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Management

A STUDY ON SUSTAINABLE AGRICULTURAL WASTE MANAGEMENT PRACTICES IN INDIA– A CASE STUDY OF FPOS OF ODISHA

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ABSTRACT Sustainable agricultural waste management practices in India draw upon rich ancient knowledge systems, offering viable alternatives for enhancing livelihoods and environmental sustainability. This study explores traditional Indian practices such as composting, vermicomposting, and bioenergy generation from organic waste, documented in ancient texts like the "Vrikshayurveda" and "Krishi-Parashara." These practices not only mitigate agricultural waste but also enrich soil fertility, supporting sustainable crop yields. Through a comparative analysis of ancient techniques and contemporary practices adopted by Farmer Producer Organizations (FPOs), this research evaluates their effectiveness in reducing environmental impact and improving rural livelihoods. Case studies from diverse regions of Odisha highlight the transformative impact of these practices on income generation, community resilience, and resource conservation. This paper explores how these traditional practices can be harnessed and integrated with modern techniques to provide sustainable livelihood alternatives. Specific attention is given to the role of Mission Shakti and Farmer Producer Organizations (FPOs) in Odisha in implementing these practices. Agriculture often places significant pressure on natural resources and the environment. Sustainable agricultural practices are intended to protect the environment, expand the Earth's natural resource base, and maintain and improve soil fertility. The findings underscore the relevance of integrating ancient wisdom with modern innovations to address current agricultural challenges sustainably. Policy recommendations emphasize the need for government support to scale up these practices nationwide, promoting food security and fostering resilient agricultural communities. By harnessing ancient knowledge, India can pave the way for sustainable livelihood alternatives that ensure long-term environmental and economic sustainability.

KEYWORDS : Sustainable Agriculture, Waste Management, Indian Ancient Knowledge, Farmer Producer Organizations (FPOs), Mission Shakti, Livelihood Alternatives, Vikashit Bharat.

INTRODUCTION

Sustainable agricultural waste management practices in India draw upon rich ancient knowledge systems, offering viable alternatives for enhancing livelihoods and environmental sustainability. This study explores traditional Indian practices such as composting, vermicomposting, and bioenergy generation from organic waste, documented in ancient texts like the "Vrikshayurveda" and "Krishi-Parashara, " "Manduka Upanishads ", "Charaka Samhita" . These practices not only mitigate agricultural waste but also enrich soil fertility, supporting sustainable crop yields. Through a comparative analysis of ancient techniques and contemporary practices adopted by Farmer Producer Organizations (FPOs), this research evaluates their effectiveness in reducing environmental impact and improving rural livelihoods. Case studies from different districts of Odisha highlight the transformative impact of these practices on income generation, community resilience, and resource conservation. The findings underscore the relevance of integrating ancient wisdom with modern innovations to address current agricultural challenges sustainably. Policy recommendations emphasize the need for government support to scale up these practices nationwide, promoting food security and fostering resilient agricultural communities. By harnessing ancient knowledge, India can pave the way for sustainable livelihood alternatives that ensure long-term environmental and economic sustainability.

Agricultural waste residues and current environmental issues like soil, water, and air pollution accumulate in the environment, causing pollution and deterioration of the environment across the globe. As a byproduct of its operations, agriculture creates a lot of trash. If crop wastes from agriculture and horticulture, such as plant biomass, are not adequately handled, the ecology could be harmed. This excludes grains, fruits, and pulses. The majority of agricultural waste is composed of residues like cellulose, lignin, chitin, keratin, and pectin, which can only be degraded by natural bacteria, fungi, protozoa, and actinomycetes that are competent for the task, furthermore, microbes play a significant role in the breakdown of different agricultural waste. To prevent environmental pollution, agriculture wastes are quickly processed by efficient native microbes that grow eco-friendly, inexpensive dynamic substrates from the field itself and create compost beds above ground level.

This paper explores how these traditional practices can be harnessed and integrated with modern techniques to provide sustainable livelihood alternatives. Specific attention is given to the role of Mission Shakti and Farmer Producer Organizations (FPOs) in Odisha in implementing these practices. Agriculture often places significant pressure on natural resources and the environment. Sustainable agricultural practices are intended to protect the environment, expand the Earth's natural resource base, and maintain and improve soil fertility.

Objective Of The Study :

The present makes an attempt to explore the various sustainable agricultural and waste management practices derived from ancient Indian knowledge systems and their modern applications based on a multi-pronged goal, sustainable agriculture seeks to: Increase profitable farm income, Promote environmental stewardship, Enhance quality of life for farmer's families and communities, Increase production for human food and fiber needs.

1. The study aims to explores the traditional Indian practices such as composting, vermicomposting, and bioenergy generation from organic waste, documented in ancient texts like the "Vrikshayurveda" and "Krishi-Parashara. Thus, the Sustainable agricultural practices are intended to protect the environment, expand the Earth's natural resource base, and maintain and improve soil fertility.

2. The study also aims to understand the agricultural waste management practices being adopted by the FPOs of Odisha in collaboration with the SHGs of the Mission Shakti program towards implementing as to how the traditional practices can be harnessed and integrated with modern techniques to provide sustainable livelihood alternatives.

3. The study aims for the transformative impact of these practices on income generation community resilience, and resource conservation

4. By harnessing ancient knowledge, India can pave the way for sustainable livelihood alternatives that ensure long-term environmental and economic sustainability

Importance of Sustainable Agriculture :

Sustainable agriculture frequently encompasses a wide range of production practices, including conventional and organic. A regionally integrated system of plant and animal production practices are designed to produce long-term results such as:

- Production of sufficient human food, feed, fiber, and fuel to meet the needs of a sharply rising population
- Protection of the environment and expansion of the natural resources supply
- Sustainment of the economic viability of agriculture systems

METHODOLOGY:

The present study is based upon understanding ancient Indian

knowledge system in impacting the agricultural waste management and the integration of ancient knowledge systems with modern sustainable practices, in promoting sustainable agriculture and waste management solutions. The study is based upon available literature and other secondary data collected from the website of Mission Shakti, FPOs of Odisha reports and the Annual reports of NABARD , ICAR and OUAT.

Ancient Knowledge Systems in Agricultural Waste Management

Indian agricultural practices documented in ancient texts such as "**Vrikshayurveda"** and **"Krishi-Parashara**", "**Manduka Upanishad**" , "**Charaka Samhita**" emphasize holistic and sustainable approaches to farming. These texts describe various waste management techniques that are environmentally friendly and economically viable.

Composting:

Traditional composting involves the decomposition of organic waste, such as crop residues and animal manure, into nutrient-rich compost. This practice enhances soil fertility, improves water retention, and promotes healthy plant growth without relying on chemical fertilizers.

Vermicomposting:

This method uses earthworms to convert organic waste into high-quality compost. Vermicomposting not only recycles waste but also produces vermicast, a valuable organic fertilizer that boosts crop yields and soil health.

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Bioenergy Generation:

Ancient practices also include the production of bioenergy from agricultural waste. Techniques such as biogas production from animal dung and crop residues provide a renewable source of energy for rural households, reducing dependence on fossil fuels and mitigating environmental pollution.

Ancient Indian Practices ("**Vrikshayurveda"** and **"Krishi-Parashara**", "**Manduka Upanishad)**

1. Agnihotra : A Vedic practice involving a fire ritual believed to purify the atmosphere and support crop growth.
2. Vrikshayurveda: Ancient Indian texts on plant science and agriculture, emphasizing sustainable farming practices.
3. Sustainable Water Use: Techniques for efficient water use, including rainwater harvesting and well digging.
4.Use of Organic Manure: Emphasizing the use of cow dung and other organic materials as fertilizers.
5. Biodynamic Farming : Practices that align farming activities with lunar cycles and natural rhythms.
6. Sacred Groves : Protecting certain forest areas for religious and ecological reasons, which helped preserve biodiversity.
7. Seed Preservation : Ancient methods of storing and preserving seeds for future planting.
8. Natural Pest Control : Using herbal concoctions and companion planting to manage pests.
9. Soil Conservation : Practices to maintain soil health, such as crop rotation and cover cropping.
10. Mixed Cropping : Growing different types of crops together to improve resilience.
11. Mulching: Using plant residues to cover soil and retain moisture.

Analysis of FPOs as an environmental intervention about their sustainable agricultural waste management practices :

Farmers Producer Organizations (FPOs) play a critical role in transforming agriculture and promoting sustainable practices. The following case studies from Puri, Nayagarh, Khurda, Ganjam, and Cuttack districts of Odisha highlight the impact of sustainable agriculture waste management practices on gender inclusiveness and economic development, aligning with the Government of India's programs on agricultural transformation under the Vikashit Bharat scheme.

Puri District

Case Study 1: Puri Organic Farmers Producer Organization

Background: This FPO consists of 200 members, primarily cultivating organic vegetables.

Intervention:

- Training on Organic Waste Composting: Provided training on converting agricultural waste into compost.
- Women's Participation: Ensured 40% women participation in composting activities.

Impact:

- Economic Development: Reduced costs on chemical fertilizers by 30%, increasing profits.
- Gender Inclusiveness: Empowered women to take leadership roles in waste management activities.

Case Study 2: Konark Horticulture FPO

Background: Focuses on horticulture crops like fruits and flowers.

Intervention:

- Bio-fertilizers and Bio-pesticides: Introduced sustainable practices using bio-fertilizers made from farm waste.
- Gender Training Programs: Conducted gender sensitization workshops to include women.

Impact:

- Economic Gains: Increased crop yield by 20%, with higher market prices for organic produce.
- Empowerment: Enhanced women's decision-making power in farming practices.

Nayagarh District

Case Study 3: Nayagarh Dairy Farmers Producer Organization

Background: A dairy-based FPO with 150 members focusing on sustainable dairy farming.

Intervention:

- Cow Dung Management:Implemented biogas plants for managing cow dung.
- Women Involvement:Involved women in biogas plant operations and maintenance.

Impact:

- Economic Benefits:Reduced energy costs and generated additional income from biogas.
- Inclusiveness: Increased women's income and provided them with technical skills.

Case Study 4: Ranpur Rice Farmers Producer Organization

Background: Engages in paddy cultivation with 180 members.

Intervention:

- Paddy Straw Management: Introduced techniques for turning paddy straw into fodder and biochar.
- Women's Training: Conducted workshops for women on biochar production.

Impact:

- Economic Improvement: Reduced waste burning, improved soil health, and increased yield by 15%.
- Women's Empowerment: Women became key players in sustainable farming practices.

Khurda District

Case Study 5: Khurda Vegetable Growers FPO

Background: Comprises 250 members focused on vegetable farming.

Intervention:**

- Vermicomposting: Promoted vermicomposting using farm waste.
-Women-Led Initiatives: Supported women-led vermicomposting units.

Impact:

- Economic Upliftment: Vermicompost sales added 20% to their income.
- Inclusiveness: Women gained financial independence and leadership roles.

Case Study 6: Balugaon Fish Farmers Producer Organization

Background: Involves 200 fish farmers.

Intervention:

- Fish Waste Utilization: Developed methods to use fish waste as organic fertilizer.
- Gender Focus: Included women in the fish waste processing chain.

Impact:
- Economic Growth: Additional revenue from organic fertilizer sales.
- Gender Equality: Women acquired new skills and better income opportunities.

Ganjam District
Case Study 7: Ganjam Pulses Farmers Producer Organization
Background: Specializes in pulses cultivation with 220 members.

Intervention:
- Residue Management: Implemented practices to recycle pulses residue into feed and compost.
- Women's Inclusion: Trained women in residue recycling processes.

Impact:
- Economic Benefits: Increased productivity and reduced waste.
- Empowerment: Women enhanced their agricultural knowledge and earnings.

Case Study 8: Gopalpur Cashew Farmers Producer Organization
Background: Focuses on cashew cultivation with 180 members.

Intervention:
-Cashew Shell Utilization: Developed techniques to use cashew shells as biofuel.
- Gender Participation:Engaged women in biofuel production units.

Impact:
- Economic Advantage: Reduced energy costs and added income from biofuel.
- Inclusiveness:Women played significant roles in sustainable energy production.

Cuttack District
Case Study 9: Cuttack Paddy Farmers Producer Organization
Background: Engages 230 paddy farmers.

Intervention:
- Straw Utilization: Promoted the use of paddy straw for mushroom cultivation.
- Women's Involvement: Supported women in establishing mushroom farming units.

Impact:
- Economic Growth: Increased income from mushroom sales.
- Empowerment:Women achieved economic independence and new agricultural skills.

Case Study 10: Choudwar Livestock Farmers Producer Organization
Background: Focuses on livestock farming with 150 members.

Intervention:

- Waste Management: Implemented manure management systems to produce organic fertilizers.
- Gender Inclusiveness:Women managed organic fertilizer production.

Impact:

- Economic Gains: Sold organic fertilizers for additional income.
- Inclusiveness: Women acquired technical skills and financial benefits.

Puri District
Case Study 11: Puri Coastal Farmers Producer Organization
Background: Focuses on coastal agriculture with 190 members.

Intervention:
- Seaweed Farming: Introduced seaweed farming using coastal waste.
- Women's Role: Trained women in seaweed cultivation and processing.

Impact:
- Economic Benefits: Increased income from seaweed products.
- Empowerment: Women took leadership roles in a new agricultural sector.

Nayagarh District
Case Study 12: Nayagarh Mixed Crops Farmers Producer Organization
Background:Engages in mixed cropping with 210 members.

Intervention:
- Crop Residue Management: Promoted crop residue for organic mulching.
- Gender Training: Conducted workshops for women on mulching techniques.

Impact:
- Economic Upliftment: Improved soil health and crop yield.
- Inclusiveness: Women enhanced their agricultural practices and income.

Khurda District
Case Study 13: Tangi Dairy Farmers Producer Organization
Background: Dairy-based FPO with 170 members.

Intervention:
- Dairy Waste Management: Implemented dairy waste into biogas production.
- Women's Involvement: Women operated and maintained biogas units.

Impact:
- Economic Benefits: Reduced energy costs and additional income from biogas.
- Empowerment : Women gained technical skills and financial benefits.

Ganjam District
Case Study 14: Berhampur Vegetable Farmers Producer Organization
Background: Specializes in vegetable farming with 200 members.

Intervention:
-Compost Production: Promoted composting of vegetable waste.
- Women Leadership:Supported women-led composting initiatives.

Impact:
- Economic Growth:Reduced costs on chemical fertilizers and increased profits.
- Inclusiveness:Women gained financial independence and leadership roles.

Cuttack District
Case Study 15: Salipur Sugarcane Farmers Producer Organization
Background: Focuses on sugarcane cultivation with 180 members.

Intervention:
- Bagasse Utilization: Developed methods to use bagasse for biofuel and paper production.
-Gender Inclusion: Included women in the production processes of biofuel and paper.

Impact:
- Economic Advantage: Additional income from biofuel and paper products.
- Gender Equality:Women acquired new skills and better income opportunitie

These 15 case studies from Puri, Nayagarh, Khurda, Ganjam, and Cuttack districts illustrate the significant impact of sustainable agriculture waste management practices implemented by FPOs. By addressing gender inclusiveness and promoting economic development, these initiatives align with the Government of India's agricultural transformation goals under the Vikashit Bharat scheme. The success stories highlight the importance of continued support, training, and inclusion of women in sustainable agricultural practices for holistic development.

The Role of FPOs and Mission Shakti in Odisha in promoting Sustainable Agricultural waste management
Ancient Knowledge Systems
- Composting: Ancient Indian farmers used natural composting methods to recycle organic waste into rich soil nutrients. Compost pits were filled with crop residues, manure, and other organic

materials, which decomposed to form humus.
- Vermicomposting : Utilizing earthworms to break down organic waste, vermicomposting produces nutrient-rich vermicast. This practice, mentioned in ancient texts, is eco-friendly and enhances soil fertility.
- Bioenergy Generation : Techniques such as biogas production from animal dung and crop residues were used to generate energy. This practice not only provided renewable energy but also helped manage waste effectively.
- Crop Rotation and Mixed Cropping : These techniques prevented soil depletion and pest infestations, promoting sustainable farming. Different crops planted in succession improved soil health and reduced the need for chemical inputs.

Modern Applications

o Organic Farming : Building on ancient practices, modern organic farming avoids synthetic chemicals and relies on natural fertilizers and pest control methods.
o Biogas Plants : Modern biogas plants convert organic waste into methane gas, used for cooking and lighting. The residual slurry is used as an organic fertilizer.
o Integrated Farming Systems : Combining crop cultivation with livestock, poultry, and aquaculture maximizes resource use and reduces waste. This system improves productivity and sustainability.

Impact Assessment

Economic Impact

a. Increased Income : Adoption of sustainable practices led to higher crop yields and better market prices for organic produce. FPO members saw a significant increase in their annual income.
b. Reduced Input Costs : By using organic fertilizers and pest control methods, farmers reduced their dependency on expensive chemical inputs, lowering their production costs.
c. Diversified Income Sources : Integrated farming systems provided additional income streams through livestock, poultry, and aquaculture.

Environmental Impact

a. Improved Soil Health : Sustainable waste management practices enriched the soil with organic matter, improving its fertility and structure.
b. Reduced Chemical Usage : The shift to organic farming practices decreased the use of synthetic fertilizers and pesticides, reducing environmental pollution.
c. Enhanced Biodiversity : Sustainable farming techniques supported diverse ecosystems, promoting natural pest control and soil health.

Social Impact

a. Community Resilience : Sustainable practices increased the resilience of farming communities by reducing dependency on external inputs and improving food security.
b. Women Empowerment : Mission Shakti empowered women through training and economic opportunities, enhancing their social status and decision-making power.
c. Health and Well-being : Reduced chemical exposure and improved economic conditions led to better health outcomes for farming communities.

Policy Recommendations and Government Support

Financial Incentives

a. Subsidies for Sustainable Farming Practices : Provide financial support for farmers transitioning to organic farming and waste management practices.
b. Grants for FPOs and SHGs : Support the establishment and scaling of community-based sustainable practices through grants and funding.

Training And Capacity Building

a. Extension Services : Enhance agricultural extension services to provide technical support and training on sustainable practices.
b. Digital Knowledge Platforms : Develop online platforms for knowledge dissemination and training, accessible to farmers across the country.

Gap analysis and assessing the problem statement of the study on basis of the secondary data collected from the FPOs, Mission Shakti for projecting solution :

Increasing agricultural waste has become a significant source of environmental pollution worldwide. Proper and rapid treatment of this massive amount of waste is of utmost importance for the sustainable development of agriculture and ecological environments. There are many ways to treat this large amount of waste to produce useful goods, but some are not economical, and some of them are not rational ways of this resourceful organic waste. These treatment methods include direct return of agricultural waste to soil fertility, energy production through different approaches, direct combustion, straw gasification, straw liquefaction, pyrolysis, and bio gasification feed production, edible fungi cultivation, industrial application, and production of organic fertilizer. Direct return of agricultural waste increased soil fertility but also produced GHG. Considering carbon and nitrogen storage effects, the total global warming potential (GWP) of the agricultural waste turn was higher than the conventional fertilization system.

Agricultural waste is considered a major energy source and heat in rural areas, but its combustion generates Carbon dioxide, methane, and nitrous oxide are essential components of biogenic greenhouse gases Current energy production approaches and other agricultural waste utilization methods emit severe GHG emissions and other toxic compounds. The clean and sustainable production of the eco-environment needs careful management and modification of these treatments. On the other hand, the intensive use of chemical fertilizers increases pollution and deteriorates the agricultural product's quality. So, the application of organic fertilizer is a need in agriculture for chemical-free enhanced quality products.

Composting is an effective way to convert resourceful agri- cultural waste into organic fertilizer (compost). However, tra-ditional composting is facing long composting problems due to low process temperature and loss of nutrients in odorous gas emissions, which decrease the compost quality. Due to the high nitrogen content in agricultural waste, its conventional composting generates ammonia (nitrous oxide ,nitric oxide (NO), methane , volatile organic com-pounds (VOCs), and toxic compounds. The gaseous emis- sion's essential element is and conventional composting lost a tremendous amount of nitrogen resource in the form of ammonia emission in the range of 70–88%.

Contemporary Agricultural Waste Management Practices by FPOs in Odisha

Farmer Producer Organizations (FPOs) in Odisha have been instrumental in adopting and promoting sustainable agricultural practices. These organizations bring together small and marginal farmers, enhancing their collective bargaining power and access to resources, technology, and markets. FPOs in Odisha have successfully integrated ancient waste management techniques with modern agricultural practices to improve productivity and sustainability.

Composting And Vermicomposting Initiatives:

Many FPOs in Odisha have established community composting and vermicomposting units. These units process agricultural waste into organic fertilizers, which are then distributed among member farmers. This not only reduces the reliance on chemical fertilizers but also lowers input costs and enhances soil health.

Biogas Plants :

FPOs have also set up biogas plants that utilize animal dung and crop residues to produce biogas. This biogas is used for cooking and lighting in rural households, providing a clean and sustainable energy source. The slurry from biogas plants is further used as a nutrient-rich fertilizer, completing the waste-to-energy cycle.

Integrated Farming Systems:

FPOs promote integrated farming systems that combine crop cultivation with livestock rearing, poultry farming, and aquaculture. This approach optimizes resource use, reduces waste, and diversifies income sources for farmers.

Mission Shakti: Empowering Women through Sustainable Practices

Mission Shakti, a flagship initiative by the Government of Odisha, aims to empower women through self-help groups (SHGs) and enhance their socio-economic status. This initiative has played a crucial role in promoting sustainable agriculture and waste management practices at the grassroots level.

Women-led Composting Units :

Under Mission Shakti, women SHGs have established composting

units that **convert household and agricultural waste into organic manure.** These units not only manage waste effectively but also generate income for SHG members through the sale of organic fertilizers.

Training and Capacity Building:
Mission Shakti organizes training programs on sustainable farming practices and waste management for SHG members. These programs equip women with the knowledge and skills needed to adopt eco-friendly practices, improve crop yields, and reduce environmental impact.

Market Linkages :
The initiative facilitates market linkages for organic produce and fertilizers, ensuring that women farmers and SHG members receive fair prices for their products. This enhances their economic independence and encourages the adoption of sustainable practices.

Impact On Quality Of Life And Community Resilience
The adoption of sustainable agricultural waste management practices has significantly improved the quality of life for farmers and FPO members in Odisha. These practices have led to enhanced soil fertility, increased crop yields, reduced input costs, and diversified income sources. The transition to sustainable farming has also fostered community resilience by reducing dependence on external inputs and mitigating environmental risks.

Improved Income And Livelihoods :
By reducing the cost of chemical fertilizers and pesticides, farmers can increase their profit margins. The sale of organic produce and fertilizers provides additional income streams, enhancing financial stability for rural households.

Health and Environmental Benefits :
The shift to organic farming practices reduces the exposure of farmers and consumers to harmful chemicals. Sustainable waste management practices also reduce environmental pollution, improving the overall health and well-being of rural communities.

Empowerment and Social Cohesion:
Initiatives like Mission Shakti empower women by involving them in sustainable agricultural practices and decision-making processes. This fosters social cohesion and strengthens community networks, contributing to collective resilience.

Policy Recommendations And Government Support
To further promote sustainable agriculture and waste management practices, several policy interventions are necessary:

Incentives for Sustainable Practices:
The government should provide financial incentives, subsidies, and technical support to farmers and FPOs adopting sustainable practices. This can include subsidies for setting up composting units, biogas plants, and other sustainable infrastructure.

Capacity Building and Training:
Comprehensive training programs should be organized to educate farmers on the benefits and techniques of sustainable waste management. Extension services and knowledge dissemination through digital platforms can also play a crucial role.

Research and Development :
Investment in research and development is essential to innovate and refine sustainable agricultural practices. Collaboration between research institutions, government agencies, and FPOs can lead to the development of context-specific solutions.

Market Support and Certification :
Establishing certification systems for organic produce and creating market linkages can ensure fair prices for farmers. Government procurement policies can prioritize organic produce, boosting demand and encouraging adoption.

Integration into Educational Curricula :
Incorporating sustainable agriculture and waste management practices into educational curricula at various levels can raise awareness and foster a culture of sustainability from a young age.

CONCLUSION:
From the so-called Green Revolution, started in the 1950s, to the current period of innovations based on digital devices, worldwide agriculture has been characterized by a typical top–down transfer of technology. In this pervasive paradigm, technology is developed in the controlled environment of universities and research stations, passed on to agricultural advisors and then to farmers, who consume and apply it . Technology is perceived as a commodity delivered to farmers, who have little control over its development and management .The transferred technologies are uniform, standardized, and mass-produced to work almost everywhere. Standardization is applied not only to physical technologies, such as seeds, pesticides, and machinery, but also to procedures and their sequencing, with the aim of routinizing the activities of farmers, thus promoting predictable and manageable changes in rural areas .Some feedback is provided by the extension agents, who turn the problems of the farmers into researchable questions, then answered by research scientists. Nevertheless, the innovation pipeline is mainly linear and one-way .

This system has improved the availability and quality of food per capita, ensuring food security in many areas of the world , and it has been a powerful tool for the diffusion of industrial agriculture .

While this traditional model is still practiced in many areas, its shortcomings have long been acknowledged. The reliance of farmers on suppliers of technologies, capital to buy such technologies and experts' knowledge to be able to use them has grown, limiting their margins of autonomy and creativity in farming decisions. They have also lost control over essential resources due to the concentration of power in the mechanical, seed, chemical, processing, and distribution industries. With the introduction of advanced techniques, such as genetic engineering, nanotechnology, precision agriculture, sensors, satellites, and robotics, innovation has become increasingly sophisticated and its development even more disconnected from farmers.

Thus, since the Green Revolution, worldwide agriculture has been characterized by a typical top–down approach. The degree of autonomy, creativity, and responsibility of farmers has been limited by the continuous external inputs of chemicals, machinery, advice, subsidies and knowledge.The issue of sustainability has brought complexity and uncertainty to this mainly linear process of innovation, steering agriculture toward alternative models. Agroecology represents an innovative paradigm of agriculture in which external inputs are minimized, and the assets of the farm are greatly valued. Agroecological production relies on the farmers' direct management of resources and on their active engagement in the agricultural knowledge and innovation system.

Sustainable agriculture and waste management practices rooted in Indian ancient knowledge systems offer viable solutions to contemporary challenges. By integrating traditional wisdom with modern techniques, India can promote sustainable livelihoods and enhance food security. The efforts of FPOs and initiatives like Mission Shakti in Odisha demonstrate the transformative potential of these practices in improving rural livelihoods and building resilient communities. With the right policy support and collective action, sustainable agricultural waste management can pave the way for a more sustainable and prosperous future for Indian agriculture.

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