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Climate change and agricultural ecosystem: Challenges and microbial interventions for mitigation

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ABSTRACT

Climate change has an impact on agricultural activity because of its direct reliance on climate. The understating of their relationship is extremely important, particularly for developing and underdeveloped or low-income countries, which rely heavily on agriculture for subsistence and lack adaptation infrastructure when compared to developed countries. Geographically high-latitude places that already have low temperatures might benefit from a prolonged growing season when temperatures rise due to climate change. GHG emissions such as carbon dioxide, nitrous oxide, and methane have an impact on agricultural lands. Gases have an impact on climate through emitting greenhouse gases. Emissions are mostly caused by tillage operations, fossil fuels, fertilized agricultural soils, and farm animal waste, and have a significant impact on the agriculture industry. Agriculture, on the other hand, might be a solution to climate change by lowering emissions and extensively implementing mitigation and adaptation measures. Best management approaches such as use of microbial inoculants to reduce fertilizer inputs, carbon sequestration and methane oxidation has potential to reduce greenhouse gases from agro-ecosystem.

Keywords : Agro-ecosystem, climate change, green house gases, Biofertilizer rice cutivate AFOLU

Climate change is one of the world's most pressing issues, having significantly transformed or is in the process of transforming the planet's agro-ecosystems. Over ages, climate has had a significant impact on Indian agriculture, and scientific studies have played a vital role in understanding and mitigating the effects of climate on agriculture, particularly low and excessive rainfall, drought, and so on.

Although climate change has been an ongoing process on Earth, the rate of variation has grown dramatically in the last 100 years or so. Since the nineteenth century, the average temperature has risen by 0.9 °C due to anthropogenic activity, mostly due to greenhouse gas (GHG) emissions in the atmosphere. According to projections, this rise will be 1.5 degrees Celsius by 2050, or possibly more, due to the rate at which deforestation is occurring, GHG emissions are growing, and soil, water bodies, and air are contaminated. The significant rise in temperature has produced in an increase in droughts, famine, unpredictable precipitation patterns, heat waves, and other severe occurrences over the world. Overall, the impact of climate change is extensive, but its far-reaching impacts are now plainly seen on the agricultural sector, on which the world's food production and economy rely (Arora, 2019). Climate disruptions to agricultural productivity have grown in the last 40 years and are expected to rise further in the next 25 years. These effects will be progressively unfavorable for most crops and livestock by the mid-century and beyond.Many agricultural regions may see crop and livestock output decreases as a result of increasing stress from weeds, illnesses, insect pests, and other climate change-induced pressures. Current losses and degradation of essential agricultural soil and water assets as a result of increased precipitation extremes will continue to provide a challenge to both rainfed and irrigated agriculture unless novel conservation strategies are applied. Because key thresholds are already being crossed, the growing frequency of weather extremes will have an increasingly severe influence on agricultural and animal output. Agriculture has been able to adjust to recent climatic changes; nevertheless, additional innovation will be required to ensure agriculture's and the accompanying socioeconomic system's

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rate of adaptation can keep pace with climate change over the next 25 years. Changes in agricultural yields and food prices, as well as effects on food processing, storage, transportation, and retailing, will have worldwide implications for food security. Some of these consequences can be delayed or reduced using adaptation techniques.

The world's population has crossed 7 billion people and global concern is to provide food, nutrition and energy security for this growing population. The United Nations Framework Convention on Climate Change (UNFCCC), which has 195 member countries throughout the world, aims to stabilize greenhouse gas concentrations in the atmosphere. The UNFCC negotiations have primarily focused on whether mitigation or adaptation should be prioritized in global agriculture in relation to climate change, keeping in mind the following points: (1) Food security is the primary concern of all developing countries, and to ensure food security, agriculture must be intensified, which may increase GHG emissions in the short term; (2) agriculture in developing countries is highly diverse, heterogeneous, and unorganized, making any organized work program for mitigation in agriculture dominated by millions of farmers with very small landholdings difficult to implement; (3) a lack of simple and cost-effective mitigation technologies; and (4) the issue of common but differentiated responsibilities (CBDR). (Pathak et al., 2014).

EMISSIONS FROM AGRICULTURE SECTOR

As per IPCC (IPCC, 2019) the energy sector accounted for 34% (20 GtCO$_2$-eq) of GHG emissions, industry accounted for 24% (14 GtCO$_2$-eq), agriculture, forestry, and other land uses (AFOLU) accounted for 22% (13 GtCO$_2$-eq), transportation accounted for 15% (8.7 GtCO$_2$-eq), and buildings accounted for 6% (3.3 GtCO$_2$-eq). Biomass burning (CO_2, CH_4) 0.1% of the 22% contributed by agriculture, forestry, and other land uses; synthetic fertilizer application (N_2O) 0.75%; manure management (N_2O, CH_4) 0.7%; rice cultivation (CH_4) 1.7%; managed soils and pasture (CO_2, N_2O) 2.5%; enteric fermentation (CH_4) 5%; and land use, land-use change, and forestry (LULUCF) CO_2 11%. Agriculture, Forestry, and Other Land Uses (AFOLU) is unique in its ability to mitigate climate change by reducing greenhouse gas (GHG) emissions and increasing removals (IPCC, 2019).

In soil, methane (CH_4) is produced through anaerobic microbial decomposition of organic molecules. Rice fields submerged in water might be a source of CH_4. Increased CH_4 emissions are caused by continuous submergence, rising organic C content, and the use of organic manure in puddled soil. Crop residue burning contributes to the global methane budget as well. Ruminant enteric fermentation is another substantial source of CH_4 emissions. Nitrous oxide is produced naturally in soil via nitrification and denitrification. Nitrification is the aerobic oxidation of ammonium to nitrate by bacteria. Nitrous oxide is a gaseous intermediary in the denitrification chemical chain and a byproduct of nitrification that escapes from microbial cells into the soil and eventually into the atmosphere. The addition of nitrogen in soil via anthropogenic net nitrogen additions to soil (synthetic fertilizers, organic fertilizers, fertilizers, crop residues, sewage sludge, etc.) or mineralization of nitrogen in organic soils is one of the most significant control elements in this response. Soil management activities such as tillage, which create carbon dioxide emissions through the biological breakdown of soil organic matter, are the primary source of carbon dioxide generation in agriculture. Tillage breaks up soil clumps, enhances oxygen delivery and exposes organic matter's surface to aid in decomposition. Carbon dioxide emissions are also caused by the use of fuel in different agricultural processes and the burning of crop leftovers. Soil is the primary source of carbon dioxide generation in agriculture. Tillage, for example, causes these emissions due to the biodegradation of organic materials in the soil. Tillage decomposes soil masses, increases oxygen availability, and exposes surface organic materials, promoting decomposition. Other sources of CO_2 emissions include the use of fuel for various agricultural operations and the burning of crop leftovers.

India is at the forefront of climate change adaptation and it is the ultimate practitioner of adaptation efforts to limit the impact on the industrial sector. In India, 85 percent of farmers are financially vulnerable. Even if greenhouse gas emissions are greatly decreased as a mitigation measure, the consequences of climate change will remain unabated in the next decades. As a result, rapid adaption action is required. Farmers' perceptions of climate change and its negative consequences have long been acknowledged as a prerequisite for adaptation activity. Farmers who see climate change and its negative consequences are more inclined to support climate change policy measures (Alam, 2017; Klöck and Nunn 2019).

Livestock populations and management

Enteric fermentation accounts for the majority of agricultural CH_4 emissions, with emissions determined by ruminant animal population and production. In addition to enteric fermentation, livestock is the primary source of agricultural emissions due to CH_4 and N_2O emissions from manure management (i.e., manure storage and application) and deposition on pasture (Tubiello, 2019). According to the most recent statistics (FAO 2021a), worldwide livestock population expansion continued between 1990 and 2019, with increases of 18% in cow and buffalo numbers and 30% in sheep and goat numbers, conforming to CH_4 emission patterns. Increased individual animal production usually necessitates higher inputs (e.g., feed), which results in higher emissions (Beauchemin *et al.* 2020).

Rice cultivation

Paddy rice agriculture is a significant source of emissions (Smith *et al.,* 2014), and its development is a critical driver of rising trends in atmospheric CH_4 concentrations (Jia *et al.*, 2019). According to the most recent data, worldwide harvested rice acreage increased by 11% between 1990 and 2019, with total paddy output growing by 46%, from 519 Mt to 755 Mt (FAO 2021a). Global rice output is expected to rise by 13% by 2028 compared to 2019 levels (OECD/FAO 2019). However, yield advances are likely to restrict cultivated area expansion, while dietary changes from rice to protein as per capita income rises are expected to lower demand in some countries, with a minor decrease in associated emissions forecast to 2030 (USEPA 2019). Between 1990 and 2019, Africa saw the highest growth (+160%) in rice farming area, followed by Asia and the Pacific (+6%), with area declines in all other areas (FAO 2021a), closely correlating to associated regional CH_4 emission. Data show that the highest increase in consumption (average annual supply per capita) happened in Eastern Europe and West Central Asia (+42%), followed by Africa (+25%), with Asia and the Pacific showing minimal change (+1%) (FAO 2017).

Synthetic fertiliser

Significant increases in global use of synthetic nitrogen fertilizers during the 1970s have been highlighted as a primary source of rising N_2O emissions (Jia *et al*., 2019). According to the most recent statistics, worldwide nitrogen fertiliser consumption grew by 41% between 1990 and 2019 (FAO 2021c), resulting in increasing N_2O emissions. greaterfertiliser usage has been driven by the quest of higher crop yields, with a 61% rise in average worldwide grain yield per hectare seen during the same time (FAO 2021c)**.**

MITIGATION POTENTIAL OF AGRICULTURE, FORESTRY AND OTHER LAND USE (AFOLU)

Agriculture has a lot of space for adaptation, and it also offers mitigation advantages. Growing stress-tolerant crops, animals, fish, and forest trees can assist increase food output. This will increase food, feed, and fuel production while decreasing GHG emissions. Increased use of conservation agriculture and resource-saving technologies may also benefit food production while reducing GHG emissions. Carbon retention in soil, on the other hand, offers significant potential for GHG reduction through agricultural and grazing land management, restoration of degraded regions, and bio-energy plants. Many of these climate-smart agro-technologies are gaining traction among farmers, and they have the potential to increase food production while lowering GHG emissions.

The AFOLU sector is distinctive in terms of mitigation for three main reasons: In contrast to other industries, AFOLU may help with mitigation in a variety of ways. AFOLU, in particular, can (i) cut emissions as a sector in and of itself, (ii) remove significant amounts of carbon from the atmosphere at a low cost, and (iii) offer raw materials to enable mitigation in other sectors such as energy, industry, and the built environment. AFOLU's emissions profile varies from other industries in that it emits a higher proportion of non-CO_2 gases (N_2O and CH_4). The effects of AFOLU mitigation efforts might change depending on which gases are targeted, due to the different atmospheric lifetimes of the gases and the different global temperature reactions to the buildup of the individual gases in the atmosphere. AFOLU mitigation methods have the potential, when properly implemented, to assist solve certain key, broader concerns while also helping to climate change adaptation. AFOLU is closely tied to some of humanity's most significant concerns, including large-scale biodiversity loss, environmental degradation, and the repercussions thereof.Because AFOLU is concerned with land management and uses a significant amount of the Earth's terrestrial surface, the sector has a significant impact on soil, water, and air quality, biological and social variety, natural habitat provision, and ecosystem functioning, hence influencing numerous SDGs.

Biochar

Biochar is created by pyrolyzing and gasifying organic materials in oxygen-limited settings (Lehmann and Joseph, 2012). Forestry and sawmill wastes, straw, manure, and biosolids are examples of feedstocks. Biochar is projected to last from decades to thousands of years in soils, depending on feedstock and manufacturing circumstances (Wang *et al.*, 2016; Singh *et al.,* 2015). Biochar systems that produce biochar for soil application as well as bioenergy provide more mitigation than bioenergy alone and other biochar applications, and are recognized as a CDR approach. Interaction with clay minerals and soil organic matter increases biochar permanence (Fang *et al.,* 2015). Additional CDR advantages result from 'negative priming,' in which biochar stabilizes soil carbon and rhizodeposits (Weng *et al.*, 2015; Wang *et al.,* 2016; Archanjo *et al.*, 2017; Hagemann *et al.*, 2017; Han Weng *et al.*, 2017; Weng et al., 2017; Weng *et al.*, 2017; Weng *et al.*, 2017). Besides CDR, additional mitigation can arise from displacing fossil fuels with pyrolysis gases, lower soil N2O emissions (Cayuela *et al.,* 2014, 2015; Song *et al.*, 2016; He *et al.*, 2017; Verhoeven *et al.*, 2017; Borchard *et al.*, 2019), reduced nitrogen fertiliser requirements due to reduced nitrogen leaching and volatilisation from soils (Borchard *et al.*, 2019), and reduced GHG emissions from compost when biochar is added (Agyarko-Mintah *et al.*, 2017; Wu *et al.*, 2017). Additional CDR advantages result from 'negative priming,' in which biochar stabilizes soil carbon and rhizodeposits (Weng *et al.*, 2015; Wang *et al.*, 2016; Archanjo *et al.*, 2017; Hagemann *et al.*, 2017; Han Weng *et al.*, 2017; Weng *et al.*, 2017; Weng *et al.*, 2017; Weng *et al.*, 2017). Besides CDR, additional mitigation can arise from displacing fossil fuels with pyrolysis gases, lower soil N2O emissions (Cayuela *et al.*, 2014, 2015; Song *et al.*, 2016; He *et al.*, 2017; Verhoeven *et al.*, 2017; Borchard *et al.*, 2019), reduced nitrogen fertiliser requirements due to reduced nitrogen leaching and volatilisation from soils (Borchard *et al.*, 2019), and reduced GHG emissions from compost when biochar is added (Agyarko-Mintah *et al.*, 2017; Wu *et al.*, 2017). Biochar may reduce soil albedo due to its black color (Meyer *et al.*, 2012), albeit this is minor at suggested rates and application methods. When given to ruminants, biochar has the potential to decrease enteric CH_4 emissions. Inadequate investment, limited large-scale production facilities, high production costs at small scale, lack of agreed approach to monitoring, reporting, and verification, and limited knowledge, standardisation, and quality control, limiting user confidence are all barriers to upscaling (Gwenzi *et al.*, 2015).

Agroforestry

Agroforestry is a collection of varied land management strategies that integrate trees and shrubs in space and/or time with crops and/or animals. Agroforestry increases land productivity, diversifies livelihoods, reduces soil erosion, improves water quality, and creates more hospitable regional climates (Ellison *et al.*, 2017; Kuyah *et al.*, 2019; Mbow *et al.*, 2020). However, include trees and shrubs in agricultural systems can have an impact on food production, biodiversity, local hydrology, and social inequality (Amadu *et al.*, 2020; Fleischman *et al.*, 2020; Holl and Brancalion, 2020). Agroforestry should be implemented as part of support systems that provide tools and information to farmers in order to reduce risks and maximize cobenefits. This may involve policy change, enhancing extension systems, and establishing market possibilities to facilitate adoption (Jamnadass *et al.*, 2020; Sendzimir *et al.*, 2011; Smith *et al.*, 2019). Carbon sequestration in the context of food and fuel production, as well as environmental co-benefits at the farm, local, and regional scales, can assist support decisions to plant, regenerate, and sustain agroforestry systems (Kumar and Nair, 2011; Miller *et al.*, 2020). Despite the benefits, biophysical and socioeconomic variables may prevent widespread adoption (Pattanayak *et al.*, 2003). Water availability, soil fertility, seed and germplasm access, land rules and tenure systems impacting farmer agency, access to financing, and information about the best species for a specific site are examples of contextual variables.

Enteric fermentation activities

Opportunities and constraints to implementation, as well as co-benefits and dangers. Mitigating CH_4 emissions from enteric fermentation can be done directly (by targeting ruminalmethanogenesis and emissions per animal or unit of feed ingested) or indirectly (by boosting production efficiency and lowering emission intensity per unit of output). Measures may be divided into three categories: food, supplements, additives, and vaccinations, and livestock breeding and general husbandry (Jia *et al.*, 2019). Improved cattle breeding has been linked to higher food security and improved climate change adaption (Smith *et al.*, 2014).

Improve rice management

Emissions from rice cultivation are mostly related with anaerobic conditions, while N_2O emissions occur through nitrification and denitrification processes as well. Improved water management (e.g., single drainage and multiple drainage practices), improved residue management, improved fertiliser application (e.g., using slow release fertiliser and nutrient specific application), and soil amendments (including biochar and organic amendments) are all measures to reduce CH_4 and N_2O emissions (Pandey *et al.*, 2014; Kim *et al.*, 2017b; Yagi *et al.*, 2020; Sriphirom *et al.*, 2020). These measures can improve water use efficiency, reduce overall water use, improve drought adaptation and overall system resilience, increase yield, reduce production costs from seed, pesticide, pumping, and labor, increase farm income, and promote sustainable development (Yamaguchi *et al.*, 2017; Tran *et al.*, 2018; Sriphirom *et al.*, 2019). However, antagonistic effects can occur in terms of CH_4 and N_2O mitigation, whereby water management can increase N_2O emissions due to the creation of alternate wet and dry conditions (Sriphirom *et al.,* 2019), with trade-offs between CH_4 and N_2O during the drying period potentially offsetting some mitigation benefits.Site-specific limitations such as soil type, percolation and seepage rates or fluctuations in precipitation, water canal or irrigation infrastructure, paddy surface level and rice field size, and social factors such as farmer perceptions, pump ownership, and challenges in synchronizing water management between neighbors and pumping stations may all be barriers to adoption (Yamaguchi *et al.,* 2017; Yamaguchi *et al.*, 2019).

Crop nutrient management

Crop nutrient management can help to lower N_2O emissions from farmland soils. Optimization of fertiliser application delivery, rates, and timing, use of different fertiliser types (i.e., organic manures, composts, and synthetic forms), and use of slow or controlled-released fertilisers or nitrification inhibitors are all practices (Smith *et al.*, 2014; Griscom *et al.*, 2017; Smith *et al.*, 2019). In addition to individual practices, integrated nutrient management, which combines crop rotations such as intercropping, nitrogen biological fixation, reduced tillage, cover crop use, manure and bio-fertiliser application, soil testing, and comprehensive nitrogen management plans, is suggested as critical for optimizing fertilizer use, improving nutrient uptake, and potentially reducing N_2O emissions (Bationo *et al*., 2012; Lal *et al.*, 2018; Bolinder *et al.*, 2020; Jensen *et al.*, 2020; Namatsheve *et al.*, 2020). Such methods may provide extra mitigation by indirectly lowering synthetic fertiliser production requirements and related emissions; however, such mitigation is accounted for in the Industry Sector and is not taken into account in this chapter. Tailored nutrient management approaches, such as 4R nutrient stewardship, are implemented in different farming systems and contexts and supported by best management practices to balance and match nutrient supply with crop requirements, provide greater stability in fertiliser performance, and reduce N_2O emissions and nutrient losses from fields and farms (Fixen, 2020; Maaz *et al.*, 2021).Improved nutrient management can improve soil quality (especially when manure, crop residues, or compost are used), carbon sequestration in soils and biomass, soil water holding capacity, adaptation capacity, crop yields, farm incomes, water quality (from reduced nitrate leaching and eutrophication), air quality (from reduced ammonia emissions), and in some cases, land sparing (Sapkota *et al.*, 2014; Johnston and Bruulsema, 2014; Zhang *et al.*, 2017; Mbow *et al.*, 2019). Under some conditions, yield decrease is a possible danger, and practice implementation should take current soil nutrient status into account. There are major geographical imbalances, with some regions enjoying nutrient surpluses as a result of overfertilization and others facing nutrient shortages and chronic deficiencies (FAO, 2021c). Furthermore, depending on the location, techniques may be unavailable, costly, or need expertise to adopt (Hedley, 2015; Benson and Mogues, 2018), while climate change impacts may affect nutrient usage efficiency (Amouzou *et al.*, 2019) and therefore mitigation potential.

Manure management

Manure management strategies attempt to reduce the amount of CH_4 and N_2O emitted by manure storage and deposition. N_2O mitigation takes into account both direct and indirect (conversion of ammonia and nitrate to N_2O) sources. According to the SRCCL, measures may include (i) anaerobic digestion, (ii) applying nitrification or urease inhibitors to stored manure or urine patches, (iii) composting, (iv) improved storage and application practices, (v) grazing practices, and (vi) dietary changes in livestock (Mbow *et al.,* 2019; Jia *et al.*, 2019). Implementing manure management alongside other livestock and soil management measures can improve system resilience, sustainability, and food security, as well as help prevent land degradation (Smith *et al.*, 2014; Mbow *et al.*, 2019; Smith *et al.,* 2019), while potentially benefiting the localised environment, such as water quality (Di and Cameron, 2016). Increased N_2O emissions from manure application to poorly drained or wet soils, trade-offs between N_2O and ammonia emissions, and potential eco-toxicity associated with particular methods are all risks.

MITIGATING GHGs EMISSION FROM INDIAN AGRICULTURE

Manicured soils are large generators of methane and nitrous oxide, both of which have substantial global warming potential. The GWP of pulses ranges from 240 kilogram CO_2 eq. ha^{-1} to 3700 kg CO_2 eq. ha^{-1} in continuously flooded rice. Agriculture has the ability to reduce GHG emissions in a cost-effective manner by implementing low-carbon agriculture technology and management techniques. The three ways to GHG reduction are as follows:

Reduction in emissions

CO_2, CH_4, and N_2O fluxes can be lowered by managing carbon and nitrogen flows in agricultural environments more effectively. For example, techniques that provide additional N to crops more effectively frequently lower N_2O emissions. Approaches to reducing GHG emissions are dependent on local variables and hence differ from area to region.

Enhancement of removals

Large amounts of carbon are stored in agricultural environments, mostly in soil organic matter. These systems have historically lost a significant amount of C, some of which can be recovered via smarter management. Any practice that increases the photosynthetic input of carbon and/or slows the return of stored carbon to CO_2 via respiration, fire or erosion, will increase carbon reserves, thereby 'sequestering' carbon or building carbon 'sinks'. Many studies throughout the world have demonstrated that considerable amounts of soil carbon may be stored by using a variety of methods tailored to local conditions. Perennial plants on agricultural grounds may also store significant amounts of vegetative carbon. Agricultural areas also remove CH_4 from the atmosphere through oxidation, although the effect is minor in comparison to other GHGs fluxes.

Avoiding emissions

Crop wastes from agricultural fields can be used as fuel either directly or after being converted to fuels like ethanol or diesel. These bio-energy feed stocks will similarly emit CO_2 when burned, but the carbon will be of recent atmospheric origin (through photosynthesis) rather than fossil carbon. The net benefit to the climate from these bio-energy sources is equal to the amount of fossil-derived emissions displaced, less any emissions from production, transportation, and processing. GHG emissions, particularly CO_2, can also be prevented by adopting agricultural management techniques that prevent the cultivation of additional areas that are already covered by forest, grassland, or other non-agricultural vegetation.GHG emissions from agriculture can be reduced by sequestering carbon in soil and lowering methane and nitrous oxide emissions from soil through changes in land-use management. Changing crop combinations to incorporate more perennial or deep-rooted plants improves the amount of carbon stored in the soil. Cultivation strategies that leave residues and decrease tillage, particularly deep tillage, promote soil carbon accumulation. Crop genetic alterations, as well as adequate irrigation, fertilizer usage, and soil management, can minimize nitrous oxide and methane emissions. Such solutions are critical not just for mitigating global warming but also for boosting soil fertility. Furthermore, GHG emissions can be lowered by substituting agricultural feed stocks (e.g. crop wastes, manure, and specific energy crops) for fossil fuels in energy generation. Policies and incentives will need to be devised to encourage farmers to implement these mitigation methods in order to reap the advantages of enhanced soil health and increased water and energy efficiency..

Methane emissions from rice fields are being reduced. Modifying water management, particularly encouraging intermittent irrigation and mid-season drainage; improving organic matter management by encouraging aerobic degradation through composting or incorporating it into soil during off-season drained periods; using rice cultivars with few unproductive tillers, high root oxidative activity, and high harvest index; and applying fermented manure such as biogas slurry in place of unfermented farmyard manure.Many studies have proposed intermittent flooding to minimize CH_4 emissions. Bhatia *et al.* (2012) demonstrated that moving water management from present practice to intermittent flooding in all irrigated rice areas of the country may cut national CH_4 flux from irrigated rice fields by 40%. However, in the case of intermittent floods, N_2O-N fluxes might rise by 6%. The India upscaling research demonstrated the complexities of GHG reduction. N_2O emissions rose when CH_4 and CO_2 emissions were decreased by intermittent flooding. Because N_2O has a greater GWP, rising N_2O offsets the advantage achieved by reducing CH_4 and CO_2 fluxes. However, total carbon equivalent emissions from the country's irrigated rice-growing areas decreased from 41.1 Tg C to 36.2 Tg C in a year with intermittent rice irrigation. Direct rice sowing (DSR) and rice intensification systems (SRI) might be promising strategies for lowering methane emissions. When soil is continually immersed in water, as in the case of typical puddled transplanted rice, methane is released. Because DSR and SRI crops do not require continuous soil submergence, they minimize or eliminate methane emissions when produced as an aerobic crop. Because DSR and SRI dramatically reduce methane emissions, they offer a significant potential to lower the GWP (by around 35-75%) when compared to standard puddled transplanted rice. Aside from delivering energy and manure, biogas technology offers a good chance for lowering GHG emissions and minimizing global warming by replacing biogas for fire wood for cooking and kerosene (for lighting and cooking) (Pathak *et al.*, 2009). A family-sized biogas plant has a global warming mitigation potential of roughly 10 t CO_2 eq. yr^{-1}. Currently, the country has 3.83 million biogas plants in operation, which may reduce global warming by 38 Mt CO_2 eq. yr^{-1}. If all of the collectible cattle dung (225 Mt) produced in the country is used for biogas production, 51.2 million family-size biogas plants can be supported, with a mitigation potential of 512 Mt CO_2 eq. yr^{-1} and the ability to earn significant carbon credits under the clean development mechanism.

Mitigation of nitrous oxide emission

The most effective management strategies for reducing nitrous oxide emissions include site-specific nutrient management and the use of nitrification inhibitors such as coated calcium carbide and dicyandiamide. Some organics generated from plants, such as neem oil, neem cake, and karanja seed extract, can also operate as nitrification inhibitors. Nitrous oxide emissions and GWP might be reduced by 11-14% with demand-driven N utilization utilizing a leaf color chart (LCC). (Bhatia et al., 2012, Jain et al., 2013).

Sequestration of carbon in agricultural soils

Increased C sequestration in soil, which involves storing C as soil organic matter, may also aid in lowering CO2 emissions from agriculture (Lal, 2004; Pathak et al., 2011). Nutrient management is crucial for tropical soil organic C (SOC) sequestration. A adequate nitrogen input to the soil can increase biomass output and SOC content. Organic manure and compost boost the SOC pool more than chemical fertilizers used in the same amount. Long-term manure application boosts the SOC pool, with long-term consequences. Increased SOC decreases CO2 emissions while simultaneously increasing soil productivity. However, it is believed that SOC sequestration is a big challenge in tropics and subtropics soils, where the temperature is harsh and resource-poor farmers cannot afford to add organic manure and crop wastes. The rate of C mineralization is high in the tropics due to high temperatures and low humification efficiency. Carbon, whether found in soil, perennial crops, or trees, helps to promote agricultural sustainability. There is optimism, however, that agricultural soil sequestration will eventually be incorporated in any long-term global agreement to decrease net GHG emissions.

Conservation agriculture

Conservation agriculture, which incorporates resource-saving strategies such as zero- or minimum-tillage with direct sowing, permanent or semi-permanent residue cover, and crop rotations, has the potential to increase the efficiency with which natural resources such as water, air, fossil fuel, and soil are used. These technologies can promote agricultural sustainability by saving resources through increased input efficiency and decreasing GHG emissions.

Genetic enhancement of crops and animals

Food production has increased significantly due to the discovery of novel kinds and hybrids, genetic selection, the use of superior breeding procedures, and genetic engineering and modification technologies. We can now discover features inside a genome that boost production, drought resilience, and insect resistance. Scientific breakthroughs will also enable us to detect and improve additional features such as greater input absorption efficiency or even the production of inputs inside the plant, as well as the improvement of beneficial nutrients in soils. These initiatives have the potential to increase overall product quality, flavor profiles, nutritional benefits, shelf-life, and carbon sequestration while lowering input demands, water content, embedded carbon and water, and waste losses along the value chain. New genetic engineering methods would also allow work on perennials to be completed in record time.Sugarcane, cocoa, coffee, palm oil, oranges, bananas, plantations, fruits, and nuts are examples of major perennials and tree crops. These crops have the potential to produce (e.g., sequester) carbon and minimize GHG emissions connected with annual crop production.

Increasing input-use efficiency

The key variables of agricultural production include land and other natural resources, labor, and capital. We clearly have a surplus of manpower and capital, but land and other natural resources are limited and even shrinking. Some research suggests that agricultural productivity is dropping due to a shortage of vital inputs such as water, nitrogen, potassium, phosphate, and so on. We are nearing the end of the amount of land and water we can use to generate food. Agriculture accounted for almost 90% of all human water usage in 1900. The percentage of total water used for agriculture had declined to 69% by 2000, while overall water usage had surged more than fivefold. Total water usage for agriculture is anticipated to grow by 13% by 2025. Without increased irrigation efficiency, we may need 50% more water by 2050 to fulfill global food demand. Fortunately, we already know a lot about how to accomplish this aim. Flood, furrow, alternating furrow, center pivot, modified center pivot, drip, and subterranean drip are all types of irrigation. Depending on how the systems are installed, the gap between the least efficient and most efficient irrigation might be as much as 10-100 times. In the case of fertilizer application, carbon dioxide emissions are indirect since natural gas is utilized as the principal ingredient in the manufacture of urea, the main nitrogenous fertilizer used in the nation. The usage of nitrogenous fertilizer results in direct N2O emissions. In terms of minimizing indirect emissions, there are essentially two aspects to consider: first, increasing the efficiency of fertilizer manufacturing, particularly urea, where the major feedstock is natural gas, and second, reducing nitrogenous fertilizer usage. Gas supplied to fertilizer companies is subsidized in several nations, including India. Furthermore, the fertilizer production units are quite old, and they use outdated and inefficient technology. There are several strategies to impact N usage, but a few stand out clearly based on experimental or farmer field experiences. These include the use of cyanobacteria, a leaf color chart, deep buried ultra granular urea, and legume intercropping. Cyanobacteria are known to fix nitrogen in soil, reducing the requirement for nitrogenous fertilizer to be applied externally. Similarly, using a leaf color chart assists the farmer in understanding when the application is less than appropriate and when it is overdosed while increasing yield.

MICROORGANISMS FOR MITIGATION OF CLIMATE CHANGE – AAU'S EFFORTS

Bioremediation is the use of living organisms, chiefly microorganisms, to degrade the environmental contaminants into less toxic forms. Using naturally occurring bacteria and fungi or plants to degrade or detoxify substances hazardous to human health and/or the environment. The microorganisms may be indigenous to a contaminated area or they may be isolated from elsewhere and brought to the contaminated site. Contaminant compounds are transformed by living organisms through reactions that take place as a part of their metabolic processes. Biodegradation of a compound is often a result of the actions of multiple organisms. For bioremediation to be effective, microorganisms must enzymatically

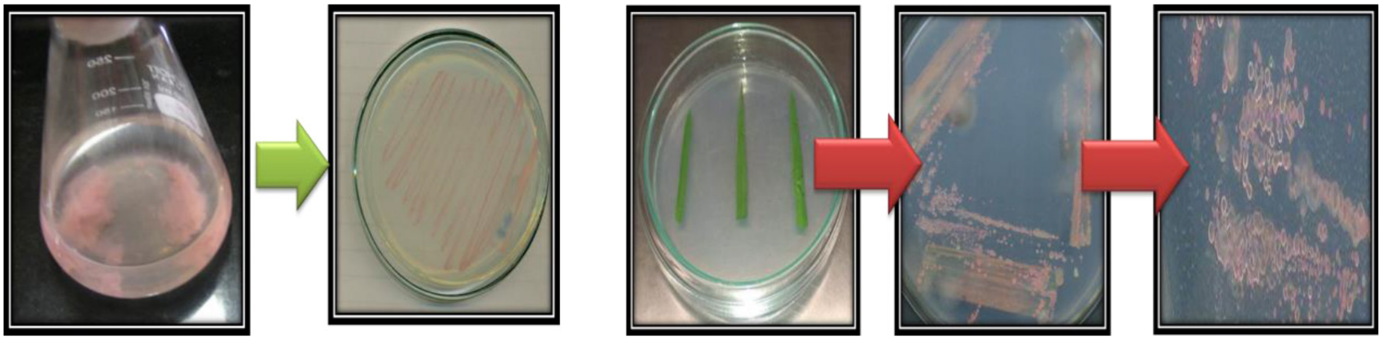

Fig. 1 : RhizosphericMethylotrophPhyllosphericMethylotroph

attack the pollutants and convert them to harmless products. Bioremediation may be employed in order to attack specific contaminants, such as pesticides, plastic wastes, agro wastes and greenhouse gases that are degraded by bacteria.

Biodegradation of greenhouse gas methane

Methane oxidation in rice fields drastically restricts methane transport to the atmosphere. Methylotrophic bacteria (Methane Oxidizing Bacteria), the sole biological sink that removes methane from the atmosphere, play a significant role by lowering the potential quantity of methane exhaled. Aerobic methane-oxidising bacteria associated with rice roots absorb around 10-30% of the methane generated by methanogens in paddies. In addition to their primary activity in methane decomposition, methylotrophic bacteria have the capacity to boost plant development via one or more processes. Several studies have decisively demonstrated that methylotrophs as PGPR increase plant development by producing phytohormones such as indole-3- acetic acid (IAA) and cytokinines and the enzyme *viz.* 1- aminocyclopropane-1-carboxylate (ACC) deaminase involved in lowering the ethylene levels in plants, production of siderophores and protection against pathogens through induced systemic resistance are mainly documented in different part of world.

Pink Pigmented Facultative Methylotrophic (PPFM) Bacteria: Mechanisms of Action for methane mitigation

- Methylotrophic bacteria are capable of utilizing methane as sole source of carbon and multiply consuming methane. Native bacteria possess highly conserved key enzymes *viz.* particulate methane monooxygenase (pMMO), soluble methane monooxygenase (sMMO) and methanol dehydrogenase (MDH) which convert methane to formaldehyde and finally mineralization to CO_2 and water.
- Methane is a key environment pollutant and methylotrophs can reduce 10-20% of methane emission annually by natural bioremediation on earth.
- Methylotrophic Bacterial Consortium Developed for Transplanted Paddy
- Transplanted paddy fields contribute 11-13% of total methane emission mainly due to anaerobic degradation of organic matter.
- A Methylotrophic Bacterial Consortium comprising of three rhizospheric (*Bacillus aerius,Paenibacillusillinoisensis, B. megaterium*) and three phyllospheric (*Staphylococcus saprophyticus, B. subtilis*sp. spizizenii,*B. methylotrophicus*) methylotrophic bacterial isolates is developed for methane management of transplanted paddy fields (Fig.1).
- Besides methane remediation, these isolates are also possess plant growth promoting traits *viz.* Phosphate and potash solubilization, Nitrogen fixation *nif* genes, ACCdeaminase production as well as antagonists to phyto-pathogenic fungi.

In transplanted paddy *cv*. Gurjari in *kharif*, apply 80 kg N/ha, 20 kg P_2O_5/ha and give treatment of methylotrophic bacterial consortium @ 5 mL/L water through seedling dip for 15 minutes before transplanting and foliar spray at 30 DATP for obtaining higher yield and net return with saving of 20% nitrogen and 20% phosphorous as well as reduction of methane gas emission from paddy in atmosphere.

Reduction of nitrous oxide emissions by microorganisms Nitrous oxide reducing bacteria : The principal mechanism of N_2O emissions from soil is denitrification, which is the whole or partial dissimilative reduction of NO_3- by microorganisms to dinitrogen gas (N_2) (Colliver and Stephenson, 2000; Kowalchuk and Stephen, 2001; Shaw *et al.*, 2006). The activation of nitrate reductase (NAR), a membrane-bound, Mo-containing enzyme expressed by the nas, nar, and nap operons, is the first step in denitrification. The narG and napA genes are often used in NO_3-reduction investigations (Tavares *et al.*, 2006; Kandeler *et al.*, 2009; Bru *et al.*, 2011). Nitrite reductase (NIR) converts nitrite to NO or N_2O, the most often used markers for which are nirK (Cu-containing) or nirS (cytochrome cd1). Cytochrome bc nitric oxide reductase (NOR) converts nitric oxide to N_2O. Nitrous oxide is frequently emitted from soil, but it can also be absorbed by nitrous oxide-reducing bacteria (Billings, 2008). The nitrous oxide reductase (NOS) enzyme is responsible for converting N_2O to N_2. The nosZ gene, which encodes the catalytic subunit of multi-Cu NOS, is commonly used in research (Chan *et al.,* 1997). Nitrous oxide reductase (N_2OR) is the final enzyme of bacterial denitrification, breaking the N_2O bond to liberate N_2 and H_2O (Zumft and Körner 2007; van Spanning, 2011).

The only known biological catalyst capable of catalyzing the conversion of N_2O to N_2 is the microbial N_2OR. The N_2ORholoenzyme is made up of two identical 65.8 kDa subunits, each with six copper atoms. It catalyzes the copper-dependent two-electron reduction of N_2O in the bacterial periplasm to water and dinitrogen gas (Pomowski *et al.,* 2011). N_2OR is encoded by the gene nosZ in P. stutzeri (Zumft, 1997). The nos operon also contains five additional nos genes, nosR, nosD, nosF, nosY, and nosL, which encode proteins that are considered to aid in the assembly of the enzyme in P. stutzeri. NosR is a transcriptional regulator, nosD, nosF, and nosY are ABC transporters, and nosL is a copper chaperone (Honisch and Zumft 2003).

Use of nitrogen fixing biofertilizer

Biofertilizers are living microorganisms when applied to seed, plant surfaces, or soil, colonizes the rhizosphere or the interior of the plant and promotes growth by increasing the supply or availability of primary nutrients to the host plant.Bio-fertilizers add nutrients through the natural processes of nitrogen fixation, solubilizing phosphorus, and stimulating plant growth through the synthesis of growth-promoting substances. Bio-fertilizers do not contain any chemicals which are harmful to the living soil. Bio-fertilizers eco friendly organic agro-input and more cost-effective than chemical fertilizers. Bio-fertilizers such as *Rhizobium, Azotobacter, Azospirillum* and blue green algae (BGA) have been in use a long time.

Nitrous oxide emission is largely dependent on usage and availability of inorganic form of nitrogen and water management in crop cultivation. Irrigation of the fields followed by drying increases nitrous oxide emission. So the only way out to minimize nitrous oxide emission from crop cultivation includes reduction in the inorganic nitrogenous fertilizer inputs. Nitrogen fixing biofertilizers have potential to reduce use of nitrogenous fertilizer to the tune of 25 % and thereby reduce nitrous oxide emission from crop cultivation.

Microalgae are becoming popular as biofertilizers in crop cultivation. One acre of algae can consume 60 tons of carbon dioxide per year whereas one acre of forest can consume 2.5 tons of CO_2 per year. Moreover, such algae can also reduce usage of fossil fuels when biomass is subjected for biofuel production which in turn reduces CO_2 production from fossil fuel burning. Besides nitrogen fixation algae which are Cultivation of 1 ton algae utilizes 1.8 tonnes of CO_2 and 1 acre algal farm can produce 60-75 tons of algal biomass per year, considering this one acre algal biomass production system can consume 135 tons of CO_2 per year which could be achieved by large scale production and dissemination of algal biofertilizers.

Biodegradation of agricultural wastes

Microorganisms have capacity to degrade complex ligno-cellulolytic agricultural wastes which helps to promote organic farming, a new era of conventional farming. Bio-degraders are the organisms that degrade complex lingo-cellulolytic material into simple form and increase rhizospheric microbial community which in turn promote plant growth. Development of biodegrading bacterial and fungal based liquid consortium for agro-waste recycling and to have enriched FYM.

Crop residues are generally disposed of by burning in the field or fossil fuel creating smokes leading to air pollution, increase the smog incidences and loss of organic carbon from nature. Instead of burning crop residues, it is necessary to recycle agro-waste to convert it in to quality manure in eco-friendly manner for improving soil fertility. Agro wastes generally comprise of cellulose and lignin. Many soil bacteria and fungi are having capacity to produce cellulolytic and lignolytic enzymes, which decompose crop residues effectively and rapidly converting in manure useful for nurturing soil health and fertility (Fig. 2).

AAU's *ANUBHAV* BACTERIAL BIODEGRADER CONSORTIUM (ABBC)

Department of Agricultural Microbiology has developed consortium of cellulolytic &lignolyticbacterial isolates for quick composting of agro-waste.

AAU Recommendation for Farmers

- Farmers can prepare vermicompost from Banana pseudostem or maize fodder using *Anubhav* Biodegradable Bacterial Consortium @ 1 lit/ton along with 5 % cow dung which gives high quality compost 15 days earlier than normal vermicomposting method (Fig. 3).
- For making good quality compost from crop residues viz., paddy, wheat, maize and pearlmillet, farmers are recommended to mix Anubhav Bacterial Biodecomposer Consortium II (ABBC II) 1.0 L/t shredded crop residues and 200 kg cow dung slurry/t (Cow dung and water in 1:2 ratio) of shredded crop residues in the pit (as per required size) to obtain the compost having optimum C:N (<20:1) from maize and pearlmillet

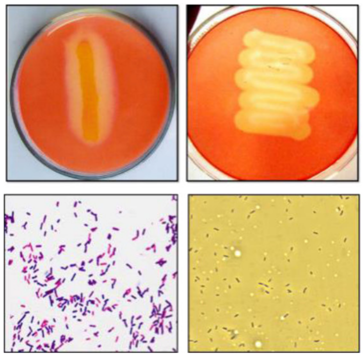

Fig. 2 : Agro waste Degrading Bacteria

Fig. 3 : Degradation of Banana Pseudo stem Waste by ABBC

residues in 75 days, from paddy residues in 100 days and from wheat residues in 150 days, which is relatively 5 to 10 days earlier than the compost prepared without mixing of ABBC II. Further, mixing of ABBC II with crop residue provides better decomposition of the residues, and there by concentrate the nutrients content in final product.

Composition of ABBC II: *Pseudomonas stutzeri*BDCT 1; *Bacillus velezensis*BDCT 2; *Lactobacillus plantarum*; *Pseudomonas* spp.; *Bacillus subtilis*; *Cellulomonas* spp.

- Good quality compost can be obtained from weed biomass *viz., Trianthemamonogyna* (Carpet weed), *Digeraarvensis* (False amaranth), *Amaranthusspinosus* (Spiny pig weed) and *Partheniumhysterophorus* (Carrot grass), by mixing Anubhav Microbial Biodecomposer Consortium I (AMBC I) 1.0 L/t and 200 kg cow dung slurry/t (cow dung and water in 1:2 ratio) with maintaining optimum moisture (~ 60%) in the pit. Finished compost with higher nutrient content can be obtained within 65-70 days from *Partheniumhysterophorus* and 70-80 days from *Trianthemamonogyna, Digeraarvensis* and *Amaranthusspinosus*, which is 10-20 days earlier in comparison to decomposition with cow dung slurry alone. Further, under weed seed bank studies, viable weed seeds were observed in finished compost of all weed biomass.

Composition of AMBC I: *Pseudomonas stutzeri*BDCT 1; *Bacillus velezensis*BDCT 2; *Streptomyces rochei*AAU BDM 10 and *Streptomyces chartreusis* AAU BDM 16

Value addition of compost and organic by microorganisms supplement

- Generally all organics are rich in carbon ranging (10 to 30%) but have low N, P, K, like essential crop nutrients and hence need to enrich for agricultural use.
- Biofertilizers are having capacity to fix atmospheric nitrogen and solubilize/mobilize phosphorous and potash in soil as well as reduction of methane emission from Agriculture sector.
- Enrichment of compost with biofertilizers like *Azotobacter* and PSB (Bio-NP) bacterial consortium improves nutrient status of compost / manures and wastes with saving costly chemical fertilizers and Government subsidy to strengthen national economy.
- Similar to compost manure, the hygienised city sludge can effectively be fortified and enriched with liquid Bio NPK Bacterial Consortium to formulate good quality organic manure.

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