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Management Approaches for Minimizing Greenhouse Gas Emissions for Climate Resilient Agriculture

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Abstract

Agriculture is now at a crossroads, as it is both a major contributor to global warming and one of the sectors most vulnerable to its impacts. Shifting towards climate-smart farming aims to reduce greenhouse gas emissions while maintaining the productivity needed to sustain a growing population. Being aware of the source of methane, nitrous oxide and carbon dioxide in the farm, growers would implement practical interventions such as conservation agriculture, agroforestry, precision nutrient management, biochar application and improved techniques of rice production. Such practices do not only assist in cooling the planet but also improve soil health; in addition to that, carbon credits provide a new opportunity for earning income. This guide is designed to help farmers transform their farms into carbon sinks as climate conditions become increasingly unpredictable, ensuring long-term food security and sustainable livelihoods.

Keywords: Carbon credits, Climate smart farming, Greenhouse gases, Precision agriculture

Introduction

Think of a farmer standing in his field with seeds on his hands looking up in the sky, not sure if it will rain, if it will be late for the farmer to plant, if it will not rain, period. Some years crops die because of lack of rain, in other years, they are washed away at a moment's notice in sudden torrential rain. These fears are not uncommon anymore but part of the new normal in farming. Climate change is no longer in distant future- it is already hurting farms, crops and livelihoods in the world. The 2015 Paris Agreement established the global imperative to limit atmospheric warming to 1.5 °C, a target further reinforced at COP26 through the Glasgow Climate Pact and the "Breakthrough Agenda," which calls for sustainable agriculture to be the most attractive option for farmers by 2030. These international frameworks highlight that reaching net-zero by 2050 is impossible without a radical transformation of the agricultural sector, which currently accounts for 21% to 37% of global greenhouse gas emissions. India is the third largest GHG emitter in the world after China and the United States and therefore has a major role to play in reducing global emissions and determining the future climate (Calvin *et al.*, 2023). Globally, agriculture is the major source of the food production; however, it is also a source of GHG emission. In India, agriculture is second largest emitter of GHGs with 14% contribution to total GHG emissions, with 54.5% originating from enteric fermentation, 19.1% from fertilizer application to agricultural soils, 17.5% from rice cultivation, 6.7% from manure management and 2.2% from field burning of agricultural residues (Padhee and Whitbread, 2022). While agriculture is essential for food production, activities such as land clearing, crop cultivation, irrigation and livestock rearing significantly influence emission levels. Enhancing food security and climate resilience while reducing carbon emissions or achieving carbon neutrality is therefore crucial for meeting sustainable development goals. Based on findings from the COP21 Paris Agreement and the COP26 Glasgow Climate Pact, stabilizing global temperatures at target levels requires achieving a balance between the release of carbon dioxide and its sequestration in sinks. The rise in net-zero pledges among nations and corporations reflects a growing recognition of this scientific necessity. It is argued that these targets can be integrated with sustainable

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development goals, allowing for different developmental contexts while securing zero-carbon prosperity.

Identifying the Hidden Sources of Emissions

Identifying where GHGs are being emitted is the first step to effective mitigation measures. The Energy and Resources Institute has highlighted that agriculture and land use systems play a central role in the climate crisis, not only as major sources of GHGs, but also as a potential climate change mitigation tool. However, there are variations in agricultural emissions, depending on cropping system, management practices and environmental conditions. For instance, soil organic matter is lost when heavily tilled; this will increase the release of CO_2 into the atmosphere. In the same way, rice production is highly water management dependent and the efficiency of nitrogen fertilizer use has a significant impact on N_2O emissions. The changes show the potential for some serious opportunity: adaptation of better farming practices has the potential to significantly lower emission levels without sacrificing productivity. Crop residue burning for field preparation, when preparing for next crop is another important source of emissions, emitting high levels of carbon dioxide, particulate matter and other pollutants. An additional factor is the indiscriminate or improper timing of nitrogen fertiliser application which can lead to greater emissions of N_2O because excess nitrogen is converted by soil microorganisms to gaseous forms that release to the atmosphere. Knowing what these large sources of emissions are is the first step to finding a way to create better farming systems that are more resource efficient and climate resilient.

Management Approaches

1. The Power of Conservation Agriculture

The best method of ensuring that carbon remains in the ground is to avoid disturbing the soil. Conservation agriculture is based on three pillars that are minimal soil disturbance (zero tillage), permanent soil cover and diversified crop rotation. Zero tillage conserved soil structure, carbon loss, improved soil organic carbon, water absorption capacity and activity of soil microorganism. Similarly, consistently growing crops over soil to retain existing crop residues or plants with roots in the soil (cover crops) prevents soil erosion, reduces soil temperature and adds organic matter to the soil, with cover crops sequestering about 0.12 Pg C per year, estimated for global conditions (Poeplau and Don, 2015). Crop diversity further promotes nutrient cycling, soil structure and reduces pest and disease cycles, ensuring long term sustainability. These practices have all been shown to work well together to boost agricultural and environmental performance in a variety of farming systems.

2. Integrating Legumes for Natural Nitrogen

The use of chemical nitrogen fertilizers is costly and can be a major source of N_2O, which is important for climate Smart Agriculture since farmers want to use these at the maximum efficiency. Farmers can access the factory of nature because with the introduction of legumes like peas, lentils and beans in the crop rotation are some of the sustainable alternatives. Legumes are unique in their capacity to biologically fix nitrogen to the soil through symbiotic association with rhizobium bacteria which decreases the need for synthetic fertilizers. Studies have shown that a cropping system that incorporates legumes is highly effective in enhancing the fertility, soil organic carbon, carbon sequestration, microbial activities and resilience of the overall system of the soil. Legume-based systems are more sustainable and climate resilient in most instances as compared to cereal-only systems. Further, a recent global synthesis found that biological N fixing by legumes represents a significant N input in various agroecosystems and can lead to a significant reduction of GHG emissions and improve soil health.

3. Managing Crop Residues and the Biochar Revolution

Crop residues are still burnt in many intensive cultivation systems, especially in rice-wheat areas, causing high emissions of greenhouse gases and loss of valuable organic matter. A more sustainable alternative is to pyrolyse crop residues to produce a stable carbon-rich product, biochar, in a low oxygen environment. Biochar is an essential element of climate-smart agriculture as it will sequester carbon in the soil for a long time and will enhance soil structure, water holding capacity, nutrient availability and soil fertility when added to the soil. It is consistently proven to be environmentally and agronomically beneficial in the field. Application of biochar has been found to lower the emissions and simultaneously boost SOC levels and crop productivity in long-term studies, it also increases the efficiency of nitrogen use, with N_2O emissions reduction by 15-30% and the effect is even greater when biochar is used in conjunction with (Sun *et al.*, 2021).

Agroforestry: Growing Trees for Carbon Sink

Growing trees with the combination of crop is one of the most promising climate smart management strategies to increase carbon storage in agricultural systems. Agroforestry is most prominent method to sequesters atmospheric CO_2 by increasing the soil organic carbon which enhances soil fertility, nutrient cycling, water conservation and farm resilience. Reliable studies have revealed that agroforestry systems have a significantly higher carbon storage potential as compared to conventional cropping systems and also shows higher amount of SOC under agroforestry. Furthermore, agroforestry also supports the continuous build-up of biomass and soil organic carbon, which have positive impacts on soil productivity and the resilience of agricultural systems under different agroecological conditions and thus contributes to climate-smart agriculture.

Precision Farming and Smart Fertilizers

To reduce the wastage of fertilizers and harm causing to environment due to that precision nutrient management shows out to be the key climate-smart interventions that aims at optimizing the inputs of nutrients to the crop by delivering the right nutrient source, quantity, timing and location. Precision farming, with the application of decision support tools (leaf colour charts, sensor-based applicators, site-specific nutrient management techniques *etc.*), will reduce nutrient loss and increase N-use efficiency while in conventional uniform fertilization no such reduction will occur. These technologies help to apply nitrogen only when and where it is needed, which decreases the amount of N_2O emitted, fertilizer expenses and crop productivity, making them an effective tool for sustainable nutrient management. This is further supported with the use of better fertilizers which have higher efficiency. Using natural coating materials such as neem, karanj, sulphur on urea delays the release of nitrogen in the soil so that the nutrient can be absorbed by the crop and thereby reduce the losses of nitrogen due to volatilization and emission of GHGs. The use of such controlled-release fertilizers has been reported to have the potential to reduce agricultural GHG emissions by 12-26% and enhance fertilizer-use efficiency, which benefits sustainable crop production (Paul *et al.*, 2024).

Revolutionizing Rice Management

Agricultural methane emissions show higher index as discussed above, primarily from paddy fields, caused by extended periods of water stagnation which is demand for the crop that provide conditions ideal for methanogenic microorganisms. Reducing water stagnation and increasing water use efficiency are emphasized in climate-smart rice management practices, including alternate wetting and drying (AWD), system of rice intensification (SRI) and direct-seeded rice (DSR). These practices help to reduce CH_4 emissions by improving soil aeration, optimizing water demand and reducing the time of anaerobic condition without affecting the crop productivity.

To reduce the impact new emerging technologies like oxygen nanobubble irrigation, which boosts dissolved oxygen in flooded soils, limits CH_4 production, aids to maintain a more favourable balance of soil microbes and promotes better root development and nutrient uptake. Nanobubble-assisted irrigation has been shown to be a practicable technique to reduce emissions with low yield loss of rice, making it a promising technology for the future to ensure sustainable rice production in the changing climate.

Future of Carbon Credits and Carbon Market

The innovation that farmers are looking at is the "carbon market." With practices done above, farmers are in fact offering a service to the planet by sequestering the carbon and reducing the damage to land. This is certain to be seen in the near future with farmers who are capable of proving that they are sequestering carbon becoming able to sell some 'carbon credits' to companies interested in offsetting their emissions. This makes climate-smart farming a moral decision-making instead of a profitable business initiative.

Conclusion

The decision of leaving traditional practices and moving to climate-smart agriculture is no longer optional; it is a necessity for the survival of the farming community. The main results shown here show that by making easy changes, like how we water rice, how we prepare the soil and how we use fertilizers can really lower the "carbon footprint" of our food. These ways of working create a "win-win" situation: they raise the number of crops we get; they help plants survive tough weather like dry periods and heavy rains, and they offer new ways to earn money through carbon credits. When farmers use these techniques, they stop being people who suffer from climate change and start being people who lead the world in helping to make the planet cooler.

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