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Smart Agri-food Systems through Sustainable Agronomic Practices

Frank Notes

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Smart agri-food systems aim to integrate cutting-edge technologies, precision farming, and sustainable agricultural practices to create more efficient, resilient, and environmentally friendly food production systems. The scope of agronomy has expanded significantly in recent years, particularly with the rise of smart agriculture. This evolution is driven by the need to meet the growing food demand of burgeoning population and preserving the environment. The term smart agri-food system refers to agricultural systems that leverage advancements in digital technologies, including the internet of things (IoT), sensors, data analytics, remote sensing, and artificial intelligence (AI), to optimise every aspect of food production. These technologies enable farmers to make informed and real-time decisions based on data about soil health, climate conditions, and crop requirements. More efficient, sustainable farming practices that reduce waste, conserve resources, and improve soil health and crop yields have been the ultimate objective of smart agriculture. Practices such as integrated nutrient management (INM), integrated pest management (IPM), agro-ecology, and regenerative agriculture have gained prominence as solutions to restore and maintain soil health, enhance biodiversity, and reduce chemical dependency in farming. These practices help balance environmental goals with the need for higher productivity, addressing key challenges like climate change, soil degradation, and nutrient imbalances.

One of the most significant innovations in modern agronomy is INM. This concept redefines how we approach fertilisation in agriculture, moving away from reliance on mineral fertilisers alone to a more holistic method that integrates mineral, organic, and biological nutrient sources. The integration of these sources helps ensure balanced soil fertility, minimize nutrient losses, and maximize crop yield, and at the same time protect the environment. Traditional agricultural model, which relies predominantly on mineral fertilisers, has led to nutrient imbalances in soils and adverse effects on environment. Over-reliance on N has led to severe issues, including nutrient runoff into water bodies, soil acidification, and the loss of soil organic carbon. This integrated approach not only improves soil health but also makes crops more resilient to climate-induced stress, like droughts and floods. Long-term field trials have demonstrated that INM significantly increases crop yields, enhances nutrient cycling, reduces GHG emissions, and promotes carbon sequestration & microbial biomass. Moreover, INM aligns with the Sustainable Development Goals (SDGs) by contributing towards food security, human nutrition, and climate resilience. Smart technologies such as real-time soil diagnostics and nutrient mapping have revolutionized INM impacts by helping farmers tailor fertiliser applications according to the specific needs of their crops.

Precision agriculture utilizes technology to precisely manage resources, such as water, fertilisers, or pesticides, at the field level. This approach ensures that inputs are applied in the right quantity at the right time, reducing wastage, lowering costs, and minimizing environmental impact. Technologies like the global positioning system (GPS), remote sensing, and drones have become integral to modern farming. For instance, drones equipped with multispectral cameras enable farmers to monitor crop health in real-time, allowing them to detect issues such as nutrient deficiencies, pest outbreaks, and water stress before they become serious problems. GPS-mounted tractors and automated sprayers ensure that fertilisers, pesticides, and herbicides are applied with pinpoint accuracy, reducing excess use and the environmental footprints. Advent of artificial intelligence (AI) and machine learning (ML) has further refined precision agriculture, enabling farmers to make data-driven decisions. AI models utilise historical data, weather forecasts, and soil nutrient levels to predict the precise amount of fertiliser and water required for optimal crop growth, thereby enhancing nutrient use efficiency (NUE). These technologies not only increase productivity but also foster environmental sustainability by reducing nutrient run-off, soil erosion, and water losses. Moreover, precision irrigation techniques, such as drip irrigation and sub-surface drip fertigation, optimize water use by delivering water directly to the root zone, thereby reducing water loss. This method is particularly beneficial in drought-prone areas, where water conservation is critical. These innovations help farmers use water and fertilisers more efficiently, thereby conserving resources and protecting the environment.

While precision agriculture and INM enhance crop

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productivity, regenerative agriculture goes a step further by focusing on restoration of soil health, biodiversity, and ecosystem services. This holistic approach emphasizes practices that work with nature rather than against it, making farming systems more resilient, productive, and environmentally friendly. Key regenerative practices include crop rotation, cover cropping, no-till farming, agroforestry, and bio-diverse systems. These methods promote soil carbon sequestration, increase soil organic matter, and restore soil biodiversity. For example, crop rotation enhances soil fertility by diversifying plant types, reducing pest cycles, and improving nutrient cycling. Cover crops, such as legumes, fix nitrogen, enhance soil structure, and reduce soil erosion. Similarly, agroforestry integrates trees and shrubs with crops, which not only boosts biodiversity but also improves water retention and mitigates the effects of climate change. Use of organic amendments, such as compost, vermicompost and biochar further enhances soil health. These amendments add organic matter to the soil, improving its water-holding capacity, nutrient availability, and microbial activity. Over time, these practices lead to healthy soils, more resilient crops, and enhanced long-term productivity. Regenerative practices also align with environmental stewardship by reducing dependency on mineral inputs and minimizing negative impacts such as GHG emissions, soil degradation, and water contamination. By adopting these practices, farmers can restore soil fertility, reduce input costs, and promote sustainable food production systems that support both ecosystem health and human well-being.

Environmental stewardship is the corner stone of smart agri-food systems. It emphasizes the responsible use of natural resources to ensure that farming can meet the food needs of the current generation without compromising the ability of future generations to do the same. In the context of agriculture, stewardship involves practices that conserve water, reduce GHG emissions, protect biodiversity, and maintain soil health. Key strategies for environmental stewardship in agriculture include the efficient use of nutrients, water conservation, and carbon sequestration. Adoption of INM, precision agriculture, and regenerative practices helps farmers reduce their environmental footprints while improving farm productivity. For example, by reducing excess fertiliser use through INM and precision farming, farmers can minimize nutrient run-off into water bodies, reducing pollution and eutrophication. Moreover, agro-ecology, which integrates ecological principles into farming practices, emphasizes sustainable food systems that operate in harmony with nature. Agroecological practices such as polyculture, companion planting, and IPM help to maintain biodiversity, improve pest control, and enhance resilience to climate change. As climate change intensifies, agriculture must adapt to new challenges, such as erratic rainfall, droughts, and temperature extremes. Smart agriculture, supported by environmental stewardship, enables farmers to mitigate these risks by making farming systems more resilient and adaptive to changing conditions. Through sustainable practices, farmers can maintain and even increase productivity while protecting the environment. Further, use of Nano fertilisers enhances NUE and reduces environmental footprints.

The future of agriculture lies in the convergence of smart agri-food systems, environmental stewardship, and sustainable agronomy. By embracing precision agriculture, INM, regenerative practices, and innovative technologies, we can create farming systems that are not only productive but also environmentally sustainable. As we move forward, policy support, education, and technological innovation will be crucial in scaling these environmentally friendly practices. Government, research institutions, and the private sector must work in tandem to support farmers in adopting these transformative solutions. Ultimately, the goal is to create climate-resilient, resource-efficient, and environmentally friendly agricultural systems that can meet global food demand while preserving the planet for future generations. The future of food production hinges on our ability to innovate, adapt, and collaborate with nature to ensure that agriculture continues to provide the world with sustainable food. This is the era where agronomy can truly drive the change needed to revolutionize how we produce food, making agriculture smarter, greener, and more sustainable.

The Indian Society of Agronomy in collaboration with Indian Council of Agriculture Research, New Delhi and ICAR-Indian Agricultural Research Institute, New Delhi, is organising the **Sixth International Agronomy Congress on Re-envisioning Agronomy for Smart Agri-food Systems and Environmental Stewardship** at New Delhi during 24-26 November 2025. Present special issue is brought out to commemorate the congress. There are 12 papers in this issue contributed by the experts in the field. It is hoped that the issue will be helpful and relevant to all those involved in agriculture, including research scientists, policy makers, extension agencies, students and the farmers. ■