Innovative Strategies for Climate-Resilient Rice Farming

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The world is at a critical juncture where the impacts of climate change are becoming increasingly evident and are reshaping the dynamics of global food security and agricultural sustainability. Increases in global greenhouse gas (GHG) concentrations are believed to be a factor in both changes in atmospheric chemistry and global warming. Among the staple crops that will have to cope with these changes, rice is a vital food source for billions of people, especially in Asia where it serves as a staple food. However, the very essence of this crop is under threat as changing climatic patterns present a range of challenges, from extreme weather events to altered precipitation regimes. Globally, an average of 220,196 lives and 90 million human possessions are directly affected by drought, flood disasters, and tropical cyclones annually, with some people experiencing more than one event per year. In the current situation, the need to establish resilient rice agriculture has become a challenge for scientists, farmers, policy makers, and communities. Changing rainfall patterns, changing temperature regimes, and increases in extreme weather events are now well-known phenomena that challenge rice-growing regions worldwide. The impacts of these changes affect rice-dependent economies and can upset the fabric of food availability, social stability, and economic progress (**Figure 1**)

New innovations such as climate-smart agriculture (CSA) provide the foundation for resilience, and rice farming is no exception. Innovative practices offer promising solutions that leverage technology, knowledge, and traditional wisdom to mitigate the impacts of climate change. From the development of climate-resilient rice varieties that have improved tolerance to drought, flooding, and heat stress to the adoption of water-efficient irrigation techniques that conserve this valuable resource, the path of innovation is paving the way to a climate-resilient future. It also addresses sustainable cropping systems that combine rice cultivation with agroforestry, aquaculture, and diversified cropping patterns to improve the resilience of entire landscapes while increasing rice production. Examining the intricate relationships between scientific research, knowledge dissemination, and local community empowerment is evidence of the collaborative nature of resilient rice agriculture.

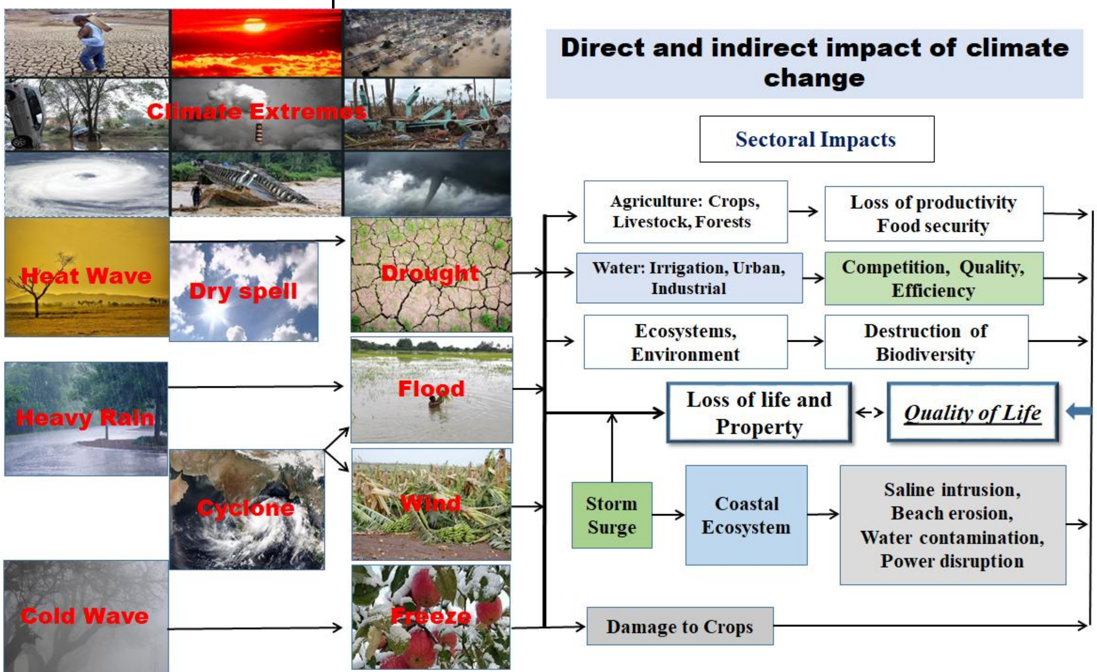

Fig. 1: Direct and indirect impact of climate change

Weather-smart technologies for rice production system

Weather-smart technologies are playing a critical role in revolutionizing rice production, providing greater resilience, efficiency, and sustainability in the face of changing climatic conditions. Rice production is closely linked to weather patterns, with temperature, rainfall and humidity having a significant impact on crop growth, development and yield. Crop insurance, weather-based crop agro-advisory, and the utilisation of information and communication technologies (ICTs) are examples of weather-smart technology that help mitigate risk by disseminating weather forecasts and climate information that enable farmers to make the best decisions at the right time.

Crop-specific insurance is needed to cover income losses due to extreme weather. Historically, there have been several crop insurances programmes, including the National Agricultural Insurance Scheme (NAIS), the Comprehensive Crop Insurance Scheme (CCIS), the Pilot Weather Based Crop Insurance Scheme (WBCIS), the Pilot Modified National Agricultural Insurance Scheme (MNAIS), and others. Currently, Pradhan Mantri Fasal Bima Yojana (PMFBY) has been approved in place of MNAIS/NAIS for implementation from Kharif season 2016.

Water-smart technologies for rice production system

One of the most important applications of water-smart technologies in rice production is irrigation alternating wetting and drying. Alternating wetting and drying periodically allows the soil to dry out between irrigation cycles, rather than constantly flooding the field. This practice not only saves water, but also promotes root development, improves nutrient uptake, and reduces methane emissions from waterlogged soils. This irrigation process saves up to 15-30% water with no/minor yield loss (Rejesus et al. 2011). SRI Practices promote growth of individual rice plants under controlled water levels, resulting in healthier plants and higher yields. When AWD is practiced in system of rice intensification (SRI) technique, it saves up to 20-25% water and increases rice productivity by 35-40%. Aerobic rice production technology involves nutrient-sensitive, high-yielding varieties in unsaturated soils that are intermittently irrigated when soil moisture content reaches a lower limit. As a water- and energy smart technology, this method could save 37 to 60% water compared to the conventional flooding.

The use of suitable irrigation methods, such as border strip irrigation, saves about 10-30% water. In addition, precision irrigation systems guided by real-time soil moisture data and weather forecasts enable farmers to deliver the right amount of water directly to the root zone of rice plants. This minimizes water runoff and infiltration at depth and ensures that water is used more efficiently and effectively. Tensiometer-based irrigation scheduling saves up to 50% irrigation water. Drip and sprinkler irrigation systems are also used to target water, reduce water waste, and optimize water distribution. Rice that was drip-irrigated produced 26% more grain yield than rainfed rice (Panigrahi et al. 2015). Due to lower evaporative losses, subsurface drip irrigation increased grain yield and biomass formation by a significant amount, reducing evapotranspiration by 26% compared to flood irrigation and by 15% compared to surface drip irrigation. Additionally, subsurface drip irrigation improves irrigation water productivity (by 20%), crop water productivity (by 25%), intrinsic water usage efficiency (by 36%), net photosynthesis (by 10%), and transpiration rate (by 22%) as compared to flood irrigation (Umair et al. 2019).

Nutrient-smart technologies for rice production system

Leaf nitrogen status of rice is closely related to photosynthetic rate and biomass production and is a sensitive indicator of changes in plant nitrogen requirements within a growing season. Leaf colour chart is an inexpensive, effective, and easily usable real-time N management tool that can help growers decide when and how much N to apply to crops. Compared to prilled urea, neem-coated urea increased yield by 6% when applied conventionally and by 21% when neem-coated urea was applied based on LCC measurement (Mohanty et al., 2017). By analyzing soil nutrient content, crop requirements, and other relevant factors, site-specific nutrient management (SSNM) helps farmers determine the exact amount and timing of fertilizer application. This approach reduces over-fertilization, minimizes nutrient runoff and ensures that nutrients are efficiently utilized by rice plants. Use controlled-release fertilizers that supply nutrients slowly over time. This not only ensures a consistent supply of nutrients to plants, but also reduces the risk of nutrients leaching into groundwater or surface waters. Green manuring and brown manuring also supply N to rice plants through biological N fixation. In in situ green manuring, plants are incorporated into the same site for 40-45 days where their seeds are broadcasted at 20-25 kg for

Sesbania aculeata and *S. rostrata* at 30-40 kg/ha. In ex situ green manuring, Sesbania is grown elsewhere and incorporated into the field with the plants. In brown manuring, Sesbania is grown in the standing rice plant and killed using herbicides. Generally, *Sesbania spp.* seeds are typically broadcasted 3 days after rice transplanting and left to grow for 30 days before being dried by spraying with 2,4-D. Azolla reduces the need for chemical N fertilizer by 25-30%, while grain yield increases by 10-30%. Microbial inoculants and biofertilizers, another facet of nutrient-smart technologies, promote the growth of beneficial microorganisms that improve nutrient availability in the soil. These microorganisms help solubilize nutrients, fix atmospheric nitrogen, and improve nutrient uptake by rice plants. By harnessing the power of natural processes, these technologies contribute to improved soil fertility and reduced reliance on synthetic fertilizers.

Carbon-smart technologies for rice production system

A method of managing agroecosystems to achieve improved and sustainable productivity, increased profits, and food security while protecting and enhancing the resource base and the environment is called conservation agriculture (CA). In the rice-maize system, zero tillage resulted in 39% lower carbon footprint, 56% lower energy consumption, and 20% lower N_2O emissions compared to conventional tillage (Lal et al. 2019). Carbon-smart technologies also include agroforestry systems that integrate trees and other plants into rice fields. Trees capture and store CO_2 from the atmosphere, mitigating the effects of climate change. Agroforestry not only sequesters carbon, but also provides shade, windbreaks, and other ecosystem services that increase the resilience of rice fields and promote biodiversity.

Energy-smart technologies for rice production system

The integration of energy-smart technologies provides innovative solutions to improve energy efficiency and minimize the environmental impact of rice production. Examples of energy efficient technologies include CA (zero and minimum tillage), various resource conservation technologies (RCT), non-puddled rice-transplanting and solar-powered machinery (solar pump, solar-powered sprayer). Minimum tillage minimally disturbs the soil compared to conventional tillage, which saves energy. In rice cultivation, non-puddled transplanting saves 31-76% fuel and 25-26% water compared to conventional tillage. Solar-powered irrigation systems, for example, use energy from the sun to drive water pumps, reducing dependence on fossil fuels and lowering operating costs. Energy-smart technologies also include the development of energy-efficient post-harvest practices. Solar dryers, for example, use solar energy to dry and preserve harvested rice grains, reducing the need for traditional drying methods that use fossil fuels. This not only saves energy, but also improves the quality of the harvested rice.

Knowledge-smart technologies for rice production system

New knowledge is helping to reduce climate-related risks and improve farmers' ability to practice CSA at scale. Intensification of cropping systems, integrated weed management, ecology-specific varieties, seed and fodder banks, and mechanical transplanting of rice are examples of knowledge smart technologies. At the heart of knowledge-smart technologies is the dissemination of knowledge and information to farmers through various digital platforms and tools. These technologies leverage advances in ICT to provide farmers with real-time weather forecasts, market trends, pest and disease warnings, and best agricultural practices. This knowledge empowers farmers to make informed decisions that optimize resource use, increase yields and reduce risks. Mobile applications and SMS-based platforms are popular tools for providing knowledge-smart solutions to rice farmers. Through these platforms, farmers can access agricultural advice, receive alerts about weather conditions, and interact with experts and other farmers to gain experience and insights. This real-time communication fosters a sense of community and the sharing of valuable local knowledge. Farmers have access to information on drought-tolerant rice varieties, pest-resistant crops, and CA techniques that improve the resilience of their cropping systems in the face of changing climatic conditions.

Conclusion

Resilient rice agriculture guided by the principles of climate-smart innovation is a promising approach to securing the future of rice production amid the complexities of climate change. Through the use of climate-resilient rice varieties, precise water and nutrient management, renewable energy integration, and informed decision-making through data-driven insights, farmers, scientists, and policymakers can embark on a path of adaptability and sustainability. The discourse embodies the collaborative spirit needed for a resilient agricultural future, combining traditional knowledge with cutting-edge solutions. Ultimately, this narrative remains a beacon of hope and a blueprint for food security, livelihoods, and ecological harmony in a rapidly changing world as we navigate the intricate interplay between climatic challenges and rice production.

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