with *Azospirillum* resulted in better growth and higher dry production in maize and was mainly attributed to nitrogen fixation and the production of plant growth regulators [54]. The major hormone produced was indole-3- acetic acid (IAA) [55]. Other hormones detected at much lower, but biologically significant level was indole -3 -lactic acid [56], indole -3- methanol [57] unidentified indole compounds [58], abscisic acid (ABA) [59], cytokinins and indole-3- butyric acid (IBA) [55], and several gibberellins [60]. Bottini, et al., (1989) [61] showed that the inoculation of *P. aeruginosa, P. cepacia, P. Putida* and *P. fluorescens* strains on winter wheat increased the plant height, root and shoot mass and number of tillers in growth chamber.

de Freitas and Germida, (1990) [62] observed higher IAA production by *Azospirillum* isolates in the presence of tryptophan in the medium. Govindarajan and Kavitha (2004) [63] observed enhanced growth and production of indole compounds by *Azospirillum brasiliense* Cd and *A. lipoferum* Br17 due to aeration of the medium. In recent years, more attention is being given for searching early root colonizers which directly or indirectly benefit plant growth. Plant growth promoting rhizobacteria belong to several genera *viz., Azospirillum, Azotobacter, Bacillus, Bradyrhizobium, Erwinia, Pseudomonas, Rhizobium* and *Serratia*.

Nitrogen Fixers

The most important nitrogen fixers are *Azospirillum, Rhizobium, Azotobacter* and *Azolla. Azospirillum* is microaerophillic, gram negative and spiral shaped bacteria, which fixes atmospheric nitrogen asymbiotically. *Azospirillum brasilense, A. lipoferum, A. amazonense, A. halopraeferans, A. irakense* and *A. dodereinera* are the different species of the genus. *Azospirillum* used to be present predominantly in acidic soil environment. Further, its population was found to be maximum in laterite soil and the minimum in extremely acid sulphate saline kari soil [64]. Piao, et al., (1992) [65] studied the growth promoting effect of two new strains of *Beijerinickia mobilis* and *Clostridium* sp. isolated from pea rhizosphere on some agricultural crops and reported that application of *B. mobilis* and *Clostridium* sp. cultures in combination with mineral fertilizers increased the crop yield by 1.5 to 2.5 times.

Mechanism of Nitrogen Fixation

Biological nitrogen fixation by non-symbiotic nitrogen fixing bacteria like *Azotobacter* and *Azospirillum* which requires a complex enzyme system since the reaction is highly endergonic and it is widely being exploited all over the world for non-leguminous crops. *Azospirillum* is a rhizospheric bacterium colonized the roots of crop plants in large numbers, making use of root exudates and fixes substantial amount of atmospheric nitrogen. The protons and electrons required for this process are generated in metabolic reactions and catalysed by an enzyme nitrogenase. It is found only in prokaryotic microorganisms and so eukaryotes can benefit from nitrogen fixation only if they interact with nitrogen fixing prokaryotes to obtain the fixed nitrogen after their death and decomposition [65]. Fixation of atmospheric nitrogen by *Azospirillum* was evaluated mainly by acetylene reduction assay and this method was useful for quantitative evaluation of nitrogen fixation by *Azospirillum* and their screening [66].

Phosphate Solubilizers

The most efficient phosphate solubilizing bacteria includes of *Bacillus* and *Pseudomonas* and that of fungi include species of *Aspergillus and Penicillium* make available insoluble phosphorus to the plants. The main mechanism in solubilizing insoluble phosphate by soil microbes is on their ability to secrete organic acids. The organic acids bring down soil pH resulting in the dissolution of immobile forms of phosphate [67] and production of organic acid by *Pseudomonas* strains decreases soil pH reported by Burgess and Lowe (1996) [68] The effect of phosphate solubilizers on plants are attributed to P solubilization plus other factors like release of phytohormones, supporting nitrogen fixation, mineralization and mobilization of other nutrients, antagonism to plant pathogens and promotion of plant growth promoting rhizosphere microorganisms [69]. Further, the potential of phosphate solubilizers in solubilizing P and mycorrhizae in mobilizing Phosphate made agricultural scientists to think over the possibility of exploiting these organisms in integrated nutrient management programme. Later he had formulated a medium having glucose as carbon source and ammonium sulphate as nitrogen source with enrichment technique and special media for the isolation of acid producing and phosphate dissolving microorganisms from soils and rhizosphere were designed by Hedge and Dwivedi (1994); Rashid, et al., (2004) [70, 71]. Bacteria, fungi, actinomycetes are active in solubilizing insoluble inorganic phosphate with high efficiency [72, 73]. Parameters affecting the ability of PGPR to express different attributes include soil and environmental conditions, microbes plant host interactions, and microbes-microbes interactions [74]. Kapoor, et al., (1989) [75] isolated the phosphate solubilizing microorganisms such as *Pseudomonas aeruginosa, P. cepacia, P. fluoresence* and *P. putida* from the rhizosphere of wheat and *Bacillus licheniformis, B. mycoides, B. megaterium* from the rhizosphere of paddy [76]. Phosphate solubilizing microorganisms are also known to produce plant growth promoting substances (PGPS). P-solubilizing bacteria isolated from the rhizosphere of wheat and rye plants produced auxin type of PGPS, when they were grown in liquid medium supplemented with tryptophan [77] Production of IAA and GA to a considerable extent by P-solubilizing *Bacillus polymyxa* [78] and *Erwinia, Pseudomonas and Serratia* from bamboo rhizosphere was observed by Watanabe and Hayano (1993) [79].

Mechanism of Phosphate Solubilization

Phosphate solubilizing microorganisms were found to produce mono carboxylic acids (acetic acid, formic acid), monocarboxylic hydroxyl acids (lactic, gluconic) dicarboxylic acids (oxalic, succinic), dicarboxylic hydroxyl acids (malic, maleic) and tricarboxylic hydroxyl acids (citric) in liquid medium from simple carbohydrates. Aliphatic acids are also found to be effective in P-solubilization than phenolic acids while citric acid and fumaric acids had highest P-solubilization ability. The organic acid production by PSB is capable of solubilizing the inorganic phosphorus in to available state so as to nourish the crop. This is the main mechanism to bring acidic soil environment which retains higher phosphorus content was reported by Mahesh Kumar, (1997) [80].

Microbes as Biocontrol Agents

In different fields of biology, biological control or biocontrol have been used, but this term is applied for the use of microbial antagonists (the biological control agent or BCA) in plant pathology. Beneficial microorganisms can suppress the growth of phytopathogens in a variety of ways such as competing for nutrients and space, limiting the supply of available nutrients to pathogens [81]. The microflora of disease-suppressive soils is usually dominated by antagonistic microorganisms that have the ability to produce diverse array of antibiotics [82] *Aspergillus*, *Penicillium, Trichoderma*, and antagonistic actinomycetes are known as potent hub to produce diverse antibiotics of varying mode of action [83]. Many strains of Trichoderma are strong opportunistic invaders [84]. Pieterse, et al., (1996) [85] reported that colonization of the rhizosphere by the biological control strain WCS417r of *R. fluorescens* resulted in a plant-mediated resistance response that significantly reduced symptoms elicited by challenging pathogens *Fusarium oxysporum* and *Pseudomonas syringae*; Moreover, growth of *R syringae* in infected leaves was strongly inhibited in R fluorescens WCS417r-treated plants.

Microbial Role on Plants Abiotic Stresses

There are wide variety of microbially produced compounds that can alleviate abiotic stresses in plants, such as the bacteriocin, thuricin 17 and signal molecules. Microbes also produce plant hormones that can aid in tolerating abiotic stresses. Production of indole acetic acid and gibberellic acid results in increased root length, root surface area, and number of root tips, leading to enhanced uptake of nutrients thereby improving plant health under stress conditions [86]. Indole acetic acid and volatile fatty acids released into the rhizosphere by microbes can alter root architecture and morphology, making them better able to absorb water and nutrients, leading to resilience. Also, microbially produced cytokinins can stimulate abscisic acid production in the plants, thus inducing stomatal closure and decreased transpirational water loss [87]. In the last few decade, to provide tolerance to host plants under different abiotic stress environmental conditions bacteria belonging to different genera including *Rhizobium* Sp., *Bacillus* Sp., *Pseudomonas* Sp., *Pantoea, Paenibacillus*, *Burkholderia etc*. have been reported [88, 89].

Microbes for Biotic Stress on Plants

Biotic and abiotic stresses leads to active expressions of plants defense mechanisms. There are two forms of induced resistance that are Systemic acquired resistance (SAR) and induced systemic resistance (ISR) wherein prior to infection or treatment plant defenses are preconditioned that results in resistance against subsequent challenge [90]. Beneficial microbes can suppress the growth of plant pathogens in a variety of ways such as competing for nutrients and space, limiting the supply of available nutrients [91].

The microflora of soils is usually dominated by antagonistic microorganisms that have ability to produce diverse array of compounds [92]. Antagonistic microbes such as *Aspergillus, Penicillium, Trichoderma, and Actinomycetes* are known as potent hub to produce various antibiotics. Antagonistic microbes have biostatic and biocidal effects on soil borne plant pathogens. In addition to locally suppressing pathogens via competition or via the production of antibiotics and siderophores, beneficial soil borne microbes can enhance plant resistance against a wide range of pathogens and herbivores in systemic plant tissues [93]. Plants have the ability to acquire enhanced level of resistance to pathogens after exposure to biotic stimuli provided by many different PGPMs. These in association with plant roots elicit a steady state of defense or ISR in plants. This is often referred to as rhizobacteria-mediated ISR. PGPR-elicited ISR was initially observed in carnation, common bean, and in cucumber with reduced susceptibility to *Fusarium* wilt, halo blight, and *Colletotrichum orbiculare*, respectively. Foliar diseases of plants can be protected by seed application of several PGPR that colonize root systems include *Pseudomonas* sp., *Bacillus pumilus*, and *S. marcescens* [94, 95].

Conclusion

Recent research has advanced understanding of the Good quality soil has capacity to maintain key ecological functions such as the formation and decomposition soil organic matter, preservation of large amount of carbon and sequestering the excess carbon leading to mitigation of rising atmospheric carbon dioxide levels. A number of factors including, soil microbial populations, climate, nature of material, soil type, age and type of vegetation, topography of land etc. regulate the amount of carbon in soil. Climate change has indirect effect on changes in incidence and excess of agricultural pest and diseases. Changes in climate leads to soil erosion are largely unknown. There are few studies in respect to the effects of changes in the intensity of extreme events such as droughts and floods, or variability in climate change.

Application of review: This review is applicable for the farmers of Northern Himalayas, where climate change is a major cause of agricultural deterioration. Because of microbial interventions they can alternatively challenge the effects and variability in climate change affecting the agriculture.

Review Category: Microbes in changing climate.

Abbreviations: BGA- Blue Green Algae, ABA- Abscisic Acid, IAA- Indole Acetic Acid, IBA- Indole Butyric Acid.

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