Compendium

37th National Convention of Agricultural Engineers & National Seminar

"Innovative Approaches in Agricultural Engineering for Agriculture of Viksit Bharat - A road map towards 2047"



August 29-30, 2025,

Compiled and Edited by

Er. K.P. Tripathi
Dr. S.I. Anwar
Dr. Jaswant Singh
Er V.P. Singh

The Institution of Engineers (India), Uttar Pradesh State Centre
Engineers' Bhawan, River Bank Colony, Lucknow

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आनंदीबेन पटेल
राज्यपाल, उत्तर प्रदेश



सत्यमेव जयते

राज भवन
लखनऊ - 226 027

26 अगस्त, 2025

संदेश

मुझे यह जानकर अत्यंत प्रसन्नता हुई कि इन्स्टीट्यूशन ऑफ इन्जीनियर्स (इण्डिया), यू.पी. स्टेट सेन्टर, लखनऊ द्वारा 29 एवं 30 अगस्त, 2025 को "विकसित भारत की कृषि के लिए कृषि इंजीनियरिंग में नवीन दृष्टिकोणः 2047 की ओर एक रोड मैप" विषय पर 37वां राष्ट्रीय सम्मेलन आयोजित किया जा रहा है। इस अवसर पर स्मारिका का प्रकाशन भी किया जायेगा।

विकसित भारत के सपने को साकार करने में कृषि इंजीनियरिंग की भूमिका महत्वपूर्ण है। तकनीकी नवाचार, यंत्रीकरण, संसाधनों का कुशल प्रबंधन और टिकाऊ कृषि पद्धतियाँ समृद्ध, आत्मनिर्भर और सतत कृषि के लिए आवश्यक हैं। आशा है यह सम्मेलन विचार–विमर्श, अनुसंधान और नवाचार के आदान–प्रदान का उत्कृष्ट मंच होगा, जो देश की कृषि नीति को नई दिशा देगा।

सम्मेलन के आयोजन एवं स्मारिका के प्रकाशन की सफलता हेतु मैं अपनी हार्दिक शुभकामनाएं प्रेषित करती हूँ।

आनंदीबेन

(आनंदीबेन पटेल)

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पत्र संख्या-275/पी0एस0-सी0एम/2025

योगी आदित्यनाथ



मुख्य मंत्री
उत्तर प्रदेश

लोक भवन,
लखनऊ - 226001

दिनांक : 26 AUG 2025

संदेश

मुझे यह जानकर अत्यन्त प्रसन्नता की अनुभूति हो रही है कि दि इन्स्टीट्यूशन ऑफ इंजीनियर्स (इण्डिया) द्वारा दिनांक 29 व 30 अगस्त, 2025 को लखनऊ में कृषि इन्जीनियरिंग क्षेत्र में अपना 37वां राष्ट्रीय सम्मेलन आयोजित किया जा रहा है।

प्रदेश के अन्नदाता किसान विकास प्रक्रिया से जुड़कर विकसित भारत की संकल्पना को साकार करने में लगातार योगदान दे रहे हैं। हमारे परिश्रमी किसान नवाचार व कृषि आधुनिकीकरण का प्रयोग कर कई गुना मुनाफा कमा रहे हैं। कृषि उत्पादन बढ़ने से प्रदेश व किसान दोनों को लाभ होता है तथा देश व प्रदेश के विकास में भी सहायता मिलती है। इसमें कृषि इन्जीनियरिंग क्षेत्र की भूमिका महत्वपूर्ण है।

विकसित भारत की परिकल्पना को साकार करने की आधारशिला कृषि बन सके, इसके दृष्टिगत सम्मेलन के दौरान 'विकसित भारत की कृषि के लिए कृषि इन्जीनियरिंग में नवीन दृष्टिकोण–2047 की ओर एक रोडमैप' विषयक 02 दिवसीय राष्ट्रीय संगोष्ठी का आयोजन सराहनीय है।

मुझे विश्वास है कि इस आयोजन में कृषि इन्जीनियरिंग क्षेत्र की नवीनतम तकनीकों एवं प्रणालियों के सम्बन्ध में सार्थक विचार–विमर्श किया जाएगा।

आयोजन की सफलता हेतु हार्दिक शुभकामनाएं।

(योगी आदित्यनाथ)

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Brajesh Pathak
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Date
14.08.2025



MESSAGE

I am delighted to know that Uttar Pradesh State Center, Lucknow of The Institution of Engineers (India) is organizing its 37th National Convention of Agricultural Engineers and National Seminar on "Innovative Approaches in Agricultural Engineering for Agriculture of Viksit Bharat - A road map towards 2047", during August 29-30, 2025.

Agriculture of India and especially of Uttar Pradesh is the back bone of the country's economy. Among the various inputs of agriculture, mechanization has proved a boon to the farmers. The mechanization starting from field preparation to harvesting and then up to processing, value addition, packing and storage not only saves time of the farmers but also ensures assured financial return. Climate change is also one the new problems which the farmers is likely to face adversely.

I am sure the participants of the above National Convention cum Seminar will deliberate these problems and suggest practicable solutions to the problems of the agriculture.

I wish very grand success to the above 37th National Convention of Agricultural Engineers and National Seminar being organized by Uttar Pradesh State Center, Lucknow of The Institution of Engineers (India).

Warm regards,

(BRAJESH PATHAK)

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The Institution of Engineers (India)

AN ISO 9001 : 2015 CERTIFIED ORGANISATION
(ESTABLISHED 1920, INCORPORATED BY ROYAL CHARTER 1935)

Er.V B Singh, FIE
President



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A Century of Service to the Nation

MESSAGE

I am delighted to note that the Uttar Pradesh State Centre of The Institution of Engineers (India) is organising the 37th National Convention of Agricultural Engineers & a National Seminar on "Innovative Approaches in Agricultural Engineering for Agriculture of Viksit Bharat – A Road Map towards 2047" during 29th & 30th August 2025 at the Uttar Pradesh State Centre, IEI, Lucknow.

As India advances towards its 2047 vision of Viksit Bharat- a future marked by a self-reliance and inclusive development-agriculture stands at the forefront of this transformation. With half of the nation's population dependent on farming and agricultural sector, contributing significantly to the GDP, it will continue to play a vital role in ensuring food security, generating employment, and driving economic progress. To achieve a developed India ("Viksit Bharat") by 2047, the roadmap for agricultural engineering must focus on innovative approaches like precision farming, technology integration, and sustainable practices. This includes leveraging technologies like drones, AI, and blockchain to enhance productivity and efficiency while ensuring environmental sustainability.

I am confident that this Convention will serve as a meaningful platform for all participants to share their insights and expertise on the various dimensions of the theme.

I extend my greetings to the organizers and all participants and convey my best wishes for the success of the National Convention.

(V B Singh)

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Message

It gives me immense pleasure to note that the Uttar Pradesh State Centre of The Institution of Engineers (India) is organizing the National Convention on "Innovative Approaches in Agricultural Engineering for Agriculture of Viksit Bharat – A Road Map towards 2047".

Agriculture continues to be the backbone of India's economy, and the vision of Viksit Bharat 2047 calls for transformative strategies that seamlessly blend traditional wisdom with cutting-edge technologies. In this journey, agricultural engineers play a pivotal role in enhancing productivity, ensuring sustainability, optimizing resource utilization, and fostering climate-resilient farming practices.

This convention is an important platform for experts, researchers, policymakers, and industry leaders to share ideas, discuss challenges, and plan for the future in line with our nation's goals. The discussions are expected to inspire new developments in mechanization, irrigation, post-harvest management, renewable energy use, and digital agriculture.

I am confident that the outcomes of this event will contribute significantly towards building a resilient, sustainable, and technology-driven agricultural sector, thereby enabling participants to contribute meaningfully towards India's journey to achieve self-reliance and global leadership in food security by 2047.

I extend my best wishes to the organizers, speakers, and participants for the grand success of this convention.

Dr. Shilpa Tripathi
Chairman, Committee for Advancement of Technology & Engineering (CATE)
Member, Chemical Engineering Division Board Member
Prof & Dean of Student Affairs, Medicaps University, Indore (MP)
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The Institution of Engineers (India)

AN ISO 9001-2015 CERTIFIED ORGANISATION (ESTABLISHED 1920, INCORPORATED BY ROYAL CHARTER 1935)

"A Century of Service Towards Engineering Advancement for Nation Building"

8, Gokhale Road, Kolkata 700020



Jai Prakash Narayan, FIE
Chairman, AG Division Board

Message

It is my immense pleasure to note that the Uttar Pradesh State Centre of the Institution of Engineers (India) is organizing **"37th National Convention of Agricultural Engineering for Agriculture of Viksit Bharat A Road Map for Next 25 Years"** on 29-30 August, 2025 at Lucknow (Uttar Pradesh).

Our journey towards Viksit Bharat faces a unique set of challenges in agriculture. We must navigate a future with declining land holdings, water stress and the pressing imperatives of climate change simultaneously. We must ensure food and nutritional security for our growing population while empowering our small and marginal farmers, who are the backbone of our agriculture economy. The answers to these challenges lie not in traditional methods alone, but in a new era of agricultural innovation- an era led by Agricultural Engineering. The roadmap for Viksit Bharat 2047 calls for a paradigm shift, moving towards a science-led, technology-driven and market-oriented agricultural ecosystem. Agricultural engineering is the engine of this transformation. By integrating cutting edge technologies and sustainable practices, we can create a resilient and profitable agricultural sector for the 21st century. We can leverage innovative agricultural engineering to pave the way to Viksit Bharat 2047 by adopting (1) Precision Agriculture and Data-Driven farming, deploying smart sensor networks, Artificial Intelligence (AI), Machine Learning, Drone technology, watershed management, precision irrigation, (2) Automation and Mechanization, promotion of custom hiring of modern machineries/implements, Robotics and AI-Enabled machinery, machinery for women. (3) Sustainable and Climate-Resilient Technologies, Renewable Energy Integration, Post Harvest and agro-waste solutions, protected cultivation (4) Post Harvest Management and value addition, modern storage and logistics, Digital Market Linkages etc.

I am sure that this 37th National Convention of Agricultural Engineering Division Board will provide a platform for sharing and discussing research works/innovative ideas and modern technologies among all the stakeholders. The recommendation out of the deliberations at this National Convention will be useful for the farmers, implementing agencies, policy makers, entrepreneur and food industries,

I extend my sincere appreciations to the organizers of this national convention for their efforts in organizing the convention.

I wish this 37th National Convention a grand success.

(J. P. Narayan)

The Institution of Engineers (India)

UTTAR PRADESH STATE CENTRE, ENGINEERS BHAWAN, RIVER BANK COLONY, LUCKNOW-226018

दि इन्स्टीट्यूशन ऑफ इंजीनियर्स (इण्डिया)

उत्तर प्रदेश स्टेट सेन्टर, इंजीनियर्स भवन, रिवरबैंक कालोनी, लखनऊ-226018

ER. SATYA PRAKASH, FIE
CHAIRMAN

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(Established 1920, Incorporated by Royal Charter 1935)

"A Century of Service to the Nation"



MESSAGE

It gives me immense pleasure to note that the 37th National Convention of Agricultural Engineers along with the National Seminar on "Innovative Approaches in Agricultural Engineering for Agriculture of Viksit Bharat – A Roadmap for 2047" is being organized on 29th & 30th August, 2025 at IEI, UP State Centre, Lucknow.

Agriculture has always been the backbone of our nation and in the journey towards Viksit Bharat @ 2047, the role of agricultural engineering will be critical in ensuring sustainability, productivity, and prosperity for our farmers. The focus on innovation, technology-driven solutions, and futuristic approaches will undoubtedly pave the way for a more resilient and modern agricultural sector.

I am confident that this convention and seminar will serve as an excellent platform for agricultural engineers, researchers, academicians, and policymakers to exchange ideas, deliberate on challenges, and chart a strategic roadmap for the future of Indian agriculture.

I extend my best wishes for the grand success of this convention and seminar, and hope that the deliberations lead to impactful outcomes benefiting farmers and the nation at large.

(Satya Prakash, FIE)
Chairman

FOREWORD

The 37th National Convention of Agricultural Engineers & National Seminar is being organized on the theme "Innovative Approaches in Agricultural Engineering for Agriculture of Viksit Bharat-A roadmap for 2047". The Convention and the Seminar plan has research papers, presentations, discussion and recommendations besides key note addresses by eminent agricultural engineers. Realizing the fact that agricultural engineering covers a vast domain, the papers presentation, keynote addresses will be addressing eight sub-themes viz. Precision Farming and Smart Agriculture, Mechanization for Small & Marginal Farmers, Climate-Resilient Farming Techniques, Post-Harvest and Food Processing Innovations, Renewable Energy Integration, Agri-Fintech and Digital Platforms, Capacity Development and Skill Development, and Circular Economy.

Key Note Addresses, research papers, abstracts received have been compiled under one cover to have easy access to look on topics of their interest and contribute by way of interaction, discussion and finalizing recommendations. Hope this compendium will be useful refence for developing a roadmap and action plan to contribute making Indian agriculture into a modern and sustainable by empowering technology, promoting sustainable practices, and empowering farmers, processors, policy makers, and others make India achieve food security, improve rural livelihood, and contribute to a developed nation by 2047.

We sincerely thank The Institution of Engineers (India) for approving this event to be organized by Uttar Pradesh State Centre (IEI), Lucknow. We also pay our gratitude to ErV.B.Singh, National President (IEI); DrShilpaTripathi, Chairman (CATE, IEI); Er Jai Prakash Narayan, Chairman Agriculture Engineering Division Board (IEI); Er Satya Prakash, Chairman Uttar Pradesh State Centre (IEI), Lucknow and Er V.P. Singh, Honorary Secretary, Uttar Pradesh State Centre (IEI), Lucknow for providing all logistic support.

Dated: 21st Aug. 2025
Bang ali Baboo, ARS, FIE, FISAE
Chairman (Technical Committee)

CONTENTS

Sl No.	Title	Page No.
1	Agricultural Engineering for Vikshit Bharat Dr. S. N. Jha, FIE	1
2	Recent Advancements in Farm Mechanization with a Focus on Drone Technology in Agricultural Engineering: A Tool for Crop Production in Viksit Bharat Prof. (Dr.) Indra Mani	8
3	Policy Environment and Farm Engineering for Viksit Bharat Agriculture @ 2047 Dr Bangali Baboo, FIE	16
4	From Sensors to Smart Villages: Reimagining Engineering Roles in Agriculture, Water, and Climate Resilience Prof (Dr) M.L. Gaur	23
5	Recent Advances in Micro Irrigation Technology Dr Kamlesh N Tiwari and Dr Manoj K Mondal	35
6	Role of AI and IoT in Precision Irrigation Systems Dr T. B. S. Rajput, FIE	41
7	Agricultural Processing Prospects in the Era of Vikasit Bharat Dr R T Patil, FIE	46
8	Agriculture 4.0: Innovations and Automation for Sustainable Mechanization Dr K.N. Agarwal and Anant Tripathi	53
9	Farm Mechanization Technologies for Small and Hill Farmers – Gender Perspective Dr Sukhbir Singh and Dr Omprabha	65
10	Application of advanced technologies for mechanization of animal husbandry Dr S.P. Singh and Rita Patle	74
11	Next Renewable Energy Technology for Carbon Footprint reduction in Agriculture Dr. Vinod Kumar Bhargav	83
12	Private Minor Irrigation in the State of Uttar Pradesh: Challenges, Contribution, and Managing Irrigation Water for the Future Er. Pratik Ranjan Chaurasia, FIE	90
13	Road Map on Mechanization of Indian Agriculture Dr Kanchan K. Singh, FIE	98
14	Climate Change – An Overview Er. K.P. Tripathi, FIE and Dr S.I. Anwar, FIE	101
15	Development of a Utility Machine for Sugarcane Juice and Jaggery Dr S.I. Anwar,FIE, Dr R.D. Singh, Dr Dilip Kumar, Dr Jaswant Singh and Dr Trishla Sahu	115
16	Sugarcane Mechanization, Artificial Intelligence tools and Climate Smart Agricultural Techniques for Food-Energy Security in India Dr L.S. Gangwar, Dr S.S. Hasan, Dr Dinesh Singh, and Dr Jaswant Singh, FIE	121
17	Post-Harvest and Food Processing Innovation in India: Trends, Challenges, and Future Prospects Dr Jaswant Singh, FIE and Dr Rajesh Modi	134
18	Efficiency Enhancement in Sugarcane Processing for Jaggery Making Dr S.I. Anwar, FIE	145
19	An Empirical Study on Drip Irrigation System in Babina Block Jhansi Districts U.P. Dr M.A. Husain, Dr Pankaj Kumar and Dr N.K. Sharma	151

20	Shifting of Traditional Agricultural Technology to AI-Driven Technology for Enhancing Agricultural Production and Sustainability Dr R. U. Modi, Dr Mayank Maurya, Dr M. K. Singh and Dr A. K. Singh	159
21	A Meta-Study on the Variability of Microclimatic Parameters in Naturally Ventilated Polyhouse K.V.L. Supraja, Dr K. Krupavathi, Dr G. Ravi Babu, and Dr Ch. Someswara Rao	166
22	Smart Solutions in Food Systems: The Role of Carbon Dots in Food Safety and Preservation Yelampalli Kavya, Dr Roopabai R S, Dr Udaykumar Nidoni, Dr Sharanagouda Hiregoudar, and Dr P.F. Mathad	174
23	Sensory Assessment of Jaggery-Coated Almond, Foxnut, and Peanut Products Dr Dilip Kumar, Dr Trishla Sahu, Dr Shadanan Patel, Dr Priyanka Singh, Dr Sunny Mishra, and Jyoti Singh	184
24	Development of HAU Green Detopping Machine for Carrot Dr Sunil Kumar, Dr AK Attkan, Dr Anil Panghal, Dr Nitin Kumar, Km. Sheetal Banga and Dr Jaivir Singh	190
25	Enhancing Viability of Agriculture as Profession in AmritKal – A Road Map Dr R. C. Srivastava	198
26	Precision Fertigation Management for Cluster bean under Semi-arid tropics of Maharashtra Dr S. B. Jadhav, Dr H. W. Awari, Dr V.K. Ingle, and Dr K.S. Giram	199
27	Puffing Machine and Process Development for increasing Entrepreneurship at Cottage Level Dr R.V. Jaybhaye, Dr H. D. Rupanawar, and Dr S.U. Khodke	200
28	Smart Water Allocation: Optimizing Use Based on Availability and ROI KaluvaiYella Reddy, SarmaVenkataraman, Chandra BabuVasasali, and Srinivas Rao	201
29	Scaling CADWM through Global Insights and Data-Driven Strategy Kaluvai Yella Reddy, SarmaVenkataraman, Chandra BabuVasasali, and Srinivas Rao	203
30	Decoding Irrigation Patterns amid Water Stress Trends Kaluvai Yella Reddy, SarmaVenkataraman, Chandra Babu Vasasali, and Srinivas Rao	206
31	Design and Development of an Automated Organic Fertilizer Application Machine Dr Pratibha Shiv	207
32	Empowering Marginal Farmers and Rural Women through Circular Economy Based Organic Moringa Farming with Waste Utilization and Carbon Credit Integration Ravindra S Girge	208
33	Yield and Water Use Efficiency of Linseed Influenced under Tillage and Mulching Practices Reena Kumari, Babloo Sharma, and Pratibha sKumari	209

34	The Future of Weed Control in Ornamentals: A Review of Autonomous Robotic Solutions Sandeep Kumar Saroj, Jayant Singh, and Sachin Chaudhary	210
35	Energy-Efficient Powertrain Architecture for Carbon-Neutral Electric Agricultural Machinery Vijayakumar Krishnan and A. Joseph Basanth	211
36	Design, Development and Field Evaluation of a Tractor-Operated Ginger Planter H.S. Pandey and CP Sawant	212
37	Comparative Impacts of Tillage and No-Till Systems on Soil Health: A Review Nitin Kumar Koumary, Anoop Kumar Dave, Viren Manish Victor, and Rajesh Kumar Naik	213
38	Engineering the Future of Indian Agriculture: A Roadmap to Viksit Bharat 2047 Pankaj Kumar Sharma, Chhavi Sharma, and AnujVerma	214
39	Design and Development of Maize Sheller for Hilly Regions Shyam Nath, Brij Mohan Pandey, Sher Singh, Kushagra Joshi, Ram Prakash Yadav, Jitendra Kumar, Vijay Singh Meena, and Lakshmi Kant	215
40	Farm pond: A Climate Resilient Farming Technique for Rainfed Eco-System ofMarathwada region, Maharashta M.S. Pendke, H.W. Awari, A.L. Aundhekar, K.S. Baig, and Indra Mani	216
41	Planning, Designing and Cost Estimation of Soil and Water Conservation measures for Sarastal Micro Watershed Vinay K. Pandey and Kamini Sahu	217
42	Development of Machinery Package to Facilitate the Adoption of Controlled Traffic Farming in Sugarcane Cultivation M. K. Singh, R. U. Modi, and A. K. Singh	218
43	Sensor based Precision Water Management in Fruit Orchard Tanushree Sahoo, A.C. Rathore, Anand Kumar Gupta, R.B. Meena, Meenakshi Badu, and Satyabrata Pradhan	219
44	Farm mechanization for cost-effective cultivation of sugarcane A K Singh, M K Singh, and R. U. Modi	220
45	Trisul Technology: A way to enhance the Pigeon pea production potential for climate resilient agriculture H. W. Awari , Indra Mani, M. S. Pemdke, A.L. Aundhekar and V. K. Ingle	221
46	Wireless soil moisture sensors-based irrigation scheduling in wheat Monalisha Pramanik, Manoj Khanna, P S Brahmanand, and Rajeev Ranjan	222
47	Groundwater Potential Zoning in Meerut District Using Remote Sensing and GIS Technique Vikash Singh, Jaivir Singh, Mayank Purohit, Abhishek Bharti and Ishu Dhankad	223
48	Spatial distribution of reference evapotranspiration for Aurangabad district of Maharashtra V. K. Ingle, S.B. Jadhav, H. W. Awari, Indra Mani, and R.T. Ramteke	224
49	Advances in Space Technologies for Agriculture Chitra Singh, Jaisvir Singh and Vikash Singh	225

50	Assessment of Plantation-Induced Variations in Soil Properties and Hydrological Processes Chitra Shukla, Jaivir Singh, P K Singh, Vikas Singh, and Rakesh Kumawat	226
51	Emerging Trends and Future Prospect of Biogas Generation from Agro-Waste Ravi Kant, Jaivir Singh, Ankit Kumar, and Rakesh Kumar Kumawat	227
52	Water Neutrality Strategy for Sustainable Agricultural Water Management in the Burhi Gandak River Basin under Changing Climate Scenarios Ambrish Kumar, Uday Mandal, Rajesh Kaushal1, Trisha Roy, Vipin Kumar Mishra and Sweta Garg	228
53	Development of Crop Coefficient of Rabi Sorghum by using Automatic Weighing type Lysimeter V.K. Ingle, H.W. Awari, Indra Mani, S.B. Jadhav, V. C. Thombare , K.S. Giram and K. K. Bhogil	229
54	Design and Development of Small Size Tractor Operated Raised Bed Seeder-cum-Sugarcane Cutter Planter Dr. Abhishek Kumar	230
55	Prediction of the standardized precipitation index based on the long short-term memory and empirical mode decomposition-extreme learning machine models: The Case of Bolangir district of Odisha Truptimayee Suna, P.S. Brahmanand, and Nandlal Kushwaha	231
56	Design of an Intelligent Robotic Platform for Selective Spraying in Precision Farming Environments R. K. Kumawat, Jaiveer Singh, Vikash Singh, Kritika Singh, Ravi Kant, and Chitra Shukla	232
57	Development of Nano-Biofilm Reinforced with Sugarcane Bagasse Residue for Biodegradable Packaging Application Kritika Singh Somvanshi, Prerana Sikarwar, Jaivir Singh, Pushpendra K. Singh, Rahul Kumar, and Rakesh Kumar Kumawat	233
58	Smart Agri-Linkages through Digital Innovation in India Uttam Sharma, Jaivir Singh, Sushil Kumar, and Utkarsh Pundir	234
59	From Crop Waste to Clean Fuel: A Review of Pretreatment Strategies for Production of Bioethanol Prerana Sikarwar, Kritika Singh Somvanshi, Jaivir Singh, Rahul Kumar, and Lokesh Kumar	235
60	Enhancing soil sustainability through management of prevailing land use systems: Assessment Using Soil Quality Indicators and Deterioration Index R. B. Meena, S.C. Meena, A. K. Gupta1, A. C. Rathore and Tanushree Sahoo	236

AGRICULTURAL ENGINEERINGFOR VIKSHIT BHARAT

Dr. S.N. Jha, FIE
DDG, Agricultural Engineering, ICAR and
President, Indian Society of Agricultural Engineers &
Bihar Agriculture Science Academy
Ratindranath Tagore Memorial Lecture

My dear delegates, scientists, engineers, ladies, gentlemen, boys and girls!

It is my great pleasure for the honour given by the Institution of Engineers(India) for this prestigiousmemorial lecture on probably the first Agricultural Engineer of India. It is great opportunity for me to share my personal views developed from my knowledge and by experience to be useful for the Viksit Bharat. It is great because the memorial lecture is for the cause of our profession, for the cause of world's food and nutritional securityand thus for our future generations, who will make our country not only the developed country but will make it once again the greatest country of the world to live in and re-establish it as Vishwa Guru. I thank all of you and especially Er K.P. Tripathi jee for this honor and opportunity!

Dear Friends!The role of Agricultural Engineers in Viksit Bharat shall be of paramount importance, subject to improvement, modernization and up-gradation of education, trainings and research in the fields of Agricultural Engineering. Education is a fundamental right and an essential cornerstone for the development of any nation. In India, the Constitution recognizes education as a fundamental right for all children aged 6 to 14 years under the Right to Education (RTE) Act, 2009. It is the age after that in fact students start thinking and taking advices from their parents and peers for choosing further course of study. Usually whoever considers himself/herself good in study, select science stream, and if they feel themselves good in mathematics even in science stream, go for Engineering stream. The first the best lot therefore chooses to prepare for Engineering stream. However, there may be an exception of selection of subjects based on interest. Among the engineering branches, many go for Computer Engineering, MechanicalEngineering, CivilEngineering, Electrical Engineering, etc. first,then probably they choose Agricultural Engineering. Usual practice of choosing branch of study is based on annual packages and future growth prospects available after B. Tech. study. No doubt,Computer Science and Engineering and some other branches enable to get better annual packages, but simultaneously these are also vulnerable to get out of job very frequently(as we hear laying off of employ by company). Actually the demand of high packaged job is highly unstable and so the job security, whereas situation for Agricultural Engineering will be reverse of those situations.

The demand of Agricultural Engineering as compared to other branches of study is always steady, stable and likely to increase at increasing rate because of labour shortages and increase in demand of food. In fact, you all agree that demand of food shall never become low, so the demand and requirement of good agricultural engineers will also be forever. As far as interest in subject is considered,this is a branch which gives opportunity to study mechanical, civil, electrical, computer and nowadays sensors, automation,

and robotics. Besides they also deal with biological system such as living plants, food grains, fruits & vegetables, greenhouse, post-harvest processing & value additions, fermentations, food quality and safety, environment management, green house structures, animal shelters, aquaculture, fish and meat processing and their well beings, energy etc. So, you name any branch and subject, agricultural engineering gives exposure to all of them to students and they can then choose any specializations based on their interest to excel in future endeavour.

The Agricultural Engineering is the most Versatile and Needed Branch to Study.

Because of the versatility of the Agricultural Engineering, the USA and many European countries have renamed it as Bio systems Engineering. Actually this is the branch of study that deals with both mathematical and biological systems. It therefore can quench the thirst of both biology and mathematics based on students' choices. It can satisfy the students who want to study veterinary or medical sciences as this is the branch which deals with both living and non-living materials throughout its career in one or other form. As far as job and annual packages are concerned, it is always stable and very good for leading a decent life if you work only in core branches of Agricultural Engineering, and for sure there is almost no layoff at all, as in case of computer engineering or any other high packaged job usually we see. If Agricultural Engineers train themselves in software, sensor technology, robotics etc. in the field of Agriculture, sky is the limit for their annual package.

The Agricultural Engineering is also the best branch of study for starting up their own business venture. The scope of business expansion is as large as that of populations living in villages and towns. We have examples of billionaire Agricultural Engineers running their business in India and abroad in almost all fields enumerated above, including management of environment/horticulture etc.to that of IG International Airport terminal 3 (T-3), New Delhi. Greenhouse and environment management for plant science, animal housing and their comforts for better yield etc. are designed, maintained and operated most effectively by the Agricultural Engineers at national and international level.Crux of the thing is that one has to be good, sincere and honest with study and open to learn anything from anywhere. I therefore suggest, in fact, recommend to all young guys to opt Agricultural Engineering while choosing their career asfirst choice to serve the people as food giver and leading a decent and stable post-study life anywhere in this world.

The future role of Agricultural Engineers is much better than that of any discipline of study. Indian Agriculture is now lesson-worthy growth story. It is feeding the world population not by filling stomach only but also providing nutritional and health securities. Four "Cs" Climate changes, Conflict between the nations, and COVID or similar pandemic, and Change in food/lifestyle (unwillingness of youth for doing agriculture in the traditional way) are affecting agriculture adversely. In addition, farmers are ageing and majority of them in India are aged above 40. In 2016, the average age of an Indian farmer was 50.1 years and the next generations of these farmers are not so interested in taking up this profession. The percentage of agricultural workers to total workers therefore declined from 59.1% in 1991 to 39.4% in 2021, of which about 45 % or more are women, and the same is likely to be about 30% with women share of 65 % in very recent time. The draft animals are also getting

invisible slowly from the Indian farms. These data indicate that we are approaching a situation where one of the biggest consumers of food may be left with only a few farmers. Maintaining production and productivity therefore may be a big challenge. But, according to a study report got conducted by the Department of Agriculture and Farmers' Welfare, Govt. of India, mechanization, which is an essential part of precision agriculture, saves 15 - 20 % seeds &fertilizers and 20-30 % time, increases germination by about 25 %, reduces weeds and labour about 20-40 % and enhances cropping intensity by 5-10 %, and yield 13 -23 %. This means mechanization is a sure shot way to mitigate these challenges; or we can say the mechanization is now a compulsion for the Indian Agriculture and in Viksit Bharat; mechatronics and robotics led automation will be in the centre stage of Agriculture.

In other side of development story, increasing demand for industrialization, urbanization, housing and infrastructure is forcing conversion of agricultural land to non-agricultural uses. Farm holding size is further reducing and thus mechanizing small and non-contiguous group of small farms is becoming against 'economies of scale' for individual ownership of farm machinery. With continued shrinkage in average farm size, more farms will fall into the adverse category thereby making individual ownership of agricultural machinery progressively more uneconomical. There is however a strong correlation between the farm power availability and productivity. The estimated farm power requirement by 2047 is about 7.5 kW/ha to assure timeliness and quality in the field operations. The present overall farm mechanization level of the country is about 47% which is lower than that of other developing countries such as China (59.5%) and Brazil (75%). The country aims to become developed nation by 2047, therefore, at least 75% level of mechanization is needed.The role of Agricultural Engineers will be invaluable than any other discipline of Agriculture.

Mechanized solutions equipped with sensors, AI and robotics suitable for small farms are being developed for the purpose and thus the Agricultural Engineering education need to be included these fields. India has emerged though a net exporter of farm machinery including tractor recently but the country need attention to increase marketing, export of small farm machinery, tools and machines to penetrate more among small farmers, which is highly scattered and unavailable in majority of the states. For increasing mechanization levels to maintain and/or increase the production and productivity, there are many other issues and all needs some policy interventions. Considering all these, the 58th Parliamentary Standing Committee on Agriculture, Animal Husbandry and Food Processing (2022-23) has recommended to establish Directorate/ Department of Agricultural Engineering in each state and has assigned target to achieve a farm mechanization level of 75% by 2047 or before from the present level of 47%.

Presently India accounts for only about 2.4% of the world's geographical area, but has to support about 17% of the world's human and 15% of the livestock populations. Agriculture is an important sector of the Indian economy, accounting for about 18 % of the nation's GDP during 2022-23. Agriculture in India is currently growing at an average compound annual growth rate (CAGR) of about 2.8% and about 45 % of population relies on agriculture as its principal source of income. Accelerating the growth of agriculture production is therefore necessary not only to meet the rising demand for food, but also to

increase income of those dependent on agriculture and thereby ensure inclusiveness in our society and that to be achieved in accelerated rate through education and extension of Agricultural Engineering technologies through deployment of Agricultural Engineers at Panchayat and block level.

Economic growth in Indian agricultural sector lags behind growth in industry and services, creating an ever widening rural-urban income gap. The production and productivity in Indian agriculture cannot be enhanced by primitive and traditional practices of farming. Agricultural mechanization plays a key role in improving agricultural production and productivity in developing counties. Increasing demand for industrialization, urbanization, housing and infrastructure is forcing conversion of agricultural land to non-agricultural uses. The scope for expansion of the area available for cultivation is limited. As per agriculture census 2015-16, small and marginal holdings of less than 2hectare account for 86% of the total operational holdings and 47% of the total operated area. The average size of holding for all operational classes (small and marginal, medium and large) have declined over the years and has come down to 1.08 hectare in 2015-16 from 2.82 hectare in 1970-71. With continued shrinkage in average farm size, more farms will fall into the adverse category thereby making individual ownership of agricultural machinery progressively more uneconomical and thus research and development of small and tiny equipment's demand in future agriculture further indicates the requirement of modern agricultural education.

The status of farm mechanization in India is analysed by the trend in growth of mechanically power-operated farm equipment over traditional human and animal power operated equipment. It was observed that there was a direct correlation between farm power availability and productivity during the past six decades. Haryana state of India has the highest tractor density per thousand hectares of net sown area of 96 tractors and followed by 79 tractors for Punjab against all India average of 43 tractors. The sale of paddy transplanter, power weeder, combine harvesters, rotavator and thresher in India is growing at a compound annual growth rate (CAGR) of 50, 50, 28, 20 and 10%, respectively. Seed drills, seed-cum-fertilizer drills, sprayers, dusters, harvesters of crops like pulses, horticulture crops/fruits however are picking up at snails' speeds. The availability of labour to work in agriculture is crucial in sustaining agricultural production. The population dynamics of Indian agricultural workers shows that by 2030, the population of agricultural workers in the country will be about 230 million of which 45% will be the female workers. The combined share of agricultural workers and draught animals in total farm power availability in India reduced from 60.8% in 1971-72 to 8% in 2020-21. It is predicted that the population in rural areas will decrease to 62.83% in 2025 and to 44.83% in 2050. This will further necessitate for agricultural mechanization in a manner that is inclusive and suitable for Indian conditions. The average farm power availability has been steadily increasing and estimated to be 3.03 kW/ha in year 2025.

The farm mechanization levels assessed for major cereals, pulses, oil-seeds, millets and cash indicates that the seedbed preparation operation is highly mechanized (more than 70%) for major crops whereas harvesting and threshing operation is the least mechanized (lower than 32%) for major crops except for rice and wheat. In seedbed preparation, mechanization level is higher in rice and wheat crops as compared to

other ones. However, mechanization level for sowing operation is the highest for wheat crop (65%). The mechanization levels in planting/transplanting operation for sugarcane and rice crops are only 20 and 30%, respectively. In case of harvesting and threshing, the mechanization levels in rice and wheat crops are more than 60% and there is no mechanization in cotton crop. The overall farm mechanization levels for rice, wheat, maize, sorghum and millets, pulses, oil-seeds, cotton and sugarcane crops are 50, 69, 45, 33, 41, 38, 35 and, 33%, respectively. The overall farm mechanization level of the country is 47% which is lower than other developing countries such as China (59.5%) and Brazil (75%).

Global trend in mechanization is towards use of precision farming techniques using sensors, AI and robotics, where GPSs are being utilized and variable rate applicators being used that monitor levels of nutrients and soil moisture and actuate the applicator for delivery. Countries like China, Japan and Korea that favoured walking/riding type power tillers and matching equipment are moving towards 4-wheel tractors and matching equipment and self-propelled machinery with automation. Quality of farm implements and machines are being improved, designs are being standardized and critical components in conformity with ISO standards. Mechanized nursery raising, transplanting, vegetable and fruit harvesters are in use employing colour sensors. Fruit and vegetable handling in vogue avoids mechanical injury, harvest is washed, graded, dried, waxed and packed on packaging lines. Farm power availability is high but specific energy consumption per unit area and produce is low because of very high productivity which makes them more competitive. Fruits and vegetables are handled through cold chain, cold stored, or stored in controlled atmosphere storage. Food grain crops are combine harvested and stored in RCC silos and steel bins. Resultant combined losses are low. Maize is harvested by corn pickers or combine harvested. Fodder crops are harvested and chopped, loaded in trolleys for feeding and ensilaging. Cotton pickers and strippers are widely used. Sugarcane harvesters are there that harvest row sown cane, strip and cut into billets and load in trailers or trucks for delivery to the sugar mills. India is also marching towards R&D and promotion of equipment in the similar direction to become a mechanized country. There are many issues pertaining to increasing the level of mechanization in the country and reduce the disparity among states, like MP and Tamil Nadu have done better in overall mechanization level, while majority of states are lagging behind, despite having power availability with good number of tractors available. The present mechanization level is more towards tracterization than use of other farm machinery. This needs to be addressed with proper policy intervention and prioritization in research and education in the field of Agricultural Engineering.

The majority of farm machinery manufacturing of the country is in form of small scale industries. These small-scale manufacturing lacks standardization in design, quality manufacturing, lack of trained manpower, concerns on further product improvement, etc. Manufacturing of sensor-based equipment and its promotion is also a major concern. Farm machinery is a capital-intensive enterprise and requires a sizable investment to procure and operate the machine in the field. Inclusion of standardization, decarbonisation and art of handholding at both manufacturing premises and at farms in Agricultural Engineering education is the need of hour.

There are several requirements on

continuous basis a for achieving the target of 75 % mechanization in the Indian Agriculture by 2047. Several action plans are in footing and thus to fulfil the requirements of the Agriculture Engineers with knowledge of modern technologies are immense. Circular bio-economy and transformation of agri-food-systems in the context of current global situations, climate change, change in food habits and life style, and priority of government to reduce imports, Agricultural Engineering education and delivery system needs to address the followings for Viksit Bharat:

i) Quality input of human resources right from the UG admission.

ii) Design of agricultural engineering courses, including applications of AI& ML in all segments of Agricultural Engineering with a special focus on precision agriculture. Augmented Reality (AR) and Virtual Reality (VR) must be encouraged as learning tools in UG/PG teaching.

iii) Offer more elective courses that match industry demands and engage agricultural engineering students with the industry throughout the years. Industry personnel and other stakeholders should be consulted and input taken while revising the syllabus.

iv) Encourage the students to select the industry-sponsored research projects and internship in Industry only.

v) National Institute of Agricultural Robotics & Al needs to be established in the NAREE system to fulfil the need of the next-gen digital Agriculture, indigenously.

vi) Digital agriculture, machine learning, deep learning, drone technology, Al, IoT, software development, apps developments, bio-informatics, statistics/modelling are purely engineering subjects and could be better implemented by engineering education, and therefore institutions/ICAR/SAUs should bring these activities/projects and developmental work under Agricultural Engineering.

To see the impact of education at delivery level following action points is needed on priority:

- Governments/academic institutions should come with a policy paper having well defined strategy to accelerate mechanization and achieve the targets of 75% level by 2047.
- Starting an independent scheme at centre and state levels exclusively for mechanization including on-farm postharvest operations.
- Setting-up departments/Directorate of Agricultural Engineering comprising, on-farm mechanization including on-farm post-harvest processing, value addition, farm irrigation and drainage (including micro irrigation) at state and centre levels.
- Recruitment of Agricultural Engineers/Diploma holders compulsorily at least one in each village, panchayat, block and districts level, besides one at each KVK to make links with field engineers/technicians for new technologies/machines developed.
- Establishment of common repairs, maintenance and service centres at village level.
- Starting of B. Tech. and diploma in Agricultural Engineering in all SAUs and IITs/NITs to have sufficient trained graduates to fulfil the requirement.

- Establishment of at least one Farm Machinery and Post-harvest machinery testing centre in each state/district level.
- Incentive-linked scheme for localized manufacturing of quality machinery and equipment.
- Organizing awareness programme on benefit of proper utilization of proper machinery/equipment.
- Micro-foods/engineered food manufacturing using machine such as 3D food printing, extraction technologies.
- Use of robots/cobots for specific farm operations/domestic helps are in very near future and thus future of Agricultural Engineering education must address the same.
- Education on soil water plant and environment relationship and modelling for mitigating climate change on crop yield.
- Climate resilience index of variety developed, their corresponding contingency plan development and training in future agriculture is the need of the hour.
- Energy from and in agriculture, renewable energy, storage (re-chargeable battery development) need priority attention in Agricultural Energy Engineering Education and training for future self-reliance of the country.
- Industrial Agricultural Research and Education may be thought of across all discipline of agriculture.

The role of Agricultural Engineering in Viksit Bharat will be of more importance than ever before, as this is the profession that can provide, speed, scale, safety, security (of food & nutrition) and sense of doing high quality job. Students, teachers, field engineers, scientists and policy makers however have to be very honest in their endeavour to provide much needed space, support and assignment of right job to right profession at right time.

Jai Hind!

RECENT ADVANCEMENTS IN FARM MECHANIZATION WITH A FOCUS ON DRONE TECHNOLOGY IN AGRICULTURAL ENGINEERING: A TOOL FOR CROP PRODUCTION IN VIKSIT BHARAT

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Introduction

As the global population continues to grow and the demand for food rises, the agricultural sector faces the challenge of increasing productivity while minimizing resource consumption. In India, a country with a significant agrarian economy, the need to enhance farming practices is of paramount importance. The innovative technologies such as farm mechanization, drones, and robotics have potential to revolutionize farming practices in India. Like other economic sectors, agriculture is increasingly affected by the digital revolution. The use of advanced technologies results in precise matching of agricultural inputs with needs and thus significantly increases profitability. By using technology as a sustainable and scalable resource, agriculture of the country can be taken to new heights, keeping farm to fork in our future. In July, 2021, Honourable Prime Minister addressed chiefs of top 100 technological institutes emphasized that inventions and innovations in agriculture are very important. Agriculture was listed among key sectors like Defence, Education, Health, and climate change and cyber security. He also urged scientists to provide solutions to various issues in agriculture through modern biotechnology, artificial intelligence, block chain technology and drone technology to counter issues like hunger, poverty and malnutrition. Future agriculture will be led by knowledge, technology innovation and skill. In fact, mechanization and automation in agriculture has been one of the top 20 inventions of 20th century in the world. Traditional farming practices often rely on manual labour and outdate methods, leading to inefficiencies, resource wastage, and yield variability. The integration of advanced technologies like mechanization, drones, and robotics holds the promise of addressing these challenges and propelling Indian agriculture towards greater productivity and sustainability.

Innovations in Farm Mechanization

Agriculture mechanisation is essential for modernising and commercialising the sector since it boosts efficiency and productivity in agricultural operations, supports value addition, lowers cultivation costs, and facilitates adaptation to climate change. In India, agricultural mechanisation is anticipated to expand quickly in light of national driving factors in relation to global driving forces. Therefore, there is no question that mechanisation needs to be improved in order to increase agricultural productivity and stabilise the economy. In light of the existing demand, modern agricultural machinery has enabled farmers to finish seed-to-seed tasks as quickly as possible and even free up equipment for special-order hiring by neighbours. However, farm mechanisation in India, at 40-45%, remains low compared to the rest of the world; in the US it is 95%, Brazil 75%, and China 57%. Despite low levels of farm mechanization in India, skills shortages and a lack of awareness among farmers about technology and machinery management pose significant obstacles to progress. A strong focus on integrating science and technology into farm mechanisation would open up new avenues for opportunity and accelerate the development of agricultural mechanisation toward Mechanisation 2.0, which

combines automation with the farm mechanisation. The mechanization industry in India has a lot of potential to grow and can play a crucial role in improving the productivity and efficiency of the agriculture sector. The Farm Machinery Industry is an industry sector that produces and supplies a range of machinery, equipment, and tools used in agriculture and farming activities such as ploughing, planting, harvesting, and more. These machines are designed to improve productivity and efficiency in farming operations, and the industry encompasses both small-scale and large-scale farming equipment. However, the industry faces a lot of challenges such as high cost of machinery, lack of awareness, lack of credit facilities, and poor infrastructure. The government, the mechanization industry, and other stakeholders need to work together to overcome these challenges and promote mechanization in agriculture. Following are some of the key interventions for bringing innovations in agricultural mechanization of the country.

- Mapping dynamic changes in agri practices and design agri equipment for all operations.
- Manufacturing operator friendly equipment to minimise farmer anxiety (fear of operator skill requirements).
- Assuring quality and durability of equipment to ensure 'Lower Cost of Ownership' in longer run.
- Developing 'Responsible & Accountable' Service Network.
- Ensuring clusters of eco-system for quick availability of genuine spares parts.
- Tractor industry has about 15000 Dealerships across the country. Leveraging this strong network for 'effective penetration' of agri equipment. These Dealerships to be used as 'Knowledge Spring-Boards' to 'Educate & Demonstrate' the advanced agri equipment.
- Agro chemical manufacturers should engage in 'contractual collaboration' with farmers making advanced crop care equipment available at farmer's doorstep to complete all crop care applications without human intervention.
- The government, SAUs, and corporate sectors can conduct awareness campaigns to educate farmers about the benefits of mechanization. This will help in increasing the demand for machinery and will also create a market for the mechanization industry.
- Tractor training centres, KVKs, and industry should be made responsible for training young farmers / owners / operators on how to select, operate and service farm machinery. They should also provide information on developments in mechanisation including the availability of new and better farm equipment for different applications.
- Front-line demonstration of farm machinery should be strengthened and handheld training to users of new generation farm machinery may encourage the extension and adoption of farm power.
- The Agricultural Skills Council of India should work at the district level to address skills shortages on the demand side.
- The collaborative efforts between government institutes, private companies and farmers groups are necessary to boost the agricultural mechanization. The Custom Hiring Centres of farm machinery may be especially useful, and Indian Council of Agricultural Research (ICAR) institutes and SAUs can offer short courses that address skills shortages on the demand side.

Climate smart agriculture through innovative water and energy saving interventions

Managing sustainable food production with judicious use of water, energy and land has become a matter of global concern due to environmental security under changing climate.Rainfed agriculture is crucial to the country's economy and food security.

In 2022-23, of the 141 million hectares of gross sown area in the country, nearly 73 million hectares, or 52%, had irrigation access, up from 41% in 2016, according to updated data from Niti Aayog.Climate-smart agriculture emphasizes the sustainable management of resources to adapt to climate change while enhancing productivity. Innovative water and energy-saving interventions, such as farm ponds, advanced irrigation techniques, and automation, play a crucial role in ensuring climate resilience. Farm ponds serve as on-farm water reservoirs, reducing dependency on erratic rainfall and supporting irrigation needs during dry periods.

The VNMKV, Parbhani has developed 56 farm implements, both animal and tractors drawn, for different operations. An innovative farming techniques like Broad Bed Furrow (BBF) serves the purpose of in-situ moisture conservation as well as drainage channel if excess water is found apart from providing proper aeration in the seedbed and root zone. Mechanization contributes more in conservation agriculture because of timeliness in farm operations. VNMKV developed multipurpose Broad Bed Furrow (BBF) planter for rainfed agriculture accomplishes bed making, sowing and fertilizer application, seed covering and weedicide application in one go. The newly developed five row BBF planter with sprayer and seed covering device can be recommended for cultivation of soybean, red gram, cotton, maize, sorghum under dryland agriculture.

Machinery powered by non-conventional energy sources are now-a-days also gaining importance looking into the excessive use of fossil fuels and their rising cost as well as harmful emissions. Non-conventional energy sources need to supplement the fossil fuels due to their reliability and sustainability. India is endowed with vast solar energy potential. About 5,000 trillion kWh per year energy is incident over India's land area with most parts receiving 4-7 kWh per sq. m per day. Solar photovoltaic power can effectively be harnessed providing huge scalability in India. Off-grid decentralized and low-temperature applications will be advantageous from a rural application. VNMKV developed multipurpose solar energy cart which supplies power to spraying unit, DC pump and lighting system. The spray boom could be oriented either in horizontal or inverted L shape for spraying row crops of different heights as per need. Such innovative technological solutions using alternate sources are energy need a major focus for eco-friendly crop cultivation.

Furthermore, the University's efforts in water conservation have led to the construction of more than 30,000 farm ponds across Maharashtra, as per recommended designed of VNMKV's specification. The VNMKV, Parbhani, has brought more than 2,500 acres of barren land under breeder seed production. Special efforts have been made to mechanize the seed and research farms of the University and adopted seed-to-seed mechanization. Last year, the University doubled its breeder seed production. VNMKV has constructed six large farm ponds with a total capacity of 9 crore litres to provide supplementary and protective irrigation for breeder seed production and has set a target to construct additional farm ponds with a total capacity of up to 26 crore litres on wasteland.

Advanced irrigation techniques like drip and micro-sprinkler systems minimize water wastage while maximizing efficiency. Automation in irrigation scheduling, driven by AI and sensor-based technologies, ensures optimal water application based on real-time crop requirements. These innovations contribute to sustainable agricultural practices, conserving essential resources and mitigating the impact of climate change on farming.



Plate 1: bbf planter developed by vnmkv, parbhani



Plate 2:Multipurpose Solar Energy Cart

AgriPVfor energy smart agriculture

Agri-Photovoltaics (AgriPV) is an innovative approach that integrates solar energy generation with agricultural production, promoting dual land use for sustainability. By strategically placing photovoltaic (PV) panels over farmland, AgriPV enables farmers to harvest solar power while cultivating crops, ensuring efficient resource utilization. This technology not only enhances energy security and reduces carbon emissions but also provides shade, reducing water evaporation and improving crop resilience to extreme weather. As India moves towards sustainable farming practices, AgriPV emerges as a promising solution for balancing food production and renewable energy generation.VNMKV, Parbhani signed a MoU with the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH (Germany) for collaborative R & D of Agricultural Photovoltaic (AgriPV) technology. The goal of the research is to devise executable crop cultivation strategies for the selected crops under the different Agrivoltaicstructures that would benefit from the environment created by the solar panels to generate higher yields or higher revenues via shifting the timing of production to off season cycles.



Plate 3: AgriPV Research Project site at Manwat, Dist. Parbhani (GIZ + VNMKV)

Digitalization in Agriculture

Digital Agriculture leverages the smart use of data and generally involves the processes of data creation and analysis, decision making, and implementation through management interventions. These processes are becoming increasingly computational, data-intensive, real-time, and precise. The main Digital Agriculture tools that exist today include cross cutting technologies such as sensors and controllers and computational decision tools. Field-based activities are also enabled by technologies such as geo-locationing, communication (cellular, broadband, and others), geographical information systems (GIS), yield monitors, precision soil sampling, proximal and remote sensing, unmanned aerial vehicles, variable rate technologies and auto-steer, guidance, and robotics. With the country achieving sufficiency in food production, there is an immediate need for the agricultural sector to adopt cutting edge digital and precision agriculture technologies to improve input use efficiency and enhance farmers' profitability by increasing productivity, reducing cost of cultivation and adding value to farm produce. The digital revolution has introduced several emerging technologies that enhance precision and decision-making in agriculture:

- Sensors and IoT: Internet of Things (IoT) devices and sensors monitor soil moisture, temperature, humidity, and crop health, enabling real-time farm management.
- Drones: Agricultural drones assist in precision spraying, crop monitoring, and disease detection, reducing input costs and improving yields.
- Robotics and AI: Robots are used for planting, weeding, and harvesting, while Artificial Intelligence (AI) and Machine Learning (ML) analyze farm data to optimize agricultural practices.The VNMKV has two grafting robots for automated plant grafting. These robots enhance precision and efficiency in grafting operations.
- Machine Learning (ML): Predictive analytics based on ML help farmers in weather forecasting, pest management, and yield prediction.

VNMKV, Parbhani has actively engaged in research and training on digital agriculture, including the use of drones for precision farming.

Future Farming through Drone Technology

Drone is one such technology that has the potential to revolutionise the farming industry through need-based precise and variable input application leading to input saving, timeliness, reduction in cultivation cost and ensuring farmers' safety from direct exposure to chemicals. Drones have proven to be among the most promising technologies emerging from the fourth industrial revolution. Drones can be used for targeted input application, timely diagnosis of nutrient deficiency, crop health monitoring, rapid assessment of crop yield and crop losses. The drones have capability to fly at low height (1m-3 m) over the crop canopy. This makes them suitable for spraying of crop protection chemicals as well as nutrients and is more adoptable compared to aerial spray. Unlike ground spraying, spraying through drones can be carried out when field conditions prevent movement of wheeled vehicles. It enables the timeliness of spray treatments without inflicting soil compaction.

Science led policy on Standard Operating Procedures (SOPs) for Drone Use in Agriculture

The Ministry of Agriculture and Farmers Welfare, Government of India, constituted six national-level committees to develop standard guidelines

and Standard Operating Procedures (SOPs) for various applications of drone technology in Agriculture. The work of the first five committees has been completed, and the final draft report of the sixth committee has been submitted (Table 1).

Table 1: Different National-Level Committees Appointed by the Ministry of Agriculture & Farmers Welfare (Govt.of India) for the Development of SOPs for Drone Use in Agriculture

Sr. No.	Work of the Committee	Chairman / Convenor of the Committee
1	Committee for development of standard guidelines for operation of drone for pesticide application	**Chairman :**Dr. K Alagusundaram, DDG (Engg.) ICAR, New Delhi **Convenor :** Dr. Indra Mani, Head, Division of Agril. Engg., IARI
2	Committee for drafting of SOP for spraying soil and crop nutrients by using drones	**Chairman :** Dr. Indra Mani, Head, Division of Agril. Engg, IARI
3	Committee for drafting of SOP for applying pesticides for Crop protection by using drone	**Chairman :** Dr Ravi Prakash, Plant Protection Adviser, CIB&RC,Faridabad
4	Committee for drafting of Crop Specific SOPs for application of pesticides with drones	**Chairman :** Dr. Indra Mani, Head, Division of Agril. Engg., IARI
5	Committee for drafting of Crop Specific SOPs for Application of various forms of soil and plant nutrients with drones	**Chairman:** Dr. Indra Mani, Vice-Chancellor VNMKV Parbhani
6	Committee to exploring the use of drones for various activities in agricultu re other than spraying of pesticides & liquid fertilizers	**Chairman :** Dr. Indra Mani, Vice-Chancellor, VNMKV, Parbhani

The first committee chaired by Dr. K. Alagusundaram, Deputy Director General (Agricultural Engineering) at ICAR, and convened by Dr. Indra Mani, Head of the Division of Agricultural Engineering at the Indian Agricultural Research Institute (IARI), this committee developed comprehensive guidelines for the safe, efficient, and environmentally friendly use of drones for pesticide application.

The second committee, chaired by Dr. Indra Mani, focused on drafting SOPs for spraying soil and crop nutrients using drones. It covered aspects such as dosage, application methods, and safety protocols to optimize nutrient management with drones. The Ministry released the Generic SOP for crop spraying with pesticides and nutrients in 2022.

The third committee, chaired by Dr. Ravi Prakash, Plant Protection Adviser at the Central Insecticides Board & Registration Committee (CIB&RC) in Faridabad, developed SOPs for applying crop protection products using drones. This committee developed detailed procedures for drone operation, pesticide application techniques, and safety measures to ensure effective and safe crop protection.

The fourth committee, chaired by Dr. Indra Mani, developed Standard Operating Procedures (SOPs) for the application of pesticides using drones for ten selected crops: rice, maize, cotton, groundnut, pigeon pea, safflower, sesame, soybean, sugarcane, and wheat. These crop-specific SOPs, released by the Ministry in 2023, aims to tailor pesticide application processes to the specific needs of different crops, thereby enhancing pest management's effectiveness and

efficiency.

The fifth committee, chaired by Dr. Indra Mani, on the Use of Drones in Various Agricultural Activities other than Spraying Pesticides and Liquid Fertilizers recently submitted its final report to the Ministry of Agriculture and Farmers Welfare, Government of India.

The crop-specific SOPs were formulated for the application of various pesticides and fungicides via drones, focusing on several key parameters: drone parameters (such as flying speed and height above the crop canopy), sprayer parameters (including nozzle and swath characteristics), crop parameters (such as canopy volume, growth stages, water volume per hectare, pesticide concentration and dosage, and optimal spraying times), and weather conditions (temperature, humidity, and wind speed) tailored to specific locations and climatic zones. Emphasis was placed on achieving optimal bio-efficacy and avoiding phytotoxicity.

VNMKV promote Digital Technology

The University has taken a leading role in promoting the use of digital technology in agriculture, focusing on innovation such as drones, robots, and sensor technology. The VNMKV, Parbhani has singed MoUs with national and international reputed institutes and companies for agricultural research and capacity building regarding advance mechanization viz., Kansas State University, University of Florida, Washington State University, MoU with Rajiv Gandhi Science & Technology Commission, TAFE, CNH (India) Industrial Pvt Ltd, ISRO-SAC, Ahemadabad, CIPHET, Ludhiana, IISR, Lucknow etc.



Plate4: Drone Spraying Demonstration on Farmer's Field by VNMKV, Parbhani

VNMKV's initiative to foster the use of drone technology

A six month professional Agri Drone Course has been started by the University, specifically designed to foster skills and entrepreneurship among agricultural graduates, farmers and rural youth. In addition, the university has established a Custom Hiring Centre to provide drone services for insecticide spraying to farmers at a reasonable price. Furthermore, it has collaborated with the drone industry to set up Remote Pilot Training Organization (RPTO) Centre, offering training and drone pilot license facility. A Centre of Excellence (CoE) in Digital and Sustainable Agriculture has been sanctioned from the Dept of Science and Technology, Govt. of India.

Conclusion

Innovations in mechanization, drones, and robotics are set to revolutionize Indian agriculture by transforming traditional farming practices into a modern, efficient, and sustainable system. These technologies enhance productivity, resource efficiency, and climate resilience, addressing key challenges faced by farmers. The rapid advancements in digital tools, automation, and precision farming will not only improve agricultural outputs but also attract young professionals, startups, NGOs, and FPOs to the sector, fostering an environment of entrepreneurship and innovation.The integration of advance engineering and technology in agriculture is crucial for achieving sustainability, food security, and economic growth. With strong collaboration among policymakers, researchers, and industry stakeholders, India is making significant strides in agricultural modernization. Coupled with vibrant industry participation and supportive government policies, mechanization and automation are poised to drive India towards the vision of Viksit Bharat @ 2047, ensuring a resilient, productive, and technologically empowered agricultural sector.

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Policy Environment and Farm Engineering for Viksit Bharat Agriculture @ 2047

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The Vision for Agriculture

Viksit Bharat @2047 envisions a developed India by 2047, and agriculture is a key sector in this vision. The plan emphasizes sustainable practices, technological advancements, and increased farmer incomes. Key strategies include enhancing productivity, ensuring food security, promoting climate resilience, and diversifying into high-value agriculture.

In essence "Viksit Bharat @ 2047" envisions a modern, sustainable, and prosperous agricultural sector that contributes to India's overall development by ensuring food security, improving farmer livelihoods, and promoting environmental sustainability.

This is a broader vision which also states broader interventions and their sub-areas. No quantified target in a time-frame has been given. Scientists, engineers, policy makers, need to deliberate the achievable targets on a reasonable time-frame to achieve the cherished goal. In this exercise agricultural engineers have a special role to carve out achievable targets on a reasonable time-frame. Once this exercise of identifying domain/area or sub-area of interventions is decided with achievable target and time, the process of innovation or innovative approach is likely to achieve some targets faster, and with less investment.

Agricultural engineers played a pivotal role in ensuring India's food security since green revolution. However, today's agriculture needs reduction in cost of production, precise application of inputs and resources, value addition, as also risk management by using digital technologies. Today's Indian agriculture is facing serious challenges such as weather extremities, diminishing natural resources, shortage of farm workers, and decreasing farmers income.

Overall, the Viksit Bharat @2047 vision for agriculture aims to transform the sector into a modern, sustainable, and prosperous engine for national development. By empowering technology, promoting sustainable practices, and empowering farmers, India can achieve food security, improve rural livelihoods, and contribute to a developed nation by 2047.

Detailed look at the vision for agriculture in Viksit Bharat @ 2047- Key Goals and Strategies:

1. Sustainable Agriculture

Promoting eco-friendly practices, such as efficient irrigation, water conservation, and reduced use of chemical inputs, to ensure long-term productivity and environmental sustainability

2. Technological Advancements

Integrating technologies like precision farming, IoT, AI, and data analytics to enhance efficiency, productivity, and resource management.

3. Farmer empowerment

Focusing on increasing farmer's incomes through better market access, financial inclusion, and access to technology and information

4. Value Addition and Processing

Encouraging the development of the food processing industry to add value to agricultural

products and create more jobs.

5. Infrastructure Development

Investing in rural infrastructure, including irrigation, cold storage, and transportation, to improve supply chain efficiency.

6. Climate Resilience

Developing climate-smart agricultural practices to mitigate the impact of climate change and ensure food security and development, and strengthening agricultural institutions.

Specific initiatives include:

1. Micro-irrigation

Promoting efficient irrigation techniques like drip and sprinkler irrigation to optimize water use and improve crop yields.

2. Agri-tech startups

Encouraging the growth of agri-tech startups to develop innovative solutions for various agricultural challenges

3. Farmer Producer Organizations (FPOs)

Strengthening FPOs to enable farmers to collectively bargain, access markets, and adopt new technologies.

4. Digital platforms

Utilizing digital platforms to provide farmers with real-time information on market prices, weather patterns, and best practices

5. Skill development

Providing farmers with training and skill development programs to enhance their knowledge and adoption of modern technologies

Present Status

There is no standard definition of a developed economy. However, World Bank categorizes economies based on per capita annual Gross National Income (GNI). These are: i) low income (up to USD1135), ii) lower middle (1136-4465 USD), iii) upper middle (4466-13845 USD), and,iv) higher income (more than 13,845 USD). India, with a per capita GNI of USD 2390 in 2022 is a lower middle-income economy by this classification. India which is world's 4th largest economy with a GDP of about Rs 3.5 lakh crores is currently classified as a developing country. With average farm holding size of 1.08 ha, the contribution to national GDP is about 18%. This contribution to GDP is low as compared to 4-5 decades back. However, it needs to be understood that this decline is relative while comparing to growth in some other sectors. In absolute terms of economy, it has been on the increase.

Can Science/Research Alone Sustain Ground Water Recharge?

India, the largest user of groundwater in the world, supports approximately 60 percent of irrigated agriculture and more than 80 percent of rural and urban water supplies. Ground water allows the users more control over quantity and timing of supply, and therefore, its use is linked with higher productivity. For example, the crop water productivity of ground water-irrigated farms is almost twice that of surface water irrigated farms. In many cases, uses of groundwater are also a response to poor service delivery of surface water systems, as in urban water supply.

India is witnessing a continuous fall in ground water level for couple of decades. Various technological interventions have not been able to stop or even sustain the ground water level. The scenario is same in both contexts i.e. rural (for agriculture) an urban (for water supply). An analytical approach reveals that despite several interventions the ground water over exploitation exceeds ground water recharge by all means

(natural and technological). Hence it is pertinent to understand that as long as over exploitation (over pumping) continues to be more than recharge the water level will keep going down and down. Since each technology has a technological limit, some policy interventions to reduce over exploitation are immediately called for both contexts i.e. rural and urban.

The scientific community needs to suggest implementable policy interventions to the policy makers at appropriate level to address the issue. This would require an in-depth analysis before making a strong case for suggested interventions. It would require policy interventions to regulate pumping of ground water aimed at maintaining a minimum thresh hold level.

Faster, More Intense, More Devastating Impacts: New IPCC Report lays out Scientific Basis of Climate Emergency

The Intergovernmental Panel on Climate Change (IPCC) released a new report, Climate Change 2021: the Physical Science Basis, which brings together the most recent advances in climate science to outline the current state of climate change. The results are grave.

The opening line of the report's Summary for Policy makers reads: "It is unequivocal that human influence has warmed the atmosphere, ocean, and land. Approved by 195 national governments, the report shows rapid human-induced change that is occurring in our climate. "We now have a much clearer picture of past, present and future climate, which is essential for understanding where we are headed, what can be done, and how we can prepare". Extreme weather events, from wild fires across North America and Southern Europe to extreme flooding in China and Western Europe, and devastating tropical cyclones on the Indian and Atlantic coasts, show the real-life consequences of a climate that has already warmed by 1.1OCsince the mid-1800s.

According to the summary for policymakers, urbanization increases heavy precipitation over cities, and coastal cities will continue to see exacerbated flooding both from sea level rise and "extreme rainfall/river flow events". Cities and urban centres are also warmer than surrounding areas-often due to lack of natural cooling influences such as water and vegetation, according to the IPCC fact sheet on urban areas.

Water Audit for Industries

The Central Ground Water Authority (CGWA), Ministry of JalShakit, Govt. of India notification dated 23.03.2023 mandates water audit compliance for industries operating in safe, semi-critical, and critical ground water assessment zones that extract more than 1 lakh/day of ground water. Industries are also required to reduce ground water use by 20% over next three years through appropriate processes or technologies. This will require strict monitoring and surprise checks, by appropriate authorities to oversee its implementation.

Circular Economy

It is an alternative to traditional linear economies, where we take resources, make things, consume them ad throw them away. This way of living uses finite raw materials, resulting in shortage/non-availability of such resources.

In a circular economy, products are used again and again, which reduces our use of precious raw materials, cuts wastes and CO2 emissions. Products are kept in use for as long as possible, through repairing: recycling and redesign-so they can be used again and again.

The way we live now is using about 60% more resources than the earth can provide, and creating too much waste, according to experts.

Switching to a circular economy is widely considered to be the way forward.

Present Scenario with Regard to Secondary Agriculture

Globally, many such examples are available where the by-product/co-product yields more value/profitas compared to the main product for which the crop was supposedly grown. For enhancing value and profitability of agriculture, following need to be addressed:

Bringing organized industry to rural areas to boost non-farm rural economy,ii) Developing technology backed circular economy through higher value addition.In a sustainable domain of all-inclusive agriculture, attention is required for both primary and secondary(higher) agriculture.Estimated figures (Mt) for biomass of a few select major crops available (2020-21) for higher processingare rice straw (91.58), wheat straw (61.42), Maize straw (21.47), pigeon pea hulls (0.44), soya meal(7.31), guar gum (0.26), citrus peel (1.37), tomato processing by-products (1.65), whey (1.65), buttermilk (6.61), and many more. Some high value products can be produced such as ethanol, enzymes,cellulose, germ oil, particle boards, animal feed, protein isolate, guar gum derivatives, flavonoids, peel oil, protein hydro lysates, mannitol etc.

Suggestive sectors and crops/agri-bio-resources to work on, during next about 5 years

1. Organized industry wastes from fruits and vegetables processing. Many fruitsand vegetablesare processed by industries for pulp, juice etc. A good number of wastes are not used; someare underused and yet some thrown away. Few examples for fruits and vegetable processingindustries are cited: apple, oranges, kinnow, pineapple, custard apple, litchi, guava, pomegranate,mango, tomato, potato, peas etc. Wastes from these industries can be easily collected as rawmaterial/agri-bio-resource for higher level of processing. It is further suggested that we could

decide to process one or more fruits and vegetables' wastes available in a city through a model andpolicy for city-based fruits and vegetables' wastes together with deteriorated fruits and vegetablesfor higher processing to useful product.

2. By-products such as cakes/meals of edible oil sector such as groundnut, coconut, mustard,sunflower, cotton, castor, linseed, neem, kusum, karanj, mahua, oil palm, mango kernel, cashewnut shell liquid etc. besides guar gum, gum meal is a huge sector. The wastes/agri-bio-resourcesfrom these industries are either used as cattle feed, manure or underused for some other purposes.The agri-bio-resources from these industries/expellers are a good source of several high value

products. This needs to be taken up.

3. The minor forest products such as guggul, aonla, tulsi, chirayata, harda, baheda have medicinalvalues. Efforts need to be made even for primary processing of such commercial and pharmaceuticalimportant plants to produce pure refined raw material for ayurvedic medicines preparations.Besides, tamarind gum has a potential for several applications. Its complete process and productdevelopment need addressed.

4. With regard to some important high value products, following may be addressed on priority: i)guar gum derivatives, ii) starch modification for developing high viscosity at fast rate, iii) exploringtamarind seed gum as substitute for use in textile industry, iv) manufacturing saponins from mahuaoil cake, etc.

Approach for Enterprise Development

i) Identify technologies that have

commercial viability for sound enterprise development. The selection/ identification of such technologies is the decision of the concerned Head of Organization. It has no attachment to intellectual property protection. This aspect has to be settled first by Head of Organization whether IP Protection before commercialization is required or not.

ii) After identifying a commercially viable technology, commercial data such as scale of production, size of plant, investment, infrastructure, manpower, site, etc. needs to be worked out.

iii) A DPR (detailed project report) on each technology need to be prepared and kept ready for interested entrepreneurs. This report needs to include all technical details, industrial laws, financial support, experts, machinery manufacturers, food laws, export regulation, list of current business houses and traders handling same products, quality standards, etc.

iv) A qualified faculty for training on entrepreneurship development would be available in the BPDU. A training manual needs to be prepared and followed for training. The faculty/ consultant may be outsourced if required.

v) For hands-on training and trials, a close liaison through MoU/Agreement with technology developer need to be signed and the developer involved in commercialization. If a pilot plant is available with the developer the facility would be allowed access to authorized entrepreneur(s)?

Some Unattended Sectors

Considerable science and engineering input has gone into development of industry in the areas of sugar, dairy, rice, pulses, oil milling, potato, tomato, peas, apple, pineapple, orange, tea, coffee, cashew etc. We need to focus some areas not addressed adequately such as millets value addition, oil cakes/meals, medicinal and aromatic plants, bakery and sweetmeats, agricultural waste recycling for soil health etc. Besides these, we need to list and develop consensus on all sectors that constitute food processing industries and propose to Statistics and Census agencies at national level for clubbing all these under one head. With this we can better understand and plan based on actual contribution of the sector in economy and employment. Such data need to be incorporated in Data Book published by ICAR- IASRI as well.

Technology Validation must before Upscaling

Technology validation is the process used by scientific community to acquire necessary information to assess the ability of a technology to reliably obtain a desired result. It also aims to assess and evaluate the relevance of technologies in use and their effect on the production output. Assessment of the technology to establish that it is (1) correct, (2) complete (3) new/modified, (4) being implemented as claimed, (5) delivering the intended outcome, (6) fulfils the requirements for a specific use, (7) the product or process conforms to defined user needs, requirements and/or specifications and (8) quality assurance plan put in place.

It is observed that most of the scientists are eager to claim having developed a technology without going through institutional mechanism of validation. Such haste leads to non-repetitive production of same results as claimed. It brings down credibility of scientific community and organization. Therefore, any claim/new findings need to be subjected to a validation process

through a well-defined and transparent institutional mechanism.

Technology validation aims at improving access to information and knowledge sharing about proven technologies in order to enhance their adoption in agriculture, livestock, fisheries, forestry etc thus addressing food security, climate change, poverty alleviation and sustainable development. Hence, technology validation addresses two guiding principles:

i) The validation of technology facilitates its dissemination, adaptation and adoption across broadly similar bio-physical, socio-economic and human environments and farming systems.

ii) It must be economically and socially acceptable, easily adaptable to bio-physical environment and environment friendly.

Ecological Approach for Economic Development

Forests are not only important source of subsistence, employment, revenue earnings, raw material toa number of industries but also play pivotal role in ecological balance, environmental stability, bio-diversity conservation, food security and sustainable development. Extensive tree wealth exists outside continuous forested areas. Vegetation plays the most critical role in maintaining and regulating the living as also the non-living components of any eco-system. Besides this, there is revival of interest in natural resins and gums due to increasing recognition of their immense social, environmental and industrial development possibilities. For sustained economic development in and outside forest areas as also deserts, mountains and degraded lands, human intervention for plantations of economic value is essential. The interventions so far, largely focused on exploitation of these resources and plantations, if any, of less-economic value trees such as fast-growing trees. Plantation of economic value is expected to ensure sustained development with stable environment.

Recommendations

1. Policy also contributes to development, sustainability, climate risk mitigation, and farmer's income.
2. Expert consultation (8-12 experts) of 2-3 hours is an effective forum to deliberate on specific issue/problem. Not large gathering like seminar /symposium etc.
3. Innovation with defined approach delivers faster, objective results with less investment. Not research done in a routine way. Research is better for basic issues, principles, hypotheses etc, and this can be done only through deeper research and analysis.
4. Innovation is often country & context specific and needs problem definition first and then to proceed for a solution.
5. For any entrepreneurship development or enterprise, techno-economic feasibility analysis is must before starting investment. A good DPR is always useful in the effort. It minimises the risk of failure.
6. Technology validation is must before upscaling.
7. Ecological approach must for economic development. Else serious consequences in terms of climate, diminishing natural resources, disasters.
8. Need focus on some less attended sectors like millets value addition, higher processing of oil cakes/meals, medicinal/ aromatic plants, bakery and sweetmeats, agricultural waste recycling etc.

9. The central government need to make a policy of documenting all lands underitscontrol,likeICAR, SAUs, CAUs, cantonments, railways, PSUs, SFCI farms, State agriculture departments, KVKs, natural water bodies under its possession to implement water harvesting, conservation, groundwater recharge etc under a mission mode. The govt. should demonstrate implementation of its own policies by themselves on their lands and buildings.

10. Each division of IE(I) at national level and state level to develop at least one policy paper of national/state level importance, every year.

References

1. Ashok Gulati, Ranjana Roy, Ritika Juneja, MK Prasad. 2024. New Deal for Agriculture for Viksit Bharat@2047-Policy Brief 18. Council for Research on International Economic Relations (ICRIER), New Delhi.
2. Central Ground Water Authority (CGWA), Govt. of India Notification dated 23.03.2023.
3. Climate Change 2021: The Physical Science Basis. Intergovernmental Panel on Climate Change (IPCC)-Summary for Policymakers.
4. Lectures, Notes, Presentations of Dr Bangali Baboo, Former National Director, NAIP, ICAR, New Delhi.

From Sensors to Smart Villages: Reimagining Engineering Roles in Agriculture, Water, and Climate Resilience

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Abstract

This keynote explores the evolving role of engineers in transforming India's agriculture and rural development through integrated technologies, sensors, AI, water systems, and digital platforms. At the intersection of food security, climate resilience, and sustainable livelihoods, it emphasizes a systems-thinking approach for inclusive, data-led, community-based smart villages. Drawing from policy momentum, grassroots pilots, and global examples, the paper envisions a future where engineering empowers both farmers and ecosystems.The convergence of advanced sensor technologies, AI-driven analytics, and integrated digital platforms is revolutionizing the way engineers approach agriculture, water management, and climate resilience. Smart villages are emerging as living laboratories, where data from IoT sensors, drones, and remote monitoring systems optimize resource use, minimize waste, and empower communities to adapt to environmental uncertainties. This paper explores how these innovations are not only boosting productivity and sustainability but also redefining engineering roles-moving from siloed technical tasks to holistic solution-building for resilient rural ecosystems.With food security, water scarcity, and climate change intersecting at unprecedented scales, engineers are called to orchestrate technology, local knowledge, and policy into unified, context-sensitive frameworks. By showcasing examples,the author has reflected his own 41 years professional journey sailing across different reputed organizations (ICAR-DARE, MOA Govt of India; AnandAgril. University-Govt of Gujarat, &Dr. C.V. Raman University Vaishali Bihar) and sharing his vast blended initiative &actionable pathways for Bharat@204. This keynote address argues that the future engineer must lead not just with technical expertise, but with a civilizational vision; integrating social, environmental, spiritual and economic imperatives for a truly smart, inclusive, and resilient rural India.

Kew Words:Viksit Bharat, Smart Farmer, Smart Farming, Sensors, AI, Water, Climate, Village

Introduction: A Civilizational Mission for Engineers

As we convene to reflect on engineering's role in nation-building, we must remember that villages are not just geographies, they are the soul of India. From groundwater recharge to grain markets, from sensor-enabled soil to solar-powered pumps, the engineer's canvas today is as rural as it is digital.This keynote calls for reimagining engineering roles-not merely as hardware developers or technicians, but as community architects, rural innovators, and ecological thinkers.Engineering in the 21st century transcends traditional design and construction;it is a civilizational mission, tasked with safeguarding humanity's essential resources and adapting ancient practices to contemporary challenges. The engineer of today must serve not just as an innovator, but as a steward, forging

alliances between technology, tradition, and community to create solutions that are robust, inclusive, and sustainable.This paradigm shift demands a new ethos among engineers-one that embraces systems thinking, community engagement, and the humility to learn from local wisdom while leveraging global best practices. As the lines between agriculture, water, and climate resilience blur, engineers are uniquely positioned to lead interdisciplinary collaborations that can transform rural landscapes into engines of growth and resilience, guided by a sense of shared destiny/social-responsibility. What we need is 4 specific key line of thoughts,

Fostering interdisciplinary teams that include local stakeholders:

1. Encouraging ethical frameworks and community-first design.
2. Promoting lifelong learning and exposure to rural challenges.
3. Attempting to unpack how engineers can bridge tradition with cutting-edge tech?

Why this matters more now, is because of the reason that Global climate is showing sharper shifts and rising food-water demands; which all together call for more sustainable, tech-led rural transformation. India's drought-prone regions need urgent, localized engineering solutions. Maharashtra's ?500 croreMahaAgri AI Policy showcases AI, drones, and vernacular tools empowering farmers.

The Imperative: Food, Farming, Water, & Climate at Crossroads

Agriculture in India is at a critical juncture. While 50% of the population remains in farming, its GDP contribution is just 17-18%, highlighting a deep productivity-income gap. Climate change is amplifying stress, erratic rainfall, depleting groundwater, pest outbreaks, and rising costs-especially in vulnerable zones like Vidarbha, Bundelkhand, Saurashtra, and Kutch. Simultaneously, the rise of digital tools, real-time sensors, and AI is creating new opportunities for transformation. With over 70% of freshwater diverted to irrigation-and nearly 60% lost due to outdated practices, efficient water and land management is now imperative. The smart village model is no longer a vision; it's an urgent, actionable need to ensure resilience, sustainability, and rural prosperity.

The Hon'ble Prime Minister's vision supports climate-resilient, tech-driven agriculture through schemes like PM-PRANAM, Digital Public Infrastructure for Agriculture (DPIA), PM-KrishiSinchayeeYojana, and PM-FasalBimaYojana, together forming a holistic framework for rural transformation. Yet, translating these policies into impact requires engineering innovation. With IPCC projections warning of up to 40% yield loss in South Asia under extreme climate conditions, rural resilience is an urgent necessity. India's challenges, monocropping, groundwater overuse, and institutional disconnect, demand targeted, technology-enabled solutions. Global models like Israel's drip systems, Dutch precision farming, and Kenya's solar irrigation prove that sustainability and technology can co-exist. In this context, engineers must lead the charge, deploying precision tools, spatial mapping, and AI-driven irrigation to build adaptive, efficient, and shock-resilient village ecosystems.

The world stands at a critical crossroads, where agriculture consumes over 70% of freshwater, much of it wasted through inefficient irrigation, while nearly half of India's workforce remains in farming, contributing only 15-17% to GDP. Climate threats like droughts, floods, and heatwaves are escalating, with IPCC projections

warning of severe yield declines and rainfall volatility across South Asia. Regions like Vidarbha in Maharashtra exemplify the crisis, marked by water stress and low adaptive capacity. This is not merely an environmental issue-it is economic, social, and moral. Our villages are not backward, but underserved, and it is engineers who must rise to the challenge with innovation, empathy, and scalable, inclusive solutions.

From Sensors to Insights: Technologies Enabling the Shift

We consider the profound role of sensors, which I call the eyes and ears of modern agro-ecological intelligence. Today, a single soil sensor can measure moisture, pH, salinity, and organic matter in real time. Leaf sensors are detecting chlorophyll content and warning of pest attacks before they visibly appear. AI-powered drones are scanning crop canopies and offering hyperlocal health maps. Micro weather stations in farms are informing decisions about irrigation and harvesting windows. In Punjab, Maharashtra, and parts of Karnataka, farmers using these tools have reported 5 to 10 percent yield increases and up to 90 percent savings in water used for pesticide spraying. These are not just numbers-they represent food on the plate, income in the pocket, and resilience in the village.

Civil engineers are instrumental in designing rainwater harvesting systems, check dams, and micro irrigation networks. Mechanical engineers are building smart implements, robotic planters, and solar harvesters. Electronics engineers are innovating ultra-low-cost, solar-powered sensor devices. Data scientists and AI engineers are creating vernacular, voice-based platforms that deliver advisory in regional languages. And management experts are crafting viable business models for farmer producer organizations (FPOs), agri-startups, and cooperatives that link field data to market intelligence.

India's digital and sensor revolution is quietly transforming village life and agricultural decision-making. Real-time soil and crop sensors now monitor moisture, salinity, pH, and plant stress, allowing farmers to fine-tune inputs and boost productivity while minimizing waste. Hyperlocal weather and microclimate sensors enable precise irrigation and spraying, helping farmers adapt to unpredictable climate events. AI-powered drones, already in use across Karnataka, have reduced pesticide water use by 90% and increased yields by up to 10%. Meanwhile, IoT-based smart irrigation systems with GSM and LoRa modules; such as those piloted in Punjab, have saved over 13 million litres of water and cut 3700 tonnes of CO? emissions in just one season. Platforms like Maharashtra's ADeX translate complex field data into actionable mobile advisories using voice-enabled AI in Marathi, guiding farmers on pests, prices, and climate alerts. Together, these innovations form a powerful "decision-making nervous system" that is redefining Indian agriculture from the ground up.

The real breakthrough in agriculture today lies not just in collecting data, but in converting it into actionable insights through the seamless integration of IoT sensors, AI analytics, and unified digital platforms. Smart irrigation systems, now dynamically adjusting water delivery based on real-time soil, weather, and crop data, have reduced water usage by up to 60% while boosting productivity. Platforms offering predictive analytics for fertilizers, pest control, and energy use are transforming farms into precision-managed ecosystems. The true power lies in orchestration, where data from soil sensors, drones, and weather stations converge into intuitive dashboards accessible to both

engineers and farmers. This collaborative intelligence, exemplified by initiatives like the NSF's IoT4Ag in the US and India's Farmout, enhances transparency, adaptability, and efficiency. In Karnataka, drone farming trials showed pesticide water use plummeting by 90% with notable yield gains. Sensors are no longer optional add-ons-they have become the foundational infrastructure of next-generation climate-smart agriculture.

The transition from isolated sensor tools to real-time decision-making has revolutionized precision agriculture. At the forefront are initiatives like NSF's IoT4Ag and companies such as Teralytic, which use biodegradable soil and leaf sensors to track moisture, nutrients, and salinity, empowering farmers with predictive, data-driven crop management. In Karnataka, drone-based agrochemical spraying not only reduced water use by 90% but also improved yields for ragi and tur dal while minimizing human exposure to harmful pesticides. Meanwhile, at IRRI's research centre in Uttar Pradesh, a fusion of soil-moisture sensors, automated depth monitors, and drone-based mapping is optimizing irrigation for direct-seeded rice, providing a model for climate-resilient farming in water-stressed regions.

The Smart Village: Not Just Connected, but Integrated

Smart villages are emerging as integrated ecosystems where engineering, ecology, and community converge to build resilient rural futures. Platforms like Farmonaut are harnessing satellite remote sensing, AI-driven NDVI imaging, pest alerts, and blockchain-based traceability to provide farmers with near real-time insights. On the ground, autonomous irrigation systems using ESP32 sensors, LSTM AI models, and solenoid valves are enabling precise, predictive water management, while GPS-guided tractors, robotic weeders, and livestock sensors enhance productivity and reduce waste. At the community level, ICAR's Climate Smart Villages initiative, spanning 446 locations, integrates drought-tolerant crops, water-saving infrastructure, and local governance for long-term resilience. In Madhya Pradesh, natural farming clusters have achieved yield increases of up to 43% and enhanced soil carbon through mulching and crop diversification. ITC's digital climate-smart village model, covering over 6,700 villages, has empowered women-led Krishi Sakhis and cut GHG emissions by up to 66%, with net returns soaring by 90%, proving that when systems work in concert, rural India thrives sustainably.

Smart villages are not defined by internet speed or digital dashboards alone. They are characterized by their ability to integrate ecological balance, economic vibrancy, and technological enablement. We see successful models emerging from ICAR's Climate-Smart Villages project where multiple disciplines converge, climate-resilient seeds, renewable energy, sensor-based irrigation, value chain optimization, and inclusive governance. In Madhya Pradesh, clusters practicing natural farming have reported a 43 percent increase in yields and 11 percent improvement in soil organic carbon. Similarly, ITC's e-Choupal 4.0, linking data dashboards, input advisories, and market access, is redefining the concept of rural value systems. These are systems where engineers are not just implementing technology-they are enabling transformation.

What then is the role of the future engineer? I propose that the modern Indian engineer must be a systems thinker, capable of integrating devices with design, data with decisions, and

science with society. We must move away from viewing engineering in silos, civil, mechanical, electronics, or computer science. Instead, we must embrace a collaborative engineering ethos where the outcome is not just innovation, but social impact. Today's village needs solar-powered IoT sensors, groundwater dashboards, agri-waste-to-energy models, AI-based crop insurance tools, automated post-harvest machines, and drone-assisted soil mapping, this is a call for engineers across all domains.Furthermore, we must consider the socio-economic transformation of farming itself. What does the Indian farm and farmer look like in 2040? The answer lies in democratizing technology. Future farms will be digitally connected, sensor-integrated, and nature-aligned. The farmer of tomorrow will be a data-literate entrepreneur, operating dashboards instead of bullocks, using AI for pest forecasting, and participating in global carbon markets via biodiversity credits and sustainable practices. Young engineers will become village technocrats, startup founders, agri-consultants, and drone pilots. The future belongs to those who combine their technical training with empathy and a rural development mindset.

Smart villages are not miniature replicas of urban smart cities, they are contextual ecosystems rooted in equity, ecology, and enterprise. Initiatives like ICAR's Climate-Smart Villages, now active in over 446 locations, offer a blueprint for climate-proof rural resilience through drought-tolerant seeds, solar pumps, water-harvesting systems, and localized governance via resilience committees. In Madhya Pradesh, natural farming clusters have recorded yield increases of up to 43% and an 11% boost in soil organic carbon, achieved through practices like mulching, composting, and intercropping that blend traditional wisdom with scientific rigour. ITC's e-Choupal has digitally enabled more than 6700 villages, improving market access and empowering women-led Krishi Sakhis, leading to income gains of 80-90% over five years. Internationally, Kenya's M-Farm mobile app has demonstrated how even under resource constraints, mobile technology can connect smallholder farmers to real-time weather data, market prices, and buyers. These examples underline a critical truth: successful smart villages thrive not by isolating technologies, but by integrating water, energy, soil, finance, and information into one seamless, user-centric system. Such villages could be taken as represent the pinnacle of integrated rural development, where digital connectivity serves as a foundation, but not the finish line. These villages use IoT platforms, renewable energy, precision irrigation, and data-driven services not merely to deliver convenience, but to foster dignity, sustainability, and self-reliance. Engineers are pivotal in designing these systems to be environmentally sound, socially inclusive, and economically viable.

The real strength of smart villages lies in their ability to weave together sectors like agriculture, water, education, healthcare, and finance into a cohesive ecosystem that enhances quality of life and fortifies communities against external shocks. The mission now is to promote cross-sectoral collaboration, develop culturally adaptable models, and institutionalize community-led governance. In doing so, we ensure that no village remains on the margins of progress, and that the promise of Viksit Bharat @2047 begins at the grassroots.Water is the lifeline of agriculture, and India's looming water crisis will be fought not in cities, but across its farmlands. Smart irrigation, powered by AI and data analytics, is emerging as a game-changer,

drip systems now regulate flow based on evapotranspiration data, solar pumps are integrated with IoT dashboards accessible via mobile phones, and reservoir sensors provide real-time groundwater intelligence to fine-tune irrigation schedules. Engineers are now developing affordable, sensor-based systems using ESP32 microcontrollers and AI algorithms to deliver predictive irrigation-proof that future-ready farming is no longer futuristic. Yet, true transformation lies not in isolated tools, but in their integration. Thus, the NextGen smart village will be defined by systems working in harmony: ICAR's Climate-Smart Villages deploy hybrid seeds, crop diversification, water harvesting, and solar energy across 446 locations; ITC's e-Choupal 4.0 empowers farmers, especially women;with digital tools and market access, while reducing carbon footprints by up to 60%; and natural farming clusters in Madhya Pradesh have seen up to 43% yield increases and a significant rise in soil health. These villages are no longer marginal; they are dynamic, living laboratories of engineering-led rural resilience.

Reimagining the Engineer: Roles Beyond The Drawing Board

The 21st-century engineer must be reimagined as a systems thinker, problem solver, and community collaborator, with people at the centre of every innovation. Today's sensor-system designers are developing affordable, solar-powered ESP32-based devices embedded in rural infrastructure, enabling real-time soil and water monitoring. AI and data scientists are crafting locally trained LSTM models that predict pest outbreaks and optimize irrigation cycles based on regional agro-climatic data. Civil engineers are integrating recharge-monitoring sensors into check dams, linked via satellite telemetry for dynamic groundwater tracking. Electronics engineers are developing rugged, weather-resistant sensor nodes tailored for India's diverse terrains-more durable than many imported alternatives. Meanwhile, platform builders are connecting farmers to advisories, crop insurance, and market prices through integrated digital ecosystems such as ADeX and Agristack. Most crucially, a new breed of community engineers is emerging, those who co-design solutions with SHGs, Panchayats, and farmers to build trust, ensure usability, and drive long-term adoption. This marks a powerful paradigm shift toward empathetic, inclusive, and ecosystem-based engineering.

To meet the demands of a rapidly evolving world, engineers must transcend their traditional boundaries and embrace multifaceted roles as educators, cultural translators, policy influencers, and sustainability champions. They are no longer confined to labs or boardrooms but are active in the field, listening to local voices and bridging the divide between technology and community needs. This expanded identity calls for continuous learning, ethical foresight, and deep social engagement. Engineers must lead with empathy, ensuring that innovation is equitable, inclusive, and grounded in human values. They must be as fluent in local dialects as in programming languages, and as committed to regenerative ecology as to productivity. By cultivating leadership skills, engaging in participatory dialogues, and upholding ethical standards, the engineer of tomorrow can truly become a catalyst for transformative change, one that aligns technology with justice, dignity, and resilience.

Greening the Grid: How Engineers are Powering Nature-Based Solutions in India &World

Across the globe, engineers are moving beyond concrete and code to embrace nature itself as a tool for resilience. From sponge cities in China to mangrove corridors in Tamil Nadu, Nature-Based Solutions (NbS) are redefining the engineering playbook-combining ecology, hydrology, and social innovation to solve the pressing challenges of floods, pollution, urban heat, and water security. India stands as a remarkable laboratory of such efforts, with hundreds of NbS projects blossoming across states and cities. The following table presents a comparative view of NbS initiatives across global, national, and local levels, highlighting how engineers, planners, communities, and governments are co-creating regenerative infrastructures that heal the earth while serving people.

Region / Example	Key NbS Focus	Notable Projects / Features	Stakeholders
@Global Level			
China	Sponge Cities, Urban NbS	30+ cities with permeable surfaces, bioswales, green roofs	Gov. of China, UN - Habitat
Europe (NL, Germany, Denmark)	Wetlands, Green Roofs, River Restoration	Rhine restoration, Berlin green corridors, Amsterdam Sponge plan	EU Horizon, Cities, NGOs
Colombia, Kenya, Uganda	Urban forests, wetland reuse, nature parks	Green towns model (IUCN), Nairobi green corridors	IUCN, UNEP, local govts
Global Urban Nature Atlas (multiple countries)	Urban NbS portfolio	1000+ documented projects worldwide	NATURVATION, UrbanNatureAtlas.org
@National (India) Level			
Gujarat	Mangrove restoration, Sponge cities	MISHTI scheme – 7,000 ha mangroves (Kutch, Bharuch), Sabarmati green restoration	MoEFCC, State Forest Dept
Odisha	Cyclone resilience via mangroves	Coastal plantation + eco - livelihoods (30% canopy rise), post-Phailin recovery	Odisha Forest Dept, UNDP

Chhattisgarh	Forest & water conservation	"Ek Ped Maa Ke Naam" – 104,000 saplings, 8,000+ soak pits/recharge trenches	Local govt, communities
Tamil Nadu	Tank restoration, Miyawaki planting	Siruthuli NGO revived Coimbatore tanks + 1000+ recharge wells	NGOs, CSR, Public Works
Maharashtra	River & mangrove restoration	Vanashakti,60 ha mangrove rewilding; Ramnadi restoration project (Pune)	NGOs, students, PCMC, citizens
@City Level in Indian States			
Delhi	Biodiversity parks, wetlands	Yamuna Biodiversity Park, Rajokri Lake Rejuvenation	DDA, CSE, NGOs
Kolkata	Wetland reuse system	East Kolkata Wetlands – 12,500 ha; sewage -fed aquaculture; Ramsar site	Local fishers, Govt, UN
Indore	Biophilic buildings	Green roofs on academic buildings; Prestige Univ.	Academic, CSR
Chennai	Canal-based mangrove corridor	250m Buckingham Canal stretch + 12,500 saplings	Civic bodies, NGOs
Hyderabad	Rain garden (stormwater infra)	Flyover green infrastructure (Begumpet)	GHMC, Designers
Raipur	Urban oxygen zone (Miyawaki)	Oxy-zone forest on 19-acre plot to reduce pollution	Local corp., volunteers
Gorakhpur	Peri-urban agriculture for flood buffer	Integrated NbS for urban flood risk management	GNN, WWF
Vadodara	Urban composting + rain harvesting	Self-help compost stations + rooftop harvesting	Local NGOs, Residents

Global: ~1000+ urban NbS (documented)	**India**: Hundreds across 15+ states, 25+ cities	Includes sponge cities, green roofs, forest corridors, water recharge, wetlands, and parks	Governments, NGOs, Communities

The New Farmer, the New Farm, the New Future

Farming in 2040 will look radically different, defined by intelligence, integration, and innovation. Fields will be rich with sensors, AI-powered dashboards, and real-time alerts on crop stress, pest risks, and moisture levels, enabling farmers to act proactively. Farmers will no longer be passive producers but empowered digital users, accessing carbon markets, securing e-insurance, and ensuring traceability through blockchain-backed FPO platforms already gaining traction in Telangana and Gujarat. Youth will lead this transformation as drone pilots, climate-tech consultants, and agri-entrepreneurs, with over 15000 trained under India's Drone Shakti Mission. At the frontier, new income streams will emerge through carbon credits and biodiversity-linked payments, as seen in pilot projects in Sikkim and Himachal Pradesh supported by NABARD and GIZ. This future is not a distant vision, it is unfolding rapidly, and engineers are at the heart of making it possible.

The modern farmer is increasingly a data-driven entrepreneur, navigating drones, predictive analytics, and e-platforms to enhance productivity and sustainability. This evolution demands a new kind of collaboration, where engineers design intuitive, adaptable systems tailored to diverse farm scales, and where farmers become co-creators in innovation. As agriculture becomes more high-tech, education and capacity building will be key. Farmers must be equipped not only with tools, but with the training and confidence to use them effectively. Engineers, therefore, must also serve as educators and enablers; facilitating partnerships, building trust, and ensuring that technology uplifts rather than alienates. In this new paradigm, the synergy between technological ingenuity and grassroots knowledge will define the success of resilient, climate-smart agriculture.

R&D Organizations and University-Led: Call to **Action**

Institutions must lead from the front in shaping the future of rural transformation, and many of our R&D organizations (ICAR, ICMR, ICFER, ICSSR, CAPART, UGC, AICTE, MHRD etc) cutting across ministries, subject lines, states and stakeholders; stands as a shining example. With the establishment of its agricultural, ecological, nature based enormous innovation labs/schools/faculties and schemes at all most all the Universities (public & private) being around 1000 in numbers; the role of engineers and technocrats has become more versatile and demand driven from not only human comfort but also socio economic and human ethical point of views too. Cutting-edge environment in R&D as well as lower to higher education domain; made it almost inevitable for all the learners/scholars to adopt and explore IoT, AI, and sensor-based solutions tailored to real-world challenges (farming v/s non farming, engineering v/s non engg, technology v/c traditions etc). This hands-on space allows learners to prototype innovations for innovative agricultural engineering interventions (soil & plant health monitoring, precision irrigation, nutrient/pest management,

water productivity, carbon, climate change etc). The organizations (R&D/Universities) must initiate pilot programs in collaboration with nearby Panchayats and Farmer Producer Organizations (FPOs), enabling students and faculty to co-design and implement technologies like solar pump automation and telemetry for community water tanks. Strategic partnerships with KrishiVigyanKendras (KVKs), agri-tech startups, and CSR foundations could be another big opportunity to strengthen the impact and scalability of these innovations. Such efforts could be further complemented by a reimagined curriculum that integrates GIS, sensor networks, water resource systems, and rural entrepreneurship; for training engineers who are not only technologically skilled but also socially grounded.

In last 1 year we have made a little effort at Dr. C.V. Raman University, being able to exemplify how academic institutions can serve as catalysts for grassroots innovation and resilience. By embedding applied research within the context of rural engagement, the university empowers students to gain a deeper, interdisciplinary understanding of agriculture, climate, and community systems. Field-based projects offer students immersive learning experiences that bridge classroom theory with village realities, ensuring that solutions are not just technically sound but also culturally appropriate and sustainable. The collaboration between students, faculty, and local communities fosters mutual respect and shared ownership of outcomes, transforming villages into living laboratories and students into empathetic changemakers. This model of action-oriented education demonstrates the vital role universities can play in nurturing the next generation of engineers who are equally comfortable coding in a lab and troubleshooting in a farm field. It redefines technical education as a force for inclusive development and rural empowerment.

The role of the 21st-century engineer is undergoing a profound transformation, one that extends far beyond labs, codes, and conventional infrastructure. Engineers are now tasked with designing entire ecosystems that respond to real-world challenges in India's rural heartlands. From developing robust sensor systems that monitor soil moisture, livestock health, and weather patterns, to crafting affordable devices powered by solar energy and connected via LoRaWAN or satellite links in network-poor areas, the mandate is clear: engineering must be inclusive, contextual, and human-centric. Predictive AI models for pest forecasting, irrigation scheduling, and yield prediction must speak the language of the land, literally, by being trained on vernacular datasets. Integrated platforms like Maharashtra's ADeX, which combine mobile apps, voice assistants, blockchain traceability, and local advisories, exemplify what's possible when engineers become platform architects. Importantly, these technologies must be co-designed with Panchayats, SHGs, and farmers to ensure trust, usability, and sustained impact. The future is not about isolated apps, it is about connected ecosystems of devices, data, and dignity.

As India strides toward its centenary milestone in 2047, this vision of Viksit Bharat hinges on engineering that is bold, inclusive, and grounded in rural reality. Imagine if every engineering institute adopted five villages as living labs; if every CSR body funded a smart village prototype as a replicable national model; if every policy mission, from Amrit Sarovar to Jal Jeevan Mission, embedded engineering innovation into its core design. Let each young engineer mentor a Farmer Producer Organization or rural startup, building a culture of immersion, empathy, and scalable

service. Let dashboards secure families, sensors prevent droughts, and smart villages become the backbone of state and national development. This isn't just a technological revolution, it's a societal transformation driven by engineers who don't just build things, but uplift lives. The Hiware Bazars of tomorrow must be digitally enabled, ecologically sound, and socially just, led by institutions and engineers who believe in the power of local to shape the future global.

Conclusion

This keynote explores the evolving role of engineers in transforming India's agriculture and rural development through integrated technologies, sensors, AI, water systems, and digital platforms. At the intersection of food security, climate resilience, and sustainable livelihoods, it emphasizes a systems-thinking approach that enables inclusive, data-led, and community-based smart villages. Drawing from the momentum of recent policies, grassroots innovations, and global success stories, the address envisions a future where engineering empowers both farmers and ecosystems. With food security, water scarcity, and climate change converging at unprecedented scales, the need for a unified, context-sensitive engineering approach has never been greater. Engineers today must blend cutting-edge technology with local knowledge and policy frameworks to build sustainable, adaptive rural systems. The address draws on insights from my 41-year professional journey across ICAR, State Agricultural Universities, and Vice-Chancellorships to chart a transformative roadmap for Bharat@2047, where smart villages become the nucleus of a resilient, self-reliant, and sustainable India.But this transformation demands a national movement. Academic institutions must restructure curricula to include climate-smart agriculture, water systems engineering, rural entrepreneurship, and digital commons. CSR units must step forward to fund village technology pilots that can become replicable models for the country. Policy think tanks must embed engineering mandates in every rural mission, from Amrit Sarovar to Jal Jeevan Mission and PM-KSY. Every engineering college must adopt villages as living labs; every young engineer must mentor at least one rural tech project. This is how we institutionalize change, by creating ecosystems of innovation rooted in soil, people, and purpose. Let us pledge: a sensor should not remain a prototype, a smart pump must not remain on paper, and a smart village must not remain a PowerPoint, it must become a lived reality.

In conclusion, let us rise beyond silos of circuits and code. Let us engineer for humanity, for ecology, for dignity. Let us design not just gadgets, but systems of prosperity. Let us pursue excellence not just with IQ, but with EQ and ethics. In the soil, the water, the hands, and the hopes of rural India lies for the destiny of this nation. And in the resolve of every engineer present here lies the potential to make that destiny bright, sustainable, and sovereign. The smart village revolution is not merely about connectivity; it is about community. It is not about automating the past;it is about architecting the future. So, let us build not just smart villages, but a smart Bharat. A resilient, inclusive, and self-reliant Bharat, Together, we will engineer a new era.

Jai Hind.

Jai Vigyan. Jai Kisan. Jai Vidya.

Bibliography / Sources of information

Adhikari, R., & Hossain, M. S. (2024). Smart village development: Integrating IoT and AI for sustainable rural transformation in South Asia. Journal of Rural Studies, 103, 115-128.

Banerjee, S., & Singh, V. (2023). Precision

agriculture and climate resilience: Engineering challenges and opportunities. Smart Agricultural Systems, 12, 44-59.

Business Insider. (2025, May 2). Farmers are using IoT to take the guesswork out of growing.

Farmonaut®.(2025). Remote sensing for smart agriculture.

Google Blog. (2025). IoT for agriculture in Punjab: Saving water and CO?.

Gupta, P., Kumar, S., & Sharma, A. (2025).Role of sensors and AI in water resource management for climate-adaptive agriculture.Agricultural Water Management, 291, 108732.

Indian Council of Agricultural Research. (2024). Climate-smart villages: Annual report.

ITC Limited. (2024). Sustainability report: e-Choupal 4.0 and Krishi Sakhis.

Kaur, M., & Rajput, N. (2022). Reimagining engineering education for sustainable smart villages: A case from India. International Journal of Engineering Education, 38(4), 855-864.

Ministry of Agriculture and Farmers Welfare. (2025). Drone Shakti Mission updates.

NABARD & GIZ.(2025). Carbon farming pilots in the Himalayas [Unpub policy report].

Scroll.in. (2024). Natural farming in Madhya Pradesh: Reviving rural soil.

Sharma, T., & Bansal, R. (2025). Engineers as agents of change in food, water, and climate security: A review. Environmental Engineering Research, 30(1), e2025002.

The Times of India. (2025, June 18). Maharashtra's ₹500 crore MahaAgri AI policy to digitize farms.

Recent Advances in Micro Irrigation Technology

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Abstract

Micro-irrigation systems deliver precise quantities of water and nutrients directly to the plant's root zone, minimizing water wastage and maximizing water and fertilizer use efficiency. This technology is vital for countries facing growing water scarcity and the challenges of climate change. This review synthesizes recent advances in micro-irrigation, with a particular focus on sensor-based automation, sustainable system components, and the integration of smart technologies. Field trials and impact studies, including those conducted by the author and their research team at IIT Kharagpur, consistently demonstrate substantial water savings, yield improvements, enhanced energy efficiency, and significant economic gains for farmers. The historical evolution, hardware innovations, and future directions of micro-irrigation are explored in detail, highlighting a clear trajectory towards smart, data-driven, and farmer-centric agriculture.

1. Introduction

Agriculture, while sustaining global populations, remains the largest consumer of freshwater, accounting for an estimated 69% of global withdrawals and over 84% of India's total water use [1, 2]. The challenge of increasing food production with diminishing water resources is compounded by the impacts of climate change, which intensifies the unpredictability of rainfall patterns and increases the frequency of droughts and floods [14]. Traditional irrigation methods, such as flood irrigation, lead to uneven water distribution, excessive water use, increased soil erosion, and the depletion of groundwater resources, negatively impacting both agricultural productivity and environmental sustainability.

Micro-irrigation systems (MIS), including drip and sprinkler systems, have emerged as a powerful solution to these challenges [1, 4, 5]. By delivering water and soluble fertilizers directly to the root zones of plants, micro-irrigation drastically reduces water wastage, minimizes weed growth, and optimizes the delivery of nutrients, thereby promoting resource efficiency. This technology provides better control over water distribution, ensuring that crops receive the right amount of water at the right time, leading to higher yields and improved crop quality.

2. Historical Development of Micro-Irrigation System (MIS)

❖ Origins and Global Spread: The concept of micro-irrigation technology has roots in the 19th century in Europe and the USA, but it was commercially pioneered and scaled in Israel in the 1960s. The initial systems relied on simple porous emitters and capillary action, which were later replaced by more durable plastic components.

❖ Adoption in India: In India, MIS was introduced on a research scale in the 1970s and 1980s by institutions such as the Indian Council of Agricultural Research (ICAR), State Agricultural Universities (SAUs), and IIT Kharagpur. Early studies demonstrated that on-farm irrigation efficiency could be enhanced to 80-90% with sprinkler and drip methods, a significant improvement over the 30-40% efficiency of flood irrigation. The adoption of MIS was accelerated by government-driven subsidy and mission programs, such as the National Mission on Micro Irrigation (2010) and the Pradhan Mantri Krishi

Sinchayee Yojana (PMKSY) in 2015, which was framed around the principle of "Per Drop More Crop" [1, 6]. These programs offered financial incentives, technical training, and institutional support to encourage farmers to transition from traditional methods.

❖ Current Status: Despite these efforts, the area under micro-irrigation in India, which had expanded to over 21.8 million hectares by 2022-23, remains only a fraction of the estimated potential of more than 72 million hectares [1, 2, 6]. To bridge this gap, State Agricultural Universities, research institutions, and government agencies must continue to play a crucial role in promoting and demonstrating the long-term benefits of micro-irrigation.

3. Recent Research Findings on Hardware Components

❖ Core Components: A typical MIS consists of a main supply line, sub-main lines, laterals, emitters (drippers, micro-sprinklers), filters, pumps, control valves, and fertigation units. The durability and performance of these components are central to the system's efficiency and longevity. Emitters are particularly critical as they directly regulate water delivery and distribution uniformity.

3.1 Selection of Suitable Emitters

❖ Crop Geometry and Soil Type: Emitters are chosen based on crop spacing, with wide-spacing crops requiring higher discharge rates and close-spacing crops benefiting from lower rates to avoid waterlogging. Soil type and climate further influence selection; for instance, clay soils require low discharge rates to prevent runoff, while sandy soils need higher rates to compensate for rapid water percolation.

❖ Water Quality: Emitters must be selected with water quality in mind. For water with high sediment loads, self-flushing or robust filtration systems are preferred. Anti-scaling features are necessary for hard water to prevent mineral buildup and clogging.

❖ Climate: Emitter selection in arid regions normally involves higher flow rates compared to humid climates to meet the higher evapotranspiration demand of the crops.

3.2 Historical Advances in Drip Emitters

❖ 2000-2010: Advanced Pressure-Compensating Emitters: During this decade, significant advancements were made in the design and performance of pressure-compensating (PC) emitters. PC emitters use an elastic diaphragm or membrane that adjusts to pressure changes, maintaining a constant flow rate over a wide range of operating pressures. This innovation was crucial for ensuring uniform water distribution across fields with varying topography, a key factor in achieving high crop yields. Studies showed that PC emitters could achieve design emission uniformities (EU) of over 90%, a marked improvement over non-PC emitters.

❖ 2010-2020: Computational Fluid Dynamics (CFD) Techniques: The application of CFD in emitter design marked a significant leap. CFD simulations were used to analyze and refine the internal labyrinth paths of emitters, which are responsible for dissipating pressure and regulating flow. This led to designs that improved flow stability, reduced turbulence, and enhanced frictional resistance, all of which helped to control flow rates more effectively and minimize clogging. This validation process allowed for the optimization of designs without extensive physical prototyping, reducing development time and costs [15].

❖ 2020 onwards: Integration of Smart Irrigation Systems: The integration of the Internet of Things (IoT) and Artificial Intelligence (AI) technologies is revolutionizing water management. IoT sensors are deployed to collect

real-time data on soil moisture, weather conditions, and crop water needs. AI algorithms, such as Partial Least Squares Regression (PLSR) and fuzzy logic, are then employed to analyze this data and predict optimal irrigation schedules, automatically adjusting water application based on real-time conditions to reduce water waste and enhance crop yield [16].

3.3 Adjustable Flow Drip Emitters

❖ The Need: Constant discharge rate drippers often lead to over-irrigation during a plant's early growth phase and under-irrigation during its mature phase. Therefore, there is a need for emitters with an easy mechanism to adjust the discharge rate, ensuring both economic and adequate irrigation throughout a plant's life cycle [13].

❖ Design Innovations: Several designs have emerged in publications and the commercial market to address this need:

❖ Manual Adjustment: Emitters equipped with dials or levers allow farmers to manually modify discharge rates based on field observations. These are simple and require no power, making them suitable for small plots.

❖ Electromechanical Systems: These systems use small motors or actuators, often controlled by an electronic module, to open or close a valve within the emitter. They can be integrated with sensors and enable automated adjustments, ensuring precise water delivery in response to real-time data from the field.

❖ IOT Integration: Smart emitters can be connected to centralized platforms, allowing for dynamic irrigation management based on environmental and crop-specific inputs received from a central controller.

❖ Associated Challenges: The primary challenge with adjustable flow emitters is the complexity and cost of implementation. Manipulating individual drippers presents a significant challenge; manual adjustment is labor-intensive and only feasible for small plots, which is particularly relevant for India's fragmented landholdings and resource-limited farmers. Electronic control systems, while precise, entail a high capital investment, as each dripper requires a sensor and actuator. This may not be cost-effective even for wealthier farmers, and the reliability of such a complex system in harsh agricultural environments can be a concern.

4. Advanced Technological Applications in MIS

4.1Smart Sensors and IoT Integration:

Modern MIS are transitioning from simple timers to fully automated, data-driven systems. An IoT-based MIS architecture typically involves a network of sensors (e.g., tensiometers for soil moisture, weather stations for evapotranspiration data) that transmit real-time data via wireless communication protocols (e.g., LoRaWAN, Zigbee) to a central gateway. This data is then sent to a cloud-based platform for analysis. Actuators, such as solenoid valves, receive commands from this platform to initiate or stop irrigation, creating a closed-loop system that optimizes water application with minimal human intervention [16].

4.2 Fertigation and Chemigation Systems:

Fertigation, the application of fertilizers through the irrigation water, and chemigation, the application of pesticides and other chemicals, are key benefits of MIS. Advanced systems use Venturi injectors or positive displacement pumps to precisely mix and inject concentrated stock solutions into the main irrigation line. This ensures uniform application of nutrients directly to the root zone, significantly reducing fertilizer runoff and associated environmental pollution. It also improves nutrient uptake by plants, leading to healthier crops and higher yields.

4.3 Biodegradable and Recyclable Materials:

To address the issue of plastic waste generated by

micro-irrigation components, research is focusing on the development of biodegradable and recyclable materials. Materials like polylactic acid (PLA) and polyhydroxybutyrate (PHB) are being investigated for use in drip tapes and emitters. These materials are designed to degrade in the soil after the cropping season, reducing the environmental footprint of agriculture [17].

4.4 Renewable Power Integration:

The move towards sustainable agriculture includes the integration of renewable energy sources. Solar-powered pumps and controllers are becoming increasingly common, especially in off-grid or remote areas. These systems reduce reliance on fossil fuels, lower operational costs, and contribute to a smaller carbon footprint, making MIS more economically viable and environmentally friendly.

5. Effect of Micro-Irrigation on Crop Yield and Efficiency

❖ Yield Improvements:

Field studies consistently show that the adoption of micro-irrigation leads to significant yield enhancements, ranging from 15% to 66% in crops such as cotton, groundnut, potato, and sugarcane, when compared to conventional methods [2, 9, 10, 11]. For example, a recent study on okra cultivation using a smart, sensor-driven system demonstrated a 13% reduction in water use while simultaneously improving water-use efficiency and crop quality [8].

❖ Water & Resource Efficiency

Water savings with MIS are substantial, typically ranging from 30% to 70%, with irrigation efficiency rising to approximately 90% in optimized systems. Furthermore, localized water application reduces weed growth by up to 50% and minimizes the spread of certain pests and diseases by keeping foliage dry [10, 11].

❖ Economic Impact

The combined effect of increased yields and reduced input costs (water, fertilizer, labor) translates to higher farm incomes. An impact evaluation by NABARD found that average farm incomes increased by 20-68% after adopting micro-irrigation [2]. This economic viability is a key driver for broader adoption.

❖ Quality and Sustainability

Micro-irrigation not only improves produce quality but also minimizes soil salinity and erosion problems. By preventing excessive soil moisture, it creates a healthier root environment and reduces the risk of nutrient leaching, contributing to long-term soil sustainability.

6. Future Directions

❖ Artificial Intelligence and Predictive Analytics:

The next generation of MIS will be driven by more sophisticated AI models. These models will use predictive analytics, integrating real-time sensor data with historical weather patterns and crop growth models, to forecast crop water needs with unprecedented accuracy. This will enable even finer-tuned irrigation scheduling and resource management.

❖ Drones and Satellite Remote Sensing

Drones and satellites will play an increasingly vital role in large-scale precision agriculture. Remote sensing data can be used to assess plant health, detect early signs of water stress, and create precise irrigation maps, allowing for highly localized water management that is not feasible with ground-based sensors alone [4, 12, 13].

❖ Cost-effective Modular Designs

The continued development of scalable, affordable, and easy-to-install systems is crucial for expanding access to small and marginal farmers, who make up the majority of the agricultural sector in many developing countries.

❖ **Enhanced Institutional Support:**

For widespread and sustained adoption, policies must continue to emphasize training, after-sales service, financing options, and stronger extension networks. These support systems empower farmers with the knowledge and resources to effectively operate and maintain their MIS [1, 3, 6].

7. Challenges and Constraints

Despite the clear benefits, the adoption of advanced micro-irrigation technologies faces several challenges. The high initial capital costs for automated and IoT-enabled systems can be a major barrier for smallholder farmers. Furthermore, the integration of smart systems raises new issues related to data privacy and cybersecurity, which must be addressed to build farmer trust. A significant challenge in rural areas is the lack of robust wireless network infrastructure to support real-time data transmission. Finally, a lack of technical knowledge among farmers about the design, operation, and maintenance of these advanced systems poses a significant constraint to widespread and effective implementation. Addressing these issues through targeted policy and technological innovation is essential for realizing the full potential of MIS.

8. Summary

Recent developments in micro-irrigation technology are marked by the integration of hardware innovations with smart, data-driven systems. This synthesis provides a clear pathway for more productive, sustainable, and climate-resilient agriculture. Studies by the author and their research team provide robust evidence of substantial water savings, higher yields, and strong economic gains [1, 3, 7, 8]. The next phase will be driven by sensor-based automation, AI, and data integration. To achieve the full untapped potential, particularly of smallholder farmers, enhanced institutional and policy support mechanisms will be pivotal [1, 2, 3, 9].

9. References

[1] StartUs Insights. "Top 10 Irrigation Industry Trends in 2024." https://www.startus-insights.com/innovators-guide/irrigation-industry-trends/

[2] NABARD, Gujarat Regional Office. "Mid-Term Impact Evaluation Of Project Supported Under Micro Irrigation Fund (Mif) In Gujarat." https://www.nabard.org/auth/writereaddata/tender/2708244711pub_180424122358990.pdf Accessed on 02.08.2025

[3] Tiwari, K.N. (2025). "Micro Irrigation Engineering," NPTEL Course Material, IIT Kharagpur.

[4] Banik, B., Korav, S., Guin, A., &Unjia, D. (2024). Impact of drip irrigation on crop growth, yield, water productivity, and weed dynamics: a review. International Journal of Environment and Climate Change, 14(4), 739-749.

[5] Farmonaut. "Agriculture Micro Irrigation System Market: 2025 Trends."https: // farmonaut.com/precision-farming/farming-technology-trends-2025-top-innovations-india

[6] IIT Kharagpur Foundation. "Spotlight Article by Prof. K N Tiwari." https:// www. iitkgp foundation.org/article.html?nl=1483

[7] ECHOcommunity.org. "Micro Irrigation Systems Design - Dr. K. N. Tiwari." https://www.echocommunity.org/en/resources/71472816-9265-4532-8218-3a29d67be20d

[8] Akter, S., Rahman, M. M., Zannat, R., RANA, M., Hossain Oliver, M. M., & Ali, M. A. (2025). Development of smart micro-irrigation system using Arduino Uno for okra cultivation in Bangladesh. Research in Agricultural Engineering, 71(1).

[9] National Mission on Micro Irrigation &Per Drop More Crop guidelines, Ministry of Agriculture, India. https://pmksy.gov.in

/microirrigation/Archive/GuidelinesMIRevised 250817.pdf

[10] Zhai, Y. M., Shao, X. H., Xing, W. G., Wang, Y., Hung, T. T., & Xu, H. L. (2010). Effects of drip irrigation regimes on tomato fruit yield and water use efficiency. Journal of Food, Agriculture & Environment, 8(3-4), 709-713.

[11] Shock, C. C., Feibert, E. B., & Saunders, L. D. (2000). Irrigation criteria for drip-irrigated onions. HortScience, 35(1), 63-66.

[12] Choudhury, A., Biswas, A., Singh, T. P., & Ghosh, S. K. (Eds.). (2022). Smart agriculture automation using advanced technologies: Data analytics and machine learning, cloud architecture, automation and IoT. Springer Nature.

[13]Ramadan, M. H., Abdel-Mageed, H. N., & Maher, M. (2003). Emitters performance in summer seasons of hot climate regions. In International Scientific Conference, Agricultural Water Management and Mechanization Factors for Sustainable Agriculture (Vol. 8, pp. 92-98).

[14] Global Water Security and Sanitation Partnership: Annual Report 2023. https://www.worldbank.org/en/topic/water/publication/global-water-security-and-sanitation-partnership-annual-report-2023. Accessed on 31.07.2025

[15] Baghel, Y. K., Kumar, J., & Patel, V. K. (2021). CFD analysis of the flow characteristics of in-line drip emitter with different labyrinth channels. Journal of The Institution of Engineers (India): Series A, 102(1), 111-119.

[16] Saraf, S. B., &Gawali, D. H. (2017, May). IoT based smart irrigation monitoring and controlling system. In 2017 2nd IEEE international conference on recent trends in electronics, information & communication technology (RTEICT) (pp. 815-819).IEEE.

[17] Hiskakis, M., Babou, E., &Briassoulis, D. (2011). Experimental processing of biodegradable drip irrigation systems-possibilities and limitations. Journal of Polymers and the Environment, 19(4), 887-907.

Additional Resources http://acl.digimat.in /nptel/courses/video/126105019/lec60.pdf

ii.https://www.nabard.org/auth/writereaddata /tender/2708244711pub_180424122358990.pdf

iii.https://www.iitkgpfoundation.org/article.html?aid=1211&nl=

iv. https://www.startus-insights.com /innovators-guide/irrigation-industry-trends/

v.https://www.pib.gov.in/PressReleaseIframePage.aspx?PRID=2003188

vi.https://pdmc.da.gov.in/files/guideline/Revised_PDMC_Guidelines2024.pdf

vii.https://onlinecourses.nptel.ac.in/noc24_ag13/preview

viii.https://www.echocommunity.org/en/resources/71472816-9265-4532-8218-3a29d67be20d

ix.https://rae.agriculturejournals.cz/artkey/rae-202501-0004_development-of-smart-micro-irrigation-system-using-arduino-uno-for-okra-cultivation-in-bangladesh.php

x.https://journalijecc.com/index.php/IJECC/article/view/4154

xi. https://www.switchon.org.in/wp-content/uploads/2024/08/Impacts-of-Micro-Irrigation-Technologies-in-Maharashtra.pdf

xii.https://www.netafimindia.com/blog/why-micro-irrigation-is-the-future-of-agriculture-in-india/

xiii. https://farmonaut.com/precision-farming/agriculture-micro-irrigation-system-market-2025-trends

Role of AI and IoT in Precision Irrigation Systems

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Introduction

Irrigation along with the use of high yielding varieties, chemical fertilizers and use of crop protection chemicals resulted in the green revolution in India. The green revolution resulted in achieving the self-sufficiency and food security in India. Post independence, Government of India has invested heavily on creation of irrigation infrastructure in the country. As a result, created irrigation potential in India increased from 22.6 Mha in 1950-51 to 113.50 Mha in 2012 (CWC, 2024). However, not enough emphasis was given to efficient utilization of created irrigation potential. Due to this, the gap between created and utilized irrigation potential kept increasing. Utilized irrigation potential was reported to be 87.92 Mha (CWC, 2021). Because of incomplete or absent in some cases the tertiary canal water distribution systems, unlined water courses and scheduling of canal irrigation supplies without any regard to the crop water requirements in its command resulted in an average overall, conveyance and application efficiencies are 38% in major canal irrigation systems. However tank irrigation and well/ tubewell irrigation these efficiencies were much higher owing basically to the possibility of need based water delivery to crops.

From the period from mid-seventies, Government of India has established several institutes and organization to develop technologies and policies for efficient utilization of water resources in agriculture sector. Studies carries out in India suggest that on-farm irrigation efficiency can be enhanced to 80-90% with efficient irrigation methods such as sprinkler and drip. Even with piped supply of irrigation water at field level, efficiency can be enhanced to 75%. Technological interventions such as laser levelling zero tillage and direct sown rice can save irrigation water by 10-33% (Jat et 2009; Ernstein et al 2007). The Government of India has also launched several initiatives such as the RashtriyaKrishiVikasYojana (2007), National Mission on Water (2010), National Mission on Sustainable Agriculture (2014), Pradhan Mantri Krishi SinchayeeYojana (2015), and to promote sustainable irrigation practices. Automation, use of AI and IoT in large canal systems seems difficult and time and money intensive proposition in view of the present status of our canal system infrastructure. Small tank and tubewell irrigated commands owing to their better water distribution control appear better for efficient irrigation. Many researches have shown that the Precision irrigation systems are the right candidate for applying AI and IOT which can significantly enhance water productivity and reduce input costs while ensuring optimal crop growth.

Need for Precision Irrigation

Traditional irrigation methods, such as flood irrigation, borders, check basins and furrow irrigation systems often lead to excessive water use, uneven distribution, and increased soil erosion. This results in significant water wastage and nutrient leaching, negatively impacting both agricultural productivity and environmental

sustainability. Additionally, inefficient irrigation contributes to the depletion of groundwater resources, which is already a major concern in India. With climate change intensifying the unpredictability of rainfall patterns, precision irrigation becomes essential to ensure efficient water use and maintain soil health.

Precision irrigation systems, including drip irrigation and sprinkler irrigation systems, provide better control over water distribution, ensuring that crops receive the right amount of water at the right time. However, even these advanced systems require manual operation or predefined schedules, which do not account for real-time variations in soil moisture, weather conditions, and crop water requirements. This is where Artificial Intelligence (AI) and the Internet of Things (IoT) may play a crucial role. These technologies enable automated, real-time decision-making to optimize irrigation based on continuous data collection, analysis and synthesis ensuring maximum water-use efficiency and higher agricultural yields.

Benefits of AI and IoT in Irrigation

The integration of AI and IoT in precision irrigation may bring multiple advantages, improving agricultural sustainability and economic viability. One of the key benefits may may be enhanced water use efficiency, as AI-driven models may analyze historical and real-time data to determine optimal irrigation schedules. These models may account for factors such as soil type, crop growth stages, weather conditions, and evapotranspiration rates to minimize water loss due to evaporation and runoff. By preventing over-irrigation and under-irrigation, AI-based systems help maintain optimal soil moisture levels, leading to healthier plant growth and higher productivity. The internet of things technologies help monitoring, collating and analyzing all different soil, water, environment and crop data without human interference making the system completely autonomous. From an economic perspective, precision irrigation using AI and IoT results in cost savings by optimizing input usage. Efficient water and fertilizer application prevent excessive use of resources, lowering production costs and enhancing crop quality and yield, leading to better market prices and increased farmer income. Furthermore, precision irrigation contributes to environmental sustainability by reducing excessive water withdrawal from groundwater sources and minimizing soil degradation.

The application of AI-powered decision support systems, remote sensing technologies, and predictive analytics ensures that precision irrigation systems remain adaptive to changing environmental conditions. For example, satellite imagery and drone technology can be used to assess plant health, detect water stress areas, and optimize irrigation in real time. Similarly, machine learning algorithms can continuously improve irrigation strategies based on past performance, making the system more efficient over time.

Components of AI and IoT-Based Precision Irrigation Systems

A. Sensors and Data Acquisition

- Soil moisture sensors measure soil water content and relay information to a central processing unit, ensuring irrigation decisions are based on actual field conditions rather than assumptions.
- Climate sensors track environmental parameters such as temperature, humidity, solar radiation, and wind speed, which influence crop water requirements.
- Soil nutritional status sensors track the status of different major and essential minor nutrients in soil, application timings and concentrations of different fertilizers, controlling fertilizer applicators,
- Water quality sensors monitor factors like pH, salinity, and nutrient levels, ensuring that irrigation water meets the required

standards for crop health and soil conservation.

B. IOT Infrastructure

*Smart controllers play a critical role by receiving real-time data from sensors and making automatic adjustments to irrigation schedules. These controllers integrate with

*Cloud computing and data analytics platforms, where AI-driven algorithms analyse sensor inputs and determine the precise amount of water needed to facilitate uninterrupted data exchange

*Wireless communication networks such as Wi-Fi, Bluetooth, LoRa, and 5G enable real-time connectivity between devices, allowing farmers to monitor and control irrigation remotely using mobile applications or web-based dashboards.

C. AI Algorithms for Irrigation Optimization

*Predictive analytics utilize machine learning models to anticipate crop water requirements based on historical weather patterns, soil characteristics, and crop growth stages

*Decision support systems assist farmers by recommending ideal irrigation schedules and fertilizer application rates, ensuring optimal resource utilization.

*Remote sensing technologies such as drone and satellite imaging provide high-resolution insights into field conditions, enabling early detection of water stress and disease outbreaks. These AI-driven tools collectively enhance the precision and effectiveness of irrigation management.

Challenges and Constraints in the Adoption of AI and IoT in Precision Irrigation

High Initial Costs

The installation of smart irrigation systems requires a substantial initial investment in various components, including sensors, automated controllers, cloud-based data storage, and AI-powered decision-making software. Although government subsidies and financial assistance programs help mitigate some of these costs, affordability remains a significant concern for small and marginal farmers.

Energy Requirements

Automated irrigation systems, particularly those relying on IoT devices, require a reliable and continuous power supply to function efficiently. However, many rural and agricultural regions suffer from frequent power outages or lack access to stable electricity. This energy constraint affects the reliability and effectiveness of AI-driven irrigation solutions. To overcome this challenge, alternative energy sources, such as solar-powered irrigation systems, are being explored but these add a further cost of the system.

Farmer Awareness and Technical Knowledge

One of the major barriers to the widespread implementation of precision irrigation technologies is the limited awareness and technical knowledge among farmers. Capacity-building initiatives, including training programs, field demonstrations, and extension services, play a crucial role in bridging this knowledge gap. Collaborative efforts between government agencies, research institutions, and agri-tech companies are necessary to enhance farmer education and encourage the adoption of smart irrigation technologies.

Data Privacy and Cybersecurity

The integration of IoT in precision irrigation involves the collection and transmission of vast amounts of real-time data, including soil moisture levels, weather conditions, crop health parameters, and water usage patterns. Ensuring data security and protecting farmers' sensitive information from cyber threats is a significant challenge. Implementing robust cybersecurity measures, such as encryption, secure authentication protocols, and regular system updates, is essential to safeguard data privacy and maintain trust in AI-powered irrigation systems.

Policy Support and Government Initiatives

The Indian government has taken several

proactive steps to promote precision irrigation, recognizing its significance in enhancing water-use efficiency and ensuring sustainable agricultural practices. Various policy measures and financial schemes have been introduced to support farmers in adopting modern irrigation technologies.

One of the key initiatives is the Micro Irrigation Fund (MIF), which provides financial assistance for micro-irrigation projects to facilitate the expansion of micro-irrigation systems across the country, reducing water wastage and improving crop productivity.

Another crucial scheme is the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) - Per Drop More Crop Component, which emphasizes the need for efficient water use in agriculture. This initiative promotes drip and sprinkler irrigation methods, encouraging farmers to optimize water resources while maintaining high agricultural yields.

To further incentivize the adoption of precision irrigation, the government provides subsidy programs that offer financial assistance to farmers investing in micro-irrigation systems.

Additionally, the government is promoting Public-Private Partnership (PPP) models to foster collaboration between government agencies, private companies, and research institutions to develop and implement affordable AI and IoT-based irrigation solutions, integrating smart technology with traditional farming practices to maximize efficiency and sustainability.

Future Prospects and Recommendations

*The integration of AI and IoT in precision irrigation has immense potential to revolutionize agricultural practices, enhancing productivity and resource efficiency. However, to accelerate its adoption and ensure widespread implementation, several key measures need to be taken.

*One of the most critical aspects is increased funding for research and development (R&D). Both government and private sectors should invest in innovative research to develop cost-effective and scalable smart irrigation solutions.

*Another crucial step is the integration of precision irrigation with renewable energy sources, particularly solar power. This approach can also lower operational costs for farmers while supporting environmental conservation.

*To ensure successful implementation, farmer training and awareness programs should be prioritized. Organizing regular workshops, field demonstrations, and knowledge-sharing platforms will help farmers understand the benefits of AI and IoT-based irrigation.

*The use of AI-based decision support tools can further enhance precision irrigation. User-friendly mobile applications equipped with real-time data analytics, weather predictions, and irrigation scheduling can assist farmers in making informed decisions, reducing water wastage and improving crop yields.

*Additionally, blockchain technology for data management can play a significant role in ensuring secure and transparent data handling for precision agriculture applications. By leveraging blockchain, farmers, researchers, and policymakers can track and analyze irrigation data more efficiently, leading to better decision-making and resource allocation.

Conclusion

Precision irrigation using AI and IoT technologies hold immense potential for revolutionizing Indian agriculture by improving water use efficiency, reducing input costs, and enhancing crop productivity. While challenges such as high costs, energy availability, and farmer awareness exist, strategic government interventions, private sector participation, and technological advancements can accelerate the adoption of these systems. By integrating modern irrigation technologies with sustainable practices, India can achieve food security while conserving vital water resources for future generations.

While the benefits of AI and IoT in irrigation are substantial, several challenges, including high initial investment costs, limited technical knowledge among farmers, and energy availability, must be addressed to ensure large-scale adoption. Government initiatives, such as subsidy programs and financial assistance schemes, play a crucial role in facilitating access to smart irrigation technologies. Additionally, integrating renewable energy sources, such as solar power, can enhance the sustainability and reliability of these systems, particularly in rural areas with unstable electricity supply.

Future efforts should focus on increasing research and development investments, promoting farmer education through training programs, and fostering public-private partnerships to develop cost-effective, scalable solutions. The use of AI-based decision support tools and blockchain technology for secure data management can further optimize irrigation practices and resource allocation.

Ultimately, the widespread adoption of AI and IoT in precision irrigation has the potential to revolutionize Indian agriculture, making it more resilient to climate change, economically viable, and environmentally sustainable. A collaborative approach involving policymakers, researchers, agri-tech companies, and farmers is essential to harness the full potential of smart irrigation systems, ensuring a water-secure future for agricultural productivity and food security in India.

Agricultural Processing Prospects in the Era of Vikasit Bharat

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Abstract

Agriculture remains the backbone of India's economy, but the transition from subsistence farming to value-driven agribusiness is essential to achieving the vision of Vikasit Bharat by 2047. Agricultural processing enhances farm profitability, generates rural employment, reduces post-harvest losses, and strengthens global trade competitiveness. This paper examines the current status, challenges, and opportunities for India's agro-processing sector, highlighting government initiatives, technological interventions, and export potential. By aligning infrastructure development, digital technologies, and sustainable practices with policy support, India can emerge as a global leader in agricultural value addition.

Keywords: Agro-processing, Vikasit Bharat, value addition, post-harvest losses, AI in agriculture, agricultural exports, food security, sustainable development

Introduction

From Fields to Global Frontiers

As India strides confidently toward the vision of Vikasit Bharat-a developed, self-reliant, and inclusive nation-the agricultural sector stands at a transformative crossroads. Traditionally the backbone of the Indian economy, agriculture is now poised to evolve beyond primary production into a value-driven ecosystem powered by processing, innovation, and global competitiveness.

Agricultural processing, which involves converting raw farm produce into consumable or industrial products, is emerging as a key driver of rural prosperity, employment generation, and export potential. In the era of Vikasit Bharat, its prospects are brighter than ever.

Unlocking the Potential: Agricultural Processing in Vikasit Bharat

The shift from subsistence farming to agribusiness marks a pivotal moment in India's development journey. Agricultural processing not only enhances the shelf life and market value of produce but also creates a ripple effect across the economy-stimulating rural entrepreneurship, reducing post-harvest losses, and integrating farmers into national and global value chains.

With initiatives like the Pradhan Mantri Formalisation of Micro Food Processing Enterprises (PMFME), the Agriculture Infrastructure Fund, and the push for Farmer Producer Organizations (FPOs), India is laying the groundwork for a robust agro-processing ecosystem. These efforts are complemented by advancements in cold chain logistics, digital platforms for farm-to-fork traceability, and skill development programs that empower rural youth.

As we envision Vikasit Bharat, agricultural processing becomes more than a strategy-it becomes a symbol of inclusive growth, technological empowerment, and sustainable development. It is the bridge between tradition and innovation, between local abundance and global opportunity.

From Policy to Prosperity: Building the Agro-Processing Revolution

The Indian government's proactive stance on agricultural transformation is evident in its multi-pronged approach. Schemes like PM-Kisan and e-NAM have digitized and democratized access to markets and capital, while the Production-Linked Incentive (PLI) scheme for food processing industries is attracting private investment and fostering innovation.

Moreover, the rise of agri-tech startups is revolutionizing how farmers interact with markets, monitor crop health, and access financial services. Technologies such as AI-driven crop analytics, blockchain-based supply chains, and IoT-enabled storage solutions are making agriculture smarter, more resilient, and more profitable.

State governments, too, are playing a vital role by creating agro-processing clusters, food parks, and export hubs that cater to region-specific crops-from millets in Karnataka to mangoes in Andhra Pradesh. These localized strategies ensure that the benefits of processing reach even the smallest farmer, turning villages into engines of economic growth.

Global Vision, Local Roots: India's Agricultural Future

India's agricultural exports have already crossed significant milestones, with processed goods like spices, ready-to-eat meals, and organic produce gaining traction in international markets. By aligning with global standards and sustainability goals, Indian agro-processing can become a cornerstone of soft power and economic diplomacy.

But beyond numbers and trade, the true promise of agricultural processing lies in its human impact. It empowers women through self-help groups, uplifts tribal communities through forest produce value addition, and creates dignified jobs for millions in rural India.

In the journey toward Vikasit Bharat, agriculture is not just about feeding the nation-it's about fueling its future. With the right blend of policy, innovation, and grassroots participation, India's fields can flourish into factories of opportunity, resilience, and pride.

Why Agricultural Processing Matters

Value Addition

Agricultural processing transforms raw produce into higher-value products, significantly boosting farmer income. For instance:

- Tomatoes turned into puree or ketchup can fetch 2-3 times the price of raw tomatoes.
- Millets are now processed into ready-to-eat mixes, snacks, and breakfast cereals, aligning with India's push for the "International Year of Millets 2023".
- According to IMPRI, the value of agricultural and processed food increased from $17.8 billion in 2015-16 to $20.65 billion in 2019-20, reflecting a growing shift toward secondary agriculture.

This value addition not only reduces wastage but also opens up new market opportunities, both domestic and international.

Employment Generation

Agro-processing units are powerful engines of rural employment. They create jobs in:

- Sorting, grading, packaging, logistics, marketing, and quality control.
- In 2017-18, over 32 lakh jobs were created in agro-based industries across selected Indian states, up from 27 lakh in 2001-02.
- These units especially benefit women and youth, with many self-help groups and

micro-enterprises emerging around food processing.

By localizing processing facilities, India can reduce rural-to-urban migration and foster inclusive development.

Food Security

Processed foods have longer shelf lives, making them easier to store and distribute. This is crucial in India, where:

- Post-harvest losses of fruits and vegetables range from 25% to 40%, amounting to over ?30,000 crore annually.
- Processing helps stabilize supply chains and ensures year-round availability of nutritious food, even in remote areas.
- According to KPMG, over 19.46 crore Indians-about 13.4% of the population-are chronically undernourished. Efficient food processing can help bridge this gap.

Export Potential

Processed agricultural products are more competitive globally due to better packaging, quality, and shelf stability.:

- India exported $48.15 billion worth of agricultural products in FY24, with processed goods making up ~17% of that total.
- Products like ready-to-eat meals, spices, organic snacks, and fruit pulps are gaining traction in markets like the USA, UAE, and Europe.
- APEDA has identified 50 high-potential products and set up 13 Agri-Cells in Indian embassies to boost exports.

With better branding and adherence to global standards, India can become a global leader in value-added food exports.

Sustainability

Efficient processing reduces post-harvest losses and promotes resource optimization. Sustainable practices include:

- Solar drying, biogas-powered units, and water-efficient cleaning systems.
- India's food-processing sector contributes to sustainability by lowering waste: cereal losses range between 3.89% and 5.92%, while fruit and vegetable losses range from 4.87% to 15.05%.
- The PM Kisan SAMPADA Yojana and PLI Scheme support eco-friendly innovations in food processing, including organic and millet-based products.

Current Landscape and Challenges in Agro-Processing

Despite its immense potential, India's agro-processing sector grapples with several structural and operational hurdles that limit its growth and impact. Here's a deeper look at the key challenges:

Fragmented Supply Chains

India's agricultural supply chains are often disjointed, involving multiple intermediaries. For example, onion farmers in Maharashtra typically sell through 4-5 layers of traders before reaching consumers, reducing their share of profits. Nearly 40% of produce can spoil during transit due to poor coordination and lack of cold chain integration. Agritech startups like Vegrow are working to streamline farm-to-fork logistics using digital platforms.

Inadequate Infrastructure

India faces a cold chain deficit of over 27 million metric tonnes, with only 15% of required refrigerated transport available. Pack-houses and ripening chambers are also severely lacking-over 90% shortfall in availability. This leads to post-harvest losses estimated at ?92,651 crore annually, especially for perishables like mangoes

and guavas.

Limited Access to Technology

Small and marginal farmers often lack exposure to modern agro-processing tools like smart sensors, AI-based crop diagnostics, and precision farming equipment. High upfront costs and limited digital literacy hinder adoption. Although India has over 1,300 agri-tech startups, their reach remains concentrated in select regions.

Regulatory Bottlenecks

Complex compliance procedures-such as multi-state licensing, redundant inspections, and outdated labelling norms-create barriers for small processors. For instance, launching a single fertilizer product nationally requires separate approvals in each state, raising costs by 8-15%. MSMEs often face delays due to non-accredited testing labs and inconsistent enforcement.

Financial Constraints

Seventy eight percent of small and medium processors report inadequate access to seasonal financing. High interest rates, lack of collateral, and limited awareness of schemes like PMKSY and AIF restrict investment. The unorganized sector, which employs over 5 million workers, struggles to scale due to poor access to formal credit and insurance.

These challenges are not insurmountable. With targeted policy reforms, public-private partnerships, and grassroots innovation, India can unlock the full potential of agro-processing as a driver of rural transformation and economic resilience.

Opportunities in The Vikasit Bharat Era

The vision of Vikasit Bharat-a developed, inclusive, and self-reliant India-ushers in a new era of possibilities for agricultural processing. With strategic reforms, technological innovation, and grassroots empowerment, the sector is poised to become a cornerstone of India's economic and social transformation.

Digital Empowerment

India's agricultural landscape is undergoing a digital revolution, with AI, IoT, and blockchain reshaping traditional farming and processing methods:

- AI-powered crop monitoring and disease detection tools like those from CropIn and Fasal help farmers make data-driven decisions, reducing pesticide use and improving yields.
- IoT-enabled smart irrigation systems can reduce water usage by up to 40%, while AI-based weather forecasting boosts productivity by 30%.
- Blockchain-based traceability platforms ensure food safety and transparency from farm to fork, enhancing consumer trust and export readiness.
- E-commerce platforms like DeHaat and AgriBazaar connect farmers directly to processors and consumers, bypassing middlemen and increasing margins.

Infrastructure Development

Robust infrastructure is the backbone of agro-processing. Under PM Gati Shakti, India is investing ₹11.17 lakh crore across 400+ integrated projects to streamline logistics and rural connectivity:

- Cold chain capacity is expanding to address the current deficit of 27 million metric tonnes, reducing post-harvest losses.
- Food parks and warehousing hubs are being developed under schemes like PMKSY, enabling cluster-based processing and storage.

- Multi-modal logistics parks and rural road upgrades are improving last-mile delivery, especially for perishable goods.

Policy Support

Government schemes are catalyzing investment and innovation in agro-processing:

- The Production Linked Incentive (PLI) Scheme for food processing has an outlay of ₹10,900 crore, targeting segments like ready-to-eat foods, millets, marine products, and organic goods.
- The scheme aims to generate ?33,494 crore in processed food output and create 2.5 lakh jobs by 2026-27.
- Simplified FPO frameworks under the 10,000 FPO Scheme empower farmers to collectively invest in processing units, access credit, and scale operations.

Skill Development

Building a skilled workforce is essential for agro-processing growth:

- Under Skill India, over 19 lakh candidates have been trained in agriculture-related roles through the Agriculture Skill Council of India (ASCI).
- Organizations like FICSI offer specialized certification in food safety, packaging, and processing, with programs tailored for rural youth and women entrepreneurs.
- Courses on millet processing, poultry farming, and food entrepreneurship are available through the Skill India Digital Hub, making skilling accessible and localized.

Sustainability and Innovation

Climate resilience and circular economy models are gaining traction:

- India produced 3.6 million metric tons of certified organic produce in FY 2023-24, with exports worth ?4,007 crore.
- Schemes like Paramparagat Krishi Vikas Yojana (PKVY) and MOVCDNER promote organic farming and value-added processing in tribal and rainfed regions.
- Waste-to-wealth models are turning by-products like husks, peels, and pulp into bioenergy, compost, and packaging materials.
- Organic liquid formulations such as Panchagavya and Jeevamrutha are improving soil health and crop quality, especially in horticulture.

The Road Ahead

In the Vikasit Bharat era, agricultural processing is not just a sector-it's a movement. It blends tradition with technology, local wisdom with global ambition, and economic growth with ecological stewardship. With the right mix of policy, innovation, and community participation, India's agro-processing industry can become a global benchmark for inclusive and sustainable development.

Global Outlook and Export Potential

India's diverse agro-climatic zones and rich culinary heritage position it uniquely to become a global leader in processed agricultural exports. With rising global demand for ethnic, organic, and health-focused foods, India's agro-processing sector is primed to tap into lucrative international markets.

Ready-to-Eat Traditional Foods

India's ready-to-eat (RTE) segment is booming, driven by demand for convenience and authentic flavors. Products like instant biryani, idli mixes, and gulabjamun kits are gaining popularity across the globe. In FY 2020-21, India exported over $2.14 billion worth of RTE, Ready-to-Cook (RTC),

and Ready-to-Serve (RTS) products, with a 24% growth in RTE alone. Major destinations include the USA, UAE, Canada, and Australia, where Indian diaspora and global consumers alike seek traditional tastes with modern packaging. Brands like Haldiram's and Bikanervala have become household names abroad, showcasing the global appetite for Indian comfort foods.

Organic and Health-Focused Products

India is the world's largest producer of organic cotton and has over 4.4 million organic farmers, the highest globally. In FY 2024-25, India's organic exports surged 35% to $666 million, led by cereals, spices, tea, and medicinal plants. With the global organic market valued at $135 billion, India's current share remains under 1%, indicating vast untapped potential. Government schemes like ParamparagatKrishiVikasYojana (PKVY) and MOVCDNER are promoting organic clusters and certification, while the revamped National Programme for Organic Production (NPOP) aligns Indian standards with global benchmarks. Organic millets, turmeric, and herbal teas are emerging as flagship exports in this category.

Ethnic Beverages and Condiments

India's spice exports reached $3.73 billion in 2022-23, with chili, cumin, turmeric, and coriander dominating the global market. Ethnic condiments like pickles, chutneys, curry pastes, and masala sauces are increasingly sought after in Europe, North America, and Southeast Asia. In FY 2023-24, India exported $1.15 billion worth of prepared vegetables, fruits, and nuts-including pickles and mixed curries. Beverages like masala soda, herbal infusions, and Ayurvedic tonics are gaining traction among health-conscious consumers. The Spices Board of India and APEDA are actively promoting these products through international expos and branding initiatives.

Plant-Based Proteins and Nutraceuticals

India's smart protein sector-including plant-based meat, dairy, and eggs-is projected to reach $3.8 billion in total market opportunity by 2030. The export potential alone ranges from $480 million to $1.4 billion, with products like pea protein, soy isolates, and herbal supplements leading the charge. India's nutraceutical exports grew 37% year-on-year, with over 1,800 shipments to 69 countries between 2023 and 2024. Key markets include the UK, Singapore, and Sri Lanka, which together account for over 55% of exports. MSMEs are leveraging India's Ayurvedic heritage and cost advantage to produce functional foods, herbal capsules, and fortified drinks, supported by schemes like PMFME and SHEFEXIL.

Conclusion

Agricultural processing is no longer a peripheral activity-it is the beating heart of India's rural renaissance. It represents a shift from subsistence to sustainability, from raw output to refined opportunity. In the era of Vikasit Bharat, this sector embodies the spirit of transformation: empowering farmers not just as cultivators, but as entrepreneurs, innovators, and global contributors.

By integrating technology, infrastructure, policy, and community participation, agricultural processing can redefine the rural economy. It has the power to reduce poverty, generate dignified employment, and ensure food security for millions. From tribal villages in Odisha producing organic turmeric to millet entrepreneurs in Rajasthan exporting gluten-free snacks, the stories of change are already unfolding.

India's vast biodiversity, rich culinary heritage, and youthful workforce give it a unique edge in building sustainable agri-value chains. With climate-smart practices, digital traceability, and

global branding, India can lead the world in ethical, nutritious, and culturally rooted food products. The sector also plays a vital role in achieving the Sustainable Development Goals (SDGs), particularly those related to zero hunger, decent work, responsible consumption, and climate action.

The seeds of change have been sown. Now, with strategic nurturing-through investment, innovation, and inclusive governance-agricultural processing will bloom into one of the defining pillars of India's developed future. It is not just about transforming crops; it is about transforming lives, landscapes, and legacies. India is rapidly embracing AI and ML in agricultural processing, with both government and private sectors driving innovation across the value chain. As India moves from farm to future, agro-processing will be the bridge that connects tradition with technology, local abundance with global ambition, and rural resilience with national pride.

Agriculture 4.0: Innovations and Automation for Sustainable Mechanization

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Abstract

India's agricultural production has a major challenge to sustain burgeoning population which will be approximately 1.7 billion people by 2050 while contending with restricted cultivable land, water, farm power and energy resources. This context sets the stage for Agriculture?4.0, which combines precision agriculture and automation to revolutionize Indian agriculture, making it more efficient, sustainable and resilient. Although the available farm machineries have helped to reduce labour cost and improve efficiency, but still lacksthe precision needed for the meticulous application of seeds, water and fertilizers on field. Technologies like sensors, GPS, GNSS, drones (UAVs), artificial intelligence (AI) and Internet of Things (IoT) are now helping farmers make better decisions and manage their farms more effectively. In India, agricultural research organizations like ICAR, SAUs and IITsare playing a key role in developing smart machineries like robotic weeders, drone sprayers, automatic harvesters and yield monitors. These advanced innovations will streamline the farming activities such as sowing, irrigation, pest control and harvesting. Government policies are also encouraging the use of drones, artificial intelligence and digital tools to make farming more effective and sustainable. The article explores key innovations and institutional contributions while also addressing the persistent barriers to adoption. It concludes by proposing strategic interventions to enhance the reach, affordability and impact of Agriculture 4.0 for sustainable growth of Indian agriculture.

Keywords: Agriculture 4.0, Mechanizations, Artificial Intelligence, IoT,

Introduction

The global challenge of ensuring food security for a projected population of 9.9 billion by 2050 necessitates a 98% increase in food production from current level(Dhanyaet al., 2022). This urgent demand must be met with constrained cultivable land, depleting water resources, rising energy costs, and increasing climate variability. In this context, a new paradigm shift is needed through integrating automation, digitization, data analytics, and precision technologies.

India, which is set to host approximately 1.7 billion people by 2050, also faces the same set of challenges. The net sown area has stagnated at around 140 million hectares and is expected to decline further. The scope for horizontal expansion of cultivable land is extremely limited. According to the Agriculture Census 2015-16, small and marginal landholdings (less than 2 ha) constitute 86per cent of all operational holdings, covering 47% of the total cultivated area. Moreover, the average landholding size has declined significantly from 2.82 ha in 1970-71 to just 1.08 ha in 2015-16, intensifying fragmentation and limiting the economies of scale necessary for mechanized and high-efficiency farming.These constraints have urgedthe necessity of producing more with less and therefore demands an urgent shift toward resource efficient and technology-driven

solutions. Efficient use of inputs capital has become imperative for sustainable agricultural intensification.(Ranganathanet al., 2018 and Agrawal and Bangale, 2023)

As rural-to-urban migration intensifies, the rural population is expected to shrink in the coming years. This reinforces the critical need for inclusive, adaptive mechanization and automation strategies tailored to smallholder-dominated systems. The basic target of the mechanization of various farm operations is to ensure timeliness of operations; proper placement of inputs, reduce the drudgery and cost of operation. The farm mechanization level of different crops is at varying level. It indicates that the seedbed preparation operation is highly mechanized (approx. 70%) for major crops whereas harvesting and threshing operation is the least mechanized (approx. 34%) for major crops except for rice and wheat crops. In seedbed preparation, mechanization level is higher in rice and wheat crops as compared to other crops. The overall farm mechanization levels for rice, wheat, maize, millets, pulses, oil-seeds, cotton and sugarcane crops are 53, 69, 46, 33, 41, 39, 36 and 35%, respectively(Mehta et al., 2023). The overall farm mechanization level of the country is 47% which is lower than other developing countries such as China (59.5%) and Brazil (75%).

To sustain the mechanization efforts, Agriculture 4.0 offers a transformative opportunity to bridge these mechanization gaps through digital innovations, automation, and precision farming techniques. Modern advancements such as Global Positioning Systems (GPS), Geographic Information Systems (GIS), remote sensing, autonomous machinery, Internet of Things (IoT), cloud computing, and data analytics are leading to create intelligent and interconnected farm ecosystems.

The agricultural innovations needs to ensure the optimal use of inputs like water, fertilizers, and pesticides resulting in waste reduction and better environmental health. Autonomous machinery and smart sensors reduce labor dependency and improve operational efficiency, particularly during critical operations like planting, irrigation, and harvesting. Cloud-based platforms and mobile applications enhance decision-making by providing real-time, location-specific advisories to farmers. This technology-driven transformation not only increases productivity and resource-use efficiency but also makes farming more climate-resilient and economically viable for small land holders. As a result, Agriculture 4.0 plays a pivotal role in promoting sustainable agricultural intensification while addressing labour shortages and resource constraints. (Agrawal and Bangale, 2023)

The paper explores how India can move towards Agriculture 4.0 by adopting innovation, automation, and sustainable mechanization. It underlines the importance of making these advancements accessible to small and marginal farmers through inclusive technologies, strong policies, and skill development.

Global Transition towards Agriculture 4.0

While Agriculture 4.0 is gaining momentum worldwide, its pace and form of adoption vary significantly across regions based on economic, technological and policy readiness. Developed countries are at the forefront of this digital transformation, implementing innovations such as robotic milking systems in Europe, autonomous tractors in the United StatesandAI-based crop management platforms in Japan. These technologies are re-shaping manual practices to automated, predictive and precision-driven systems. In contrast, developing countries like India are also gradually integrating precision

and digital technologies with drone-based applications for crop monitoring, pesticide spraying and field mapping.

In Brazil, the adoption of drone-assisted spraying, remote sensingand yield mapping technologies has significantly improved sugarcane and soybean productivity. China has promoted Agriculture 4.0 through national-level programs encouraging AI, big data, and smart sensors for real-time farm monitoring, pest forecasting and intelligent irrigation. Likewise, European Union countries are leveraging subsidies under the Common Agricultural Policy (CAP) to motivate the adoption of digital twins, blockchain traceability and carbon farming technologies.

High-income countries are leading the adoption of precision mechanization in agriculture with technologies such as Global navigation satellite system (GNSS) guided machinery, autonomous robots, and drone-enabled input applications. These innovations significantly improve labour efficiency, ensure timely operations, and reduce soil compaction. However, adoption remains minimal among smallholder farms in low-income regions, particularly across Africa and Asia due to high costs, limited infrastructure and poor adaptability to fragmented landholdings.

In the domain of food processing and post-harvest technology, developed nations are leveraging AI-powered sorting systems, IoT-based monitoring tools, and block-chain for traceability to minimize losses and improve product quality. These technologies are transforming global value chains, yet their penetration in developing countries remains limited due to high capital investment needs and a lack of skilled workforce.Soil and water conservation practices have also been revolutionized by Agriculture 4.0. Smart irrigation systems incorporating IoT sensors for real-time monitoring of soil moisture and environmental parameters are being piloted in regions like Southeast Asia and Africa. These systems enable more precise and efficient water use, reducing both water wastage and labor input.

However, a major concern in the global discourse is the digital divide. In regions of Sub-Saharan Africa, South Asia, and parts of Southeast Asia, challenges such as high cost of technologies, low internet penetration, inadequate digital literacy and weak mechanization infrastructure hinder the widespread adoption of these technologies. The success of these technologies depends not only on innovation but also on the availability of localized data, user-friendly platformsand affordable business models tailored to smallholder realities.

Trends and Prospects in India

India is steadily embracing Agriculture 4.0, with notable advancements in digital and automated farming technologies aimed at addressing the constraints of fragmanted agriculture. Key innovations include the adoption of drones for pesticide spraying and crop monitoring, sensor-based precision irrigation systems and mobile-based advisory platforms powered by artificial intelligence. Government initiatives such as the Sub-Mission on Agricultural Mechanization (SMAM) and financial incentives for drone use are accelerating the transition. Also, the agritech start-ups are playing a crucial role in making smart technologies more accessible to small and marginal farmers. Despite progress, the widespread adoption of Agriculture 4.0 remains challenged by high initial costs, limited digital literacy, and inadequate rural infrastructure. Nonetheless, with growing policy support, private sector engagement and localized R&D, India holds significant potential to scale sustainable mechanization and emerge as a key player in the global digital agriculture movement.

Power specific machinery and implements

The development of agricultural machinery is moving towards efficiency and sustainability, prioritizing power systems that meet, but do not exceed, actual operational demands. In the present scenario, a farmer is using the same power source for both heavy and low powered implement resulting in wastage of energy and resources.This mismatch not only leads to higher fuel consumption but also increases operational costs and environmental impact. So to minimize and obtain a specific power demaning machine, the approach of self-propelled machinery has been blooming up.This type of designed machine and implements minimizes unnecessary energy and fuel consumption, thereby enhancing overall efficiency and promoting environmental sustainability.

Land preparation

The application of next generation technologies in seedbed preparation has brought a paradigm shift toward precision, energy efficiency, and soil-specific mechanization. Globally, advancements such as GNSS-based navigation, sensor-assisted tillage depth control and real-time soil parameter monitoring have significantly improved the uniformity and quality of seedbeds. In India, several region-specific mechanization technologies tailored for fragmented farming have been developed and promoted. Tractor-operated adjustable rotavator (ICAR-CIAE, Bhopal developed) and sensor-integrated tillage implements provide soil-responsive feedback for efficient field preparation. Among the notable technologies, laser land leveling has emerged as an effective precision land preparation method, reducing irrigation water losses caused by undulating topography and lowering energy use by minimizing irrigation duration (Ali et al., 2018; Aryalet al., 2015; Nareshet al., 2011). Successful adoption of laser land levelers has been reported across irrigated belts of Punjab, Haryana, and Western Uttar Pradesh. The similar concept of laser land levelling has been used for development of tractor operated system for controlled level puddling operation by AICRP on FIM, TNAU, Coimbatore centre(Anonymous, 2022a). This controlled level peddler covers 0.26 ha area in one hour with Rs. 2300 per hectare as cost of operation.

Seeding and Planting

Seed or plant saplings are input which requires to be optimized for economic gains. The significant transition from conventional practices to smart, data-driven, and energy-efficient systems, particularly in the area of seeding and planting has been fostering up rapidly. These operations directly impacts the yield potential and resource use efficiency of crops. Precision planting technologies ensure uniform seed placement at predefined depths and intra-row spacing, promoting uniform crop emergence and reducing inter-plant competition for water, nutrients, and sunlight. In this context, several Indian institutions have developed machinery integrated with sensors, microcontrollers and control systems. As first strep, a ground-speed sensor-based seed-cum-fertilizer drill, incorporating a PWM motor to minimize skidding, has been developed with operational speed ranging from 2.6 to 4.5 km/h. The system demonstrated variation in seed rate and fertilizer rate from -3.14 to 2.43 % and -1.61 to 4.55%, respectively, indicating a high level of precision in metering mechanism.

To address the challenges of small and fragmented land holdings in hilly and wetland areas, CAU, Gangtokhas developed a remote-controlled direct rice seeder. It is operated via android-based smartphone using Wi-Fi

connectivity. The equipment enables sowing of pre-germinated rice in wet fields with a field capacity of 0.02 ha/h and a forward speed of 0.7 km/h. The hill spacing uniformity was reported at 94%, highlighting its suitability for precision sowing in difficult terrains.The microcontroller based seed metering units have also been successfully implemented in precision planters for crops like maize, cotton, soybean, and groundnut. A precision planter developed at PJTAU, Hyderabad for maize and cotton reported a quality feed index of 84% at an average operating speed of 2.5 km/h, reflecting the role of embedded electronics in achieving consistent seed spacing and placement.

In transplanting, automation and remote operation are gaining traction. A multi-functional remote-controlled ride-on rice transplanter has been developed at ICAR-CIAE Regional centre, Coimbatore. The system includes programmable control units for steering, movement, and transplanting functions with remote accessibility up to 500 m. It achieved a field capacity of 0.24 ha/h, with 71% field efficiency and a fuel consumption of 3.1 l/ha at 1.61 km/h forward speed and 12per cent wheel slip.Punjab Agricultural University (PAU), Ludhiana, has also introduced a virtual reality (VR)based system for a two-row rice transplanter. The machine is operated remotely via FPV (first-person view) cameras and head-mounted display (HMD), allowing real-time visualization and control of transplanting in the field. This innovation signifies a new frontier in precision agriculture through immersive automation.The integration of such smart seeding and planting technologies with data analytics will further enable the reduced labour, optimized input usage, and enhanced crop productivity, particularly within the constraints of Indian farming system.

Fertilizer applications

Nutrient management plays a crucial role in determining crop productivity and soil health. Among all inputs, fertilizers account for a significant portion of energy use and input costs. However, indiscriminate or imbalanced application of fertilizer often results in yield loss and long-term soil degradation. Though the soil testing providesthe scientific information about the soil's fertilizer requirements, but its adoption remains limited due to the time-consuming nature of laboratory analysis. To address this, new techologies promotes the integration of digital tools and real-time sensors that enable site-specific nutrient management, encouraging farmers to adopt more precise and sustainable fertilization practices.

Nutrient sensing technologies have advanced with the development of specialized NPK sensors capable of real-time measurement of nitrogen (N), phosphorus (P), and potassium (K) levels in soil. These sensors operate on colorimetric and photoconductivity principles, enabling the detection of nutrient concentrations with considerable accuracy. The sensor data is directly transmitted to a processing unit or system-on-chip (SoC) for preliminary analysis. Further computational processing is performed through fog or edge computing paradigms. In fog computing, data processing is performed near the sensing node, minimizing latency and reducing data transmission requirements. In edge computing, the data is processed through an edge server connected via the internet. Fuzzy logic-based decision algorithms are then applied to interpret the data and provide site-specific recommendations for fertilizer dosages based on localized requirements.

To assess the nitrogen status of standing crops, a portable and cost-effective SPAD measurement

device has been developed by ICAR-CIAE, Bhopal. This handheld sensor facilitates non-destructive estimation of chlorophyll content in crop leaves, thereby serving as an indirect indicator of plant nitrogen status. The device can be interfaced with an OTG-enabled Android smartphone, enabling real-time display and logging of SPAD values for data-driven nitrogen management in the field.GPS-based variable rate fertilizer applicators have also been developed at ICAR-CIAE, Bhopal and IIT Kharagpur, to address field-level nutrient variability. These systems employ differential GPS (DGPS), electronic control units, and digital application maps to modulate fertilizer application rates with high precision. Reported application accuracies range from 89 to 98%, with field-level variability managed between 11.7 to 15 %. A similar GPS-based variable rate applicator for granular fertilizers incorporates DC actuators, distance sensors, and customized control software to adjust dispensing rates dynamically based on spatial nutrient maps.

In sequence, a spectral reflectance-based variable rate urea applicator has been developed for top-dressing in rice and wheat crops. The system utilizes NDVI as an input to assess crop health and predict yield potential. Android and web-based applications have been developed for estimating crop specific nitrogen requirements based on NDVI values. The accompanying electronic control system regulates the fertilizer metering and dispensing mechanisms in real-time, ensuring precise application as per crop needs.For horticultural applications, a site-specific fertilizer applicator for grape vineyards has been developed at ICAR-CIAE, Bhopal. The system includes a mechanical sensing mechanism designed to identify plant positions and apply fertilizer directly in the root zone beneath the plant canopy, optimizing nutrient uptake and reducing wastage.

In Agriculture 4.0, these advancements in fertilizer application will further automate with the help of data analytics and automationfor advancing spatial variability into field-scale operations. Such technologies will not only reduce input costs and environmental impacts but also promote the adoption of sustainable mechanization practices tailored to Indian agro-ecological conditions.

Irrigation Systems and Water Management

The efficient water management system is crucial for meeting India's future food demands. The "per drop more crop" strategy, a cornerstone of India's agricultural policy, emphasizes optimized water use to enhance crop productivity while conserving the scarce resource. The integration of advanced technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), cloud computing, and decision support systems (DSS), is revolutionizing irrigation and water management practices in Indian agriculture.

Site-specific irrigation management, driven by automation technologies, offers a transformative approach to optimize water use efficiency across spatially variable fields. Wireless sensor-based irrigation control systems have shown significant potential to improve crop productivity by automating irrigation scheduling based on real-time soil moisture data. In a field experiment with wheat, irrigation was scheduled at 30% depletion of available soil moisture using sensor-based systems. In addition, a digital flume with IoT connectivity was developed using an ESP8266 micro-controller and ultrasonic depth sensors to continuously monitor flow rates in open channels. The system calculates discharge using flume equations and transmits the data wirelessly to a cloud server (ThingSpeak), enabling real-time flow monitoring and improved irrigation water management

To support micro-irrigation in complex topographies like terraced fields, a Decision Support System (DSS) was developed at CAEPHT, Gangtok, Sikkim. The DSS aids in designing gravity-based drip irrigation systems by enabling easy computation of hydraulic parameters, material requirements and installation cost. Similarly, a DSS-based automatic sprinkler irrigation system, equipped with telemetry-enabled soil moisture sensors and wireless control of pumps and valves, has been developed to automate irrigation based on real-time field data. These developments has to go further ahead in automating the irrigation systems based on real time measurement and addressing the field level variability as per crop demand. The further advancement will lead to reduction of water requirement with maximized production.

Weed and Pest management

The reliance on chemical-based pest control methods in traditional agriculture poses considerable risks to environmental sustainability and human health. IOTenabled pest surveillance systems can remotely monitor insect populations such as codling moths in apple orchards, facilitating timely and targeted control measures. Since climatic factors significantly influence pest populations, real-time weather monitoring through IoT-based systems enhances forecasting accuracy and supports early warning models, improving readiness and response strategies.

In terms of weed management, conventional uniform herbicide application leads to increased greenhouse gas emissions, and environmental degradation. Agriculture 4.0 technologies enable site-specific weed control through advanced imaging (RGB and infrared sensors), robotics, and AI-based classification algorithms. This precision reduces herbicide usage and improves efficiency. Smart spraying systems integrated with sensors and AI algorithms are capable of identifying weed-infested zones and directing the spray accordingly.

Innovative spraying equipment such as air-assisted sprayers, ULV sprayers, ultrasonic sensor-based sprayers, canopy sprayers, and electrostatic sprayers can improve the efficacy of spray (Subeesh & Mehta, 2021). This will reduce the application rate as well as the number of sprays in the field and horticultural crops, Consequently, this will reduce the pesticide requirement, mitigate the risks associated with over-application, and reduce environmental pollution.

Variable rate vertical boom type air assisted sprayer with sensor attachment has been developed at MPUAT, Udaipur. This system includes microcontroller operated solenoid valves and has demonstrated a 33% saving in spray liquid while ensuring precision application. At ICAR-CIAE, Bhopal, a uniform-rate spraying system was developed, which ensured consistent application rates irrespective of the tractor's forward speed and minimized chemical loss at turning points, with only a 4.92 to 6.3per cent discharge variation observed due to pressure fluctuations.

Additionally, ANGRAU, Bapatla developed a remote-controlled, sensor-based site-specific chemical applicator for wide spaced crops like chillies. The system achieved an application rate of 73.32 l/ha with 11.47% sprays coverage and 62% application efficiency, covering 0.26 ha/hour. A camera-based real-time weedicide applicator was also developed for cotton crops, achieving an average weedicide saving of 25.43±3.52 %, with a weeding efficiency of 86.74±1.95%, and an average application rate of 537.85±14.96 l/ha for site-specific application

compared to 400.87±17.01 l/ha for fixed rate methods.

To address the challenges of spraying in enclosed environments, an automated spraying system for polyhouse conditions was developed at ICAR-CIAE, Bhopal. The system composed of an automatic spraying unit (ASU) and row changing unit (RCU), integrates Arduino Mega, ultrasonic sensors, and a DC motor-based platform operating on a guided rail between raised beds. It operates at 0.79 km/h forward speed,250 mm spray distance and 0.4 MPa pressure, achieving optimized coverage and droplet size. Compared to a knapsack sprayer, the system saves 85.5% time and 87.5% labour, with a comparable operational cost.

These innovations exemplify the transformative impact of Agriculture 4.0 on pest and weed management. By leveraging AI, IoT, robotics, and automation, these systems reduce input waste, enhance target specificity, and mitigate environmental and health risks-contributing to a more sustainable and mechanized agricultural future.

Harvesting and Yield Estimation

Accurate and timely yield estimation supports informed decision-making related to post-harvest management, crop insurance, resource allocation and market planning. Traditional practices of yield estimation, such as manual sampling and data extrapolation based on historical and weather-related parameters, are often labour-intensive, time-consuming, and prone to variability due to human and computational error.

Advancements in imaging technologies and artificial intelligence have paved the way for more efficient and accurate yield prediction systems. In a study conducted at CIAE, Bhopal mandarin oranges yield from UAV captured images (low altitude remote sensing data) was used to estimate the yield using convolutional neural networks (CNN). The models were trained on RGB images collected by UAV. Results showed that the web-based application developed eases the process of yield estimation, and with RGB images captured from the orchards, the farmer or any stakeholder can easily estimate the yield.

In addition to pre-harvest estimation, real-time yield monitoring during harvesting has also received significant attention. An automated yield monitoring system has been developed and validated at ICAR-CIAE, Bhopal and integrated onto a self-propelled combine harvester. The system comprises an optical sensor for yield sensing, a grain moisture sensor, a GPS module for geolocation tracking and an on-board field computer for data logging and visualization. Field experiments in soybean crops reported a mean estimation error of approximately 9%, indicating the feasibility of monitoring system for creating geospatial yield maps. These spatial yield maps can be utilized to generate prescription maps for site-specific nutrient and input management, enhancing overall farm productivity (Chandelet al., 2013).

Crop specific requirement for harvesting of different types of crops has thrown major challenge. The crops like fruits and vegetables demand multiple picking, which require system with ability to harvest based on maturity. Cotton also has similar issue of single or multiple picking. Such automated harvesting system will require a largescale data analysis within least time to judge the right pick.

Other Application

Apart from the field operations, the Indian research institutions have increasingly adopted autonomous, sensor-basedand AI-integrated technologies for enhanced monitoring, decision-

making, and sustainable resource managementfor development of devices for early detection of plant diseases, gas emission, monitoring of storage systems, traceability of product, etc. At ICAR-CIAE, Bhopal, a handheld device for disease identification in field crops has been developed using a plant stress imaging system equipped with RGB cameras. This system, built around a Raspberry Pi IV microcontroller with a capacitive touchscreen and Sony IMX219 camera, achieved stress detection accuracy of 93 and 98% in wheat and maize respectively, with a response time of 200 milliseconds. Similarly, the institute also developed vertical soil strength profilers and automated soil samplers for rapid and precise soil assessment. These tools provide essential data for managing inputs such as fertilizers and irrigation with spatial accuracy, contributing to site-specific farming practices.

Another remarkable innovation in the environmental monitoring space was led by PAU, Ludhiana, where a sensor-based carbon sequestration system was designed to quantify CO? emissions during in-situ paddy straw management. Incorporating SCD30 and K30 sensors for carbon dioxide detection and DHT11 sensors for temperature and humidity measurement, the system delivers real-time environmental data to assess the ecological impact of residue management practices. Post-harvest losses, another major concern in Indian agriculture, are being addressed through automation and smart storage systems. ICAR-CIAE, Bhopal has developed an e-sensing system (e-nose) to monitor VOCs that indicate the onset of spoilage in perishable produce. Consisting of metal oxide semiconductor sensors, a signal processing unit, and a 32-bit ARM processor running Java and Cbased programs, the system delivers spoilage predictions with 92.7% accuracy in stored onions, completing each evaluation cycle in seven minutes (Anonymous, 2022b).

To reduce losses in tuber crops, CIAE also developed a one tonne capacity non-refrigerated storage system for potatoes, which utilizes sensor driven aeration and humidification systems. This storage unit regulated by temperature and relative humidity sensors, significantly improves tuber quality over time by reducing rotting, weight loss and texture degradation compared to traditional storage methods. Furthermore, post-harvest operations such as cleaning, sorting, and packaging of horticultural produce have also been automated. Automated packing line of CIAE, Bhopal can handle fruits up to 400 kg per hour and sorts it on the basis of programmable colour detection. Colour accepted fruit can be graded on the basis of weight into three categories. These categories can be changed depending on the type of produce being handled with 88% efficiency. Heat sealed cylindrical 72 micron LDPE packets can be formed with desired number of fruits.

Challenges and Constraints

Despite the promising potential of transforming Indian agriculture through innovations and automation, several significant challenges hinder its widespread adoption. One of the foremost barriers lies in the diversity of cropping systems, soil types and agro-climatic zones across India. It is difficult to develop standardized precision farming technologies suited to all contexts (Subeesh and Mehta, 2021). Altering such technologies to the varied conditions requires extensive customization which consumes both time and cost. Moreover, a major gap exists in awareness and technical literacy among farmers regarding the capabilities and benefits of precision tools. Many farmers lack knowledge and skill required to operate advanced equipment or to interpret the data generated from sensors and digital platforms. This technological illiteracy is particularly evident

among small farmers, who constitute more than 85% of India's farming community.

Another critical challenge is the high cost of procuring precision agriculture equipment, such as GPS-enabled machines, UAVs, IoT sensors, and data analytics platforms. For small and marginal farmers, the return on investment may not justify the expenses due to limited land size, thereby limiting the economies of scale. Further, inconsistent internet connectivity and unreliable electricity supply in rural and remote areas severely constrain the operation of smart systems that rely on real time data and cloud based platforms. Institutional and policy-level challenges also exist. While the government has introduced various schemes and initiatives to promote digital agriculture, the regulatory frameworks remain fragmented and insufficiently aligned with ground-level realities. Addressing these multi-layered issues requires coordinated efforts involving government agencies, agricultural research institutes, agri-tech startups and local farmer organizations.

Future Prospect

- Indigenous Development of Low-Cost Sensors: Promote the design and manufacturing of low-cost sensors for real-time monitoring to support precise and sustainable application of inputs like water and fertilizers.
- Enhanced UAV Applications: UAVs (Drones) with appropriate sensors be used for a quick survey to identify within field variations in nutrient status, as well as pest infestation for timely action. This is cost-effective and eco-friendly. An appropriate power source for drones, however, needs to be defined.
- Strengthening Rural Digital Infrastructure: Build a reliable multi-modal digital support network in rural areas to support GPS and IoTenabled precision farming tools. This includes consistent internet access and sensor integration (Subeesh and Mehta, 2021).
- Development of Decision Support Systems (DSS): Integrate AI, machine learning, GIS, GPS, and sensor data into intelligent DSS tools. These systems should provide real-time, evidence-based recommendations to farmers, replacing traditional trial-and-error methods.
- Promotion of Agricultural Robotics: Many agriculture-related activities can be easily done by robots. In India, their presence is barely noticeable. Development of field worthy robots will be key to engage them in agricultural farm operations.
- Human Resource Development (HRD): Skilled human resource is required for implementing precision agricultural practices. The agricultural universities have to initiate HRD through specially designed training modules and course curricula for different levels of activities including teaching, training and research. This essentially requires exposure and training of faculty in advanced centres of excellence.
- Upgrading the Farm Machinery Industry: Traditional farm machinery manufacturing industry is hardly equipped to convert research prototype in field worthy sensor-based equipment, the industry has to develop facility for production, supply and ensuring after sales service.
- Strengthening Extension Networks: Establish capacity-building programs for extension workers and create a structured

framework to educate farmers on adopting smart technologies. Demonstrations, pilot projects, and farmer field schools can enhance outreach.

- Policy and Institutional Support: Design farmer centric policies that provide financial incentives, subsidies and risk mitigation for adopting precision technologies. Streamlined regulatory frameworks will also encourage private investment and innovation in agri-tech.

Conclusion

Agriculture 4.0 represents a significant shift in Indian agriculture by embedding automation, digitization and data-driven systems into core farm operations. This new paradigm has enabled improved productivity, reduced input waste and real-time decision-making through technologies such as IoT, UAVs, AI-based imaging, and sensor integrated machinery. The advent of opto-electronic technology and improved data acquisition and analytic capacity has enabled the world in general and India in particular to manage field level variation for better input management, higher yield and reduce the losses. Application of these technologies will enable farm machines to be capable of assessing the on-field variations, biotic and abiotic stresses of crop, crop growth pattern, yield estimates in real time and enable the farmers to take right decision at right time. Scalable adoption of Agriculture 4.0 in India requires flexible deployment models and the indigenous development of machinery tailored to farmers' needs. Achieving this goal demands coordinated efforts among research institutions, industry stakeholders, and policymakers. Realizing the full potential of Agriculture 4.0 for sustainable agriculture will depend not only on technological advancements but also on inclusive, cost-effective, and context-specific implementation strategies suited to India's diverse agro-ecological zones and farming communities.



References

Agrawal, K. N. and Bangale R. 2023. Mechanizing Indian agriculture with precision farming technologies: Challenges and perspective.RASSA Journal of Science and Society. 5(2&3); 129-138.

Ali, A., Hussain, I., Rahut, D. B., and Erenstein, O. 2018. Laser-land leveling adoption and its impact on water use, crop yields and household income: Empirical evidence from the rice-wheat system of Pakistan Punjab. Food Policy, 77(2), 19-32. https://doi.org/10.1016/j.foodpol.2018.03.018

Anonymous. 2022a. Research Highlights 2022. All India Co-ordinated Research Project of Farm Implements and Machinery, CIAE, Bhopal. Report No. CIAE/FIM/TB/2022/327.

Anonymous. 2022b. Annual Report 2022. ICAR-Central Institute of Agricultural Engineering, Bhopal. Report No. CIAE/AR/2023/42.

Aryal, J. P., Mehrotra, M. B., Jat, M. L., & Sidhu, H. S. 2015. Impacts of laser land leveling in rice-wheat systems of the north-western indo-gangetic plains of India. Food Security, 7(3), 725-738. https://doi.org/10.1007/s12571-015-0460-y

Chandel, N. S., Agrawal, K. N., Tiwari, P. S., and Golhani, K. 2013. IDW Interpolation of Soybean Yield Data acquired by Automated Yield Monitor.

International Journal for Science and Emerging Technologies with Latest Trends, 3(1), 36-45.

Dhanya, V. G., Subeesh, A., Kushwaha, N. L., Vishwakarma, D. K., Nagesh Kumar, T., Ritika, G., and Singh, A. N. 2022. Deep learning based computer vision approaches for smart agricultural applications. Artificial Intelligence in Agriculture, 6, 211-229. https:// doi.org/ 10.1016/ j.aiia.2022.09.007.

Mehta, C. & Bangale, Rashmi & Chandel, Narendra & Kumar, Mohit. (2024). Farm Mechanization in India: Status and Way Forward. 54. 75-88.

Naresh, R. K., Gupta, R. K., Kumar, A., Prakesh, S., Tomar, S. S., Singh, A., Rathi, R. C., Misra, A. K., and Singh, M. (2011). Impact of laser land leveler for enhancing water productivity in Western Uttar Pradesh. International Journal of Agricultural Engineering, 4(2), 133-147.

Ranganathan, J., Waite, R., Searchinger, T., and Hanson, C., 2018. How to Sustainably Feed 10 Billion People by 2050, in 21 Charts.

Subeesh, A. and Mehta C. R. 2021. Automation and digitization of agriculture using artificial intelligence and internet of things. Artificial Intelligence in Agriculture. 5: 278-291

Farm Mechanization Technologies for Small and Hill Farmers - Gender Perspective

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Farm mechanization is ancrucial factor in modernizing agriculture, improving productivity and reducing the physical strain on farmers. It involves the use of machines and tools to perform various agricultural operations more efficiently, reducing the dependency on human and animal labor. Mechanization not only boosts productivity but also enhances the timeliness of farm operations leading to increased crop yields and reduced costs of production (Singh 2005; Singh, 2007).In many developing countries including India, traditional farming methods are labor-intensive often involving repetitive and strenuous tasks that contribute to drudgery. Drudgery in agriculture refers to the physically demanding and time-consuming activities that reduce the efficiency and well-being of farm workers. Mechanization addresses these challenges by introducing equipment that can perform tasks such as tillage, planting, weeding, harvesting and post-harvest processing with minimal manual effort.

In India, mechanization has made significant pace in certain regions particularly in northern states but many areas still rely on manual labor and animal power. This regional disparity in mechanization levels is influenced by factors such as landholding patterns, terrain and the socio-economic conditions of farmers. Additionally, small and marginal farmers who constitute the majority of India's farming population face challenges in accessing expensive machinery. Efforts to reduce drudgery through farm mechanization must focus on affordable location-specific equipment that is accessible to small-scale farmers.

Women in rural India play a major role in shaping the economy particularly in the agriculture and allied sectors. In 2024, the women workforce in these sectors was accounting for 38.6% of total rural workers. By 2033, this percentage is expected to rise to 39.6% with the number of female agricultural workers reaching around 133.36 million (Table 1). Women participate in various production and post-production agricultural operations including storage, packaging, transportation and marketing. Additionally, they are primarily responsible for the management of cattle and other farm animals alongside their household responsibilities.

Studies have shown that women in rural India work up to 14 hours a day performing physically demanding tasks both on the farm and at home. Despite the ongoing modernization of agriculture the nature of the jobs attended by women has remained largely unchanged. Although significant work has been done to develop agriculture with a focus on technical and economic achievements gender-specific issues have received little attention. Technology development and transfer programs are often carried out under the assumption that technologies are gender-neutral or that men are the primary users and decision-makers. This is often incorrect as women have distinct technological needs due to differences in ergonomic characteristics, education levels, experiences and skills.To effectively reduce drudgery for women in agriculture there is a

pressing need to develop technologies that cater specifically to their requirements. Gender-sensitive approaches to farm mechanization must be prioritized to ensure that women benefit from the modernization of agriculture which will lead to enhanced productivity and reduced physical strain for women workers.

Overall, farm mechanization plays a pivotal role in increasing efficiency, improving working conditions and boosting agricultural output. By reducing the drudgery of farming activities mechanization not only helps retain labor in rural areas but also promotes more effective farm management and a better quality of life for farmers across the country (Singh 2014).The adoption of farm mechanization can lead to increased precision, faster and more efficient farm operations, and often contributes to sustainable agriculture practices.Sustainable mechanization practices to ensure that the benefits are realized without causing harm to the environment or local communities. Farm mechanization provides numerous economic and social benefits to the farmers in terms of saving inputs like seeds and fertilizers up to 15-20% and labour requirement and operational time by 20-30%. On the other hand, it increases cropping intensity by 5-20% and crop productivity by 10-15%. It helps in attracting the rural youth towards agriculture as a profession and to work in the field. Now a days, the pace of adoption of mechanization technologies by the farmers in India is at a faster rate in comparison to past.

Table 1: Population dynamics of Indian agricultural workers in India(No. in million)

S.No.	Particulars	2001	2011	2020	2024	2033
1	Country's population	1029	1211	1347.3	1411.5	1570.9
2	Total no. of workers	402	482	553.2	587.6	674.9
3	No. of workers as % of population	39.0	39.8	41.06	41.63	42.96
4	No. of agricultural workers	234	263	290.99	304.37	336.76
5	% of agricultural workers to total workers	58.2	54.6	52.6	51.8	49.9
6	No. of male agricultural workers	143.0	165.7	179.83	185.8	203.39
7	No. of female agricultural workers	91.0	97.31	111.15	116.8	133.36
8	% of females in agricultural work force	39.0	37.2	38.2	38.6	39.6

Mechanization levels in different crop

The highest mechanization levels in Indian agriculture are observed in wheat, boasting an impressive average of 69%(Table2). Following closely is rice, which has an average mechanization level of 53%. These crops benefit significantly from substantial investments in machinery and technology, resulting in notable reductions in labor, particularly in seed bed preparation and harvesting operations. In contrast, crops such as sugarcane exhibit much lower mechanization levels, with an average of only 35%. Cotton harvesting presents an even more critical situation, with a mechanization level of 0%. This stark disparity underscores the urgent need for targeted interventions to introduce efficient tools and technologies for labor-intensive operations, especially in areas like harvesting and planting. Addressing these gaps is essential for enhancing productivity and alleviating the physical demands placed on farmers in these sectors. The varying levels of mechanization among different crops emphasize the need for customized approaches to reduce

agricultural drudgery. Increasing mechanization for crops with lower levels can greatly enhance productivity and improve working conditions, particularly for women, who are crucial to agricultural labor in rural India. Efforts should focus on investing in suitable technologies, providing training, and implementing supportive policies to encourage the widespread adoption of mechanized tools in Indian agriculture.

Table 2: Mechanization levels for major crops in India (2020-21)

Crop	Seedbed preparation	Sowing/ planting	Interculture and protection	Harvesting and threshing	Average
Rice	80	35	35	60	53
Wheat	85	65	50	75	69
Maize	70	45	40	30	46
Millets	60	30	20	20	33
Pulses	65	40	25	35	41
Oilseed	65	40	20	30	39
Cotton	70	40	35	0	36
Sugarcane	65	25	30	20	35
Average	**70**	**38**	**32**	**34**	**47**

Sources: *Mehta et al., 2023*

The population of agricultural workers has increased from 131 million in 1960-61 to 291 million in 2019-20 and the compound annual growth rate in workers population estimated was 1.13%. The share of draught animal power has reduced with -1.79% CAGR and the population of mechanical power sources like tractors, power tillers and diesel engines has increased with CAGR of 8.49%, 10.34% and 0.95% respectively (Table3).

Table 3:Population of farm power sources in India

Year	Number of farm powe r sources, million					
	Agricultural workers	Draught animal power	Tractors	Power tillers	Diesel engines	Electric motors
1960-61	131	80.4	0.037	0	0.23	0.20
1970-71	126	82.6	0.168	0.0096	1.70	1.60
1980-81	148	73.4	0.531	0.0162	2.88	3.35
1990-91	185	70.9	1.192	0.0323	4.80	8.07
2000-01	234	60.3	2.546	0.1147	6.226	13.25
2010-11	263	51.3	4.427	0.2943	8.134	17.488
2019-20	291	43.8	8.370	0.700	8.860	21.07
2023-24*	304	40.9	11.00	1.040	9.190	22.89
2032-33*	336	34.8	20.360	2.530	10.03	27.57
CAGR(%)*	1.13	-1.79	8.49	10.34	0.95	2.09

predicted Sources: Singh (2015), Singh et al. (2015), Anonymous (2015) and Tiwari et al. (2019)

On Indian farms, different types of power sources are being used viz. mechanical power, manual power and electric power sources. Mechanical power plays an important role as a source of farm power and it contribute about 74.4 % of total available power.During 2020-21, the total power available with different sources was 386.57 million kW and on per hectare basis it was 2.76 kW/ha (Table 4).

Table4: Power available from different sources during different periods in the country

Year	Source of power availability, million kW						Total power million kW	Net sown area, million ha	Available power per ha, kW
	Human	Animal	Tractor	Power tiller	Diesel engine	Electric motor			
1961-62	6.55	30.628	0.9657	-	1.590	0.962	40.696	135.4	0.301
1971-72	6.285	31.464	4.3848	0.0633	10.214	6.423	58.835	139.72	0.421
1981-82	7.4	27.816	13.8591	0.094	18.950	13.120	81.240	141.93	0.572
1991-92	9.265	26.714	31.1112	0.212	27.328	32.123	126.753	141.63	0.895
2001-02	11.705	21.579	70.31768	0.690	36.529	50.324	191.144	140.73	1.358
2011-12	13.15	16.903	118.8229	1.927	45.987	66.130	262.921	140.98	1.865
2020-21	11.5	11.694	229.5291	3.951	54.225	75.678	386.576	140	2.761

Source: Singh and Singh 2021

In India, the majority of the farm holdings fall under small and marginal category (86%) and the average size of land holding is about 1.08 ha (Table 5). Table also revealed that number of land holdings having less than 2.0 ha farm size has increased in 2015-16 as compared to 2010-11.

Table 5: Number and size of operational holding by size group

Category of holdings	No. of holdings ('000 no.)		Area ('000 ha)		Average size of holdings (ha)	
	2010-11	2015-16	2010-11	2015-16	2010-11	2015-16
Marginal (<1 ha)	92826 (67.0)	100251 (68.45)	35908 (22.5)	37923 (24.0)	0.39	0.38
Small (1.0-2.0 ha)	24779 (17.9)	25809 (17.6)	35244 (22.08)	36151 (22.9)	1.42	1.40
Semi-medium (2.0-4.0 ha)	13896 (10.0)	13993 (9.55)	37705 (23.6)	37619 (23.8)	2.71	2.69
Medium (4.0-10.0 ha)	5875 (4.2)	5561 (3.79)	33828 (21.2)	31810 (20.15)	5.76	5.72
Large (10.0 ha & above)	973 (0.7)	838 (0.57)	16907 (10.6)	14314 (9.06)	17.38	17.07
All Holdings	**138348 (100.0)**	**146454 (100.0)**	**159592 (100.0)**	**157817 (100.0)**	**1.15**	**1.08**

Source: Agriculture Census 2015-16 (Phase I), Agriculture census Division, Department of Agriculture, Co-operation & Farmers Welfare, Ministry of Agriculture & Farmers Welfare, Government of India, 2019.

Benefits of farm mechanization

❖ Labor Savings: Farm mechanization helps to improve the shortage of agricultural labor, particularly in regions where labor is scarce or expensive. Mechanized tools/ equipment can replace or assist human labor in tasks such as weeding, interculturing, plowing, planting, harvesting, and post-harvest processing.

❖ Increased Productivity: Mechanization allows farmers to finish tasks more quickly and efficiently, leading to increased productivity. Tractors, power tillers, harvesters, and other improved machinery enable larger areas to be covered or cultivated, reducing the time required for various farming operations.

❖ Timely Operations: The main focus in agriculture is to carry out various operations timely. Mechanization enables farmers to carry out agricultural activities at the optimal time. Timely planting, irrigation, harvesting and threshing are crucial for maximizing yields and overall farm efficiency.

❖ Cost Efficiency: The initial cost of purchasing farm machinery can be high but the long-term benefits of using these machines often compensate the expenses. Mechanization can reduce the overall cost of production by saving on labor costs, minimizing losses, and improving the use of inputs.

❖ Conservation of Natural Resources: Sustainable farm mechanization practices can contribute to the conservation of natural resources. For example, precision irrigation systems help conserves water, while conservation tillage methods reduce soil erosion.

❖ Precision Agriculture: Modern farm equipment is equipped with advanced technologies, such as GPS and sensors, allowing for precision agriculture. This helps farmers optimize resource use, minimize waste, and enhance the overall sustainability of farming practices.

❖ Capacity Building: Mechanization enables farmers to manage larger areas of land more efficiently, allowing for the expansion of farm operations. This can contribute to the economic growth of rural areas and enhance the overall capacity of the agricultural sector.

❖ Adaptation to Climate Change: Climate variability and change can impact traditional farming practices. Mechanization, especially with climate-smart technologies, allows farmers to adapt to changing climate conditions and minimize risks associated with weather-related challenges.

❖ Post-harvest Handling: Farm mechanization extends beyond field operations to post-harvest activities such as threshing, sorting, and packaging. Efficient post-harvest handling helps reduce losses and ensures the delivery of quality produce to markets.

❖ Global Food Security: In the context of a growing global population, farm mechanization plays a crucial role in meeting the increasing demand for food. It helps to ensure a stable and sufficient food supply by optimizing agricultural processes.

Health Hazards Faced by Farm Women in Agricultural Activities

Various health hazards encountered by farm women during different agricultural activities are numerous. Understanding these

hazards is essential for developing ergonomic interventions that can effectively reduce risks and enhance working conditions for women in agriculture.

1. **Farm activities**

   a) **Transplanting:** This activity exposes women to significant physical strain due to repetitive movements and awkward postures, highlighting the need for tools that minimize bending and enhance comfort.

   b) **Harvesting:** The harvesting process requires prolonged manual labor, which can lead to fatigue and musculoskeletal disorders. Ergonomic equipment that assists in lifting and reduces strain can be beneficial.

2. **Post-Harvest Activities:**

   a) **Threshing:** This task often involves heavy lifting and repetitive motions, necessitating the use of mechanized threshers designed for ease of operation and reduced physical effort.

   b) **Drying:** The drying process can also pose risks due to the physical demands of moving and spreading harvested crops. Ergonomic tools can aid in reducing the strain associated with these tasks.

   c) **Parboiling:** High exposure levels indicate significant physical demands and potential hazards. Introducing equipment that simplifies the parboiling process can alleviate physical burdens.

3. **Livestock Management:**

   a) **Shed Cleaning:** This activity can expose women to zoonotic infections and physical strain. Ergonomic tools for cleaning can reduce the risk of injury and improve hygiene.

   b) **Fodder Collection:** The lifting and carrying involved can lead to chronic pain. Specialized tools can minimize the manual handling of heavy loads.

   c) **Milking:** Prolonged and repetitive movements during milking can cause discomfort. Ergonomic milking machines can reduce strain and improve efficiency.

Table6 emphasizes the high prevalence of health hazards in various farm activities undertaken by women. Addressing these issues through ergonomic designs and tools can significantly improve their health and overall productivity in agriculture.

Table 6: Type of health hazards faced by farm women

Activities	Health hazards percentage
Farm activities	
Transplanting	50%
Harvesting	26.5%
Post harvest activities	
Threshing	50%
Drying	33%
Parbolining	67%
Livestock management	
Shed cleaning	47%
Fodder collection	23%
Milking	27.5%

Sources:*TNAU Agritech Portal: Women and Agriculture*

To reduce health hazards faced by women in agriculture and enhance their working efficiency, it is importantto develop specialized drudgery reduction equipment. These equipment should focus on:

1. **Ergonomic Designs:** Prioritizing ergonomic features in agricultural tools can significantly reduce physical strain and improve comfort for women workers.
2. **Safety Features:** Incorporating safety features into machinery and tools will protect women from injuries related to pesticide exposure animal handling and operating heavy equipment.
3. **Efficient Handling:** Implementing equipment that allows for efficient handling of heavy loads and reduces repetitive tasks will alleviate the physical demands of agricultural work.
4. **Training and Education:** Providing training and education on proper usage and safety protocols will empower women farmers to utilize these tools effectively.

The various occupational health hazards such as physical strain, dust, infections, pesticides, back pain, animal attacks, musculoskeletal disorders, respiratory problems, generalized body aches, poisoning are being faced by women in agriculture and they have theses specific risks and strong implications on health.

Involvement of Women in Indian Agriculture

Rural women in India play a vital role in agriculture, undertaking labor-intensive tasks such as sowing, transplanting, weeding, harvesting, and threshing, as well as primary processing activities like cleaning, grading, drying, and milling. They are especially important in commercial agriculture, including the cultivation of tea, coffee, sugarcane, cotton, and tobacco. Additionally, women engage in various agro-processing tasks such as bidi making, jute retting, lac cultivation, and spices picking.While some hand tools are available for these operations, most have been designed for male workers, forcing women to adapt to equipment not suited for their needs. This mismatch leads to lower productivity and contributes to several occupational health issues (Singh and Vatsa, 2015). Furthermore, the introduction of improved tools often shifts these tasks to male workers, resulting in unemployment or underemployment for women in the agricultural sector.

The introduction of improved hand tools and equipment for women workers can facilitate several key benefits:

a) **Reduce Physical Strain:** Ergonomically designed tools minimize the physical demands of labor-intensive tasks, making work more comfortable.

b) **Increase Efficiency of Resource Utilization:** Enhanced tools enable better use of agricultural inputs, leading to cost savings and higher efficiency.

c) **Ensure Timeliness of Operations:** Improved equipment allows for timely execution of field tasks, reducing the turnaround time between crops and optimizing yield.

d) **Boost Productivity of Worker-Machine Systems:** The integration of suitable machinery with worker efforts enhances overall productivity and maximizes output.

e) **Conserve Energy:** Optimized tools are designed to require less physical effort, helping workers conserve energy and reducing fatigue during long working hours.

f) **Enhance Work Quality and Output:** Upgraded tools improve the quality of both the work performed and the agricultural products produced, leading to better market value.

g) **Improve Quality of Work Life:** By reducing the burden of manual labor, improved equipment can significantly enhance the working conditions and overall quality of life for agricultural workers.

h) **Promote Gender Inclusivity:** Developing tools specifically for women can empower them and encourage their participation in various agricultural activities, fostering greater gender equality in farming.

i) **Facilitate Skill Development:** Training on the use of modern equipment can enhance women's skills, making them more effective and efficient in their work.

j) **Increase Safety Measures:** Improved tools often incorporate safety features that reduce the risk of injuries and accidents on the job.

k) **Support Sustainable Practices:** New technologies can promote sustainable farming methods, encouraging environmentally friendly practices among women farmers.

l) **Encourage Cooperative Work:** Enhanced tools can facilitate group work, enabling women to collaborate more effectively in agricultural tasks and share resources.

m) **Enhance Market Access:** Improved efficiency and quality of work can enable women to engage more actively in local and regional markets, increasing their economic independence.

n) **Boost Community Resilience:** By empowering women with better tools and equipment, communities can become more resilient to agricultural challenges, enhancing food security and economic stability.

Gender-neutral improved farm tools and equipment/Interventions

Many improved farm tools and equipment have been developed by different Institutes/ Universities to reduce human drudgery and cost of operation as compared to traditional practices. The most common farm tools and equipment arePAU seed drill,CIAE seed drill,TNAU paddy seeder, Dr. BSKKVhand cranking two row rice transplanter and bbattery powered two row root washed type manual transplanter, OUAT three row manual rice transplanter, TNAU cono weeder, CIAE twin wheel hoe, CIAE and Dr. BSKKV improved sickle, CAEPHT improved large cardamom harvesting knife, NERIST fruit harvester, TNAU tea plucker, OUAT pedal operated paddy thresher, CRRI paddy winnower, IARI hand operated chaff cutter with safety devices, TNAU groundnut stripper, CIAE groundnut decorticator (sitting and standing type), IISR sugarcane stripper-cum-detopper, IISR manual multicrop planter, IISR solar powered manual sprayer, Dr. BSKKV pedal operated arecanut dehusker, CIAE tubular maize sheller, IARI Self-propelled (battery power) variable height platform with telescopic steering system, NERIST power operated mini rhizome planter, Dr.BSKKV fish dressing platform and PPE kit for spraying, CAEPHT manual conical device for segregation of capsules (bulbs) from large cardamom spikes, NERIST pineapple leaves pruner and kiwi vines pruner, IARI sensor-based braking system for chaff cutter, IARI robot for spraying operation in the greenhouse to minimize drudgery and some other improved tools/interventions. Some power sources like power tillers (10-15hp) and power weeders (4-7

hp) are also commercially available and are suitable for small and terrace fields of hills. Proper training in operation and maintenance of the power tiller and other machines is also required for the farmers.

Conclusion

The need based improved tools and equipment/ interventions have been developed by different organizations/ institutions to cater the need of small and hill famers that reduces the drudgery, cost of operation and improves the work efficiency. But still there is need to popularize these technologies among the famers through demonstrations/ trainings /awareness camp/ field days so that the benefits reach all levels of farmers particularly those in underserved regions to enhance productivity while reducing the physical demands of farm labor.

REFERENCES:

Anonymous. 2019. Agriculture Census 2015-16 (Phase I), Agriculture census Division, Department of Agriculture, Co-operation & Farmers Welfare, Ministry of Agriculture & Farmers Welfare, Government of India, 2019.

Singh S. 2015. Agricultural mechanization status on Indian farms.Souvenir.Agricultural machinery manufacturers' meet (AMMM) - 2015, Hotel lemeridien, Coimbatore, July 17-18.

Anonymous. 2015. Agricultural statistics at a glance.Department of agriculture, cooperation and farmer's welfare, Ministry of Agriculture and Farmers Welfare, New Delhi.

Tiwari, P.S., Singh, K.K., Sahni, R.K. and Kumar, V. 2019. Farm mechanization - trends and policy for its promotion in India, Indian Journal of Agricultural Sciences 89 (10): 1555-62.

Mehta, C. R., Chandel, N. S., Senthilkumar T. 2014. Status, challenges and strategies for farm mechanization in India.Agricultural Mechanization in Asia Africa and Latin America, 45(4), 43-50.

Mehta, C. R., Bangale, R. A., Chandel N. S. and Kumar, Mohit. 2023. Farm Mechanization in India: Status and Way Forward. Agricultural Mechanization in Asia Africa and Latin America, 54(2), 75-88.

Potdar RR, KN Agrawal and A. Khadatkar (2017). Drudgery Reducing Improved Technologies for Farm Women. Technical Bulletin No.ESA/2017/232.ICAR-Central Institute of Agricultural Engineering, Bhopal.

Singh, S.P. and Singh, Surendra. 2021. Farm Power Availability and its Perspective in Indian Agriculture. RASSA Journal of Science for Society 3(2): 114-126, August 2021.

Singh Sukhbir.2007. Hill Agricultural Mechanization in Himachal Pradesh- A Case Study in Two Selected Districts. Agricultural Mechanization in Asia Africa and Latin America (AMA), Vol. 38 (4): 18-25.

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http://agritech.tnau.ac.in/women_in_agri/farm_enter_women_empowerment_durgery_index.html2. 1.

Singh Sukhbir. 2005. Farm mechanization in mountains-Problems and Prospects. In proceedings of 33rd International Symposium of "Actual Task on Agricultural Engineering" held at Agricultural Engineering Department, University of Zagreb, Croatia w.e.f February 21-25, 2005; p: 21-36.

Singh Sukhbirand Vatsa DK.2015. Need of ergonomically mechanized interventions in selected farm operations in hills of Himachal Pradesh. Agricultural Mechanization in Asia Africa and Latin America (AMA), Vol. 46 (2): 23-28. Singh Sukhbir. 2014. Farm mechanization in hills of Uttarakhand, India- A review. Agriculture for sustainable development. 2(1): 65-70. ISSN 2347-5358 (Print)/ 2349-2228 (Online).

Application of advanced technologies for mechanization of animal husbandry

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Abstract

The integration of advanced technologies in animal husbandry is revolutionizing traditional livestock practices by enabling precision with efficiency for improved animal welfare. This paper presents the latest developments under the All India Coordinated Research Project on Mechanization of Animal Husbandry (AICRP-MAH), which focuses on sensor-based systems for monitoring, diagnosis, and automation in livestock management. Key innovations include IoT-based thermal imaging for early infection detection, RGB sensor systems for non-invasive pregnancy testing, acoustic monitoring for poultry disease detection, computer vision-based automatic feeding systems, and solar-powered environmental control technologies. These solutions leverage artificial intelligence, computer vision, and embedded systems to automate critical tasks such as feeding, housing, disease surveillance, and reproduction monitoring. Validation trials show high accuracy, reduced labour, and improved economic efficiency. The findings highlight the role of digital tools in promoting sustainable, animal welfare and data-driven livestock farming practices, especially for small and marginal farmers in India.

Introduction

Farm mechanization plays a pivotal role in improving productivity and efficiency across agricultural systems. In India, the interdependence of livestock and crop production forms the backbone of mixed crop-livestock systems. Recognizing the significance of animal energy, the Indian Council of Agricultural Research (ICAR) initiated the All India Coordinated Research Project (AICRP) on "Increased Utilization of Animal Energy with Enhanced System Efficiency" on July 1, 1987, coordinated by ICAR-Central Institute of Agricultural Engineering, Bhopal. The scheme has led pioneering research in draughtability, harness systems, work-rest cycles, rotary usage, loading systems, treadmills, and precision instruments to measure animal output under varied conditions. It has also developed about 100 animal-drawn implements and technologies for different unit farm operations across India.

The scheme has presently been renamed as AICRP on Mechanization of Animal Husbandry (MAH). The revised mandate focuses on mechanizing essential livestock operations such as feeding, watering, manure handling, and milking, thereby enhancing productivity and reducing management-related drudgery. It also emphasizes improved housing, sanitation, and health measures to ensure a better environment for livestock.

The four pillars of livestock management feeding, breeding, weeding, and heeding can now are more efficiently managed through the integration of IoT and sensor-based technologies. These tools support improved farm management, animal nutrition, health, and movement tracking.

Animal husbandry is now positioned at the forefront of modern agricultural practices, especially in promoting sustainable and resilient farming systems. As food security concerns and

environmental pressures intensify, innovative technologies are reshaping livestock management and welfare (Rojas-Downing et al., 2017). These innovations include advanced health monitoring systems, modern breeding techniques, farm automation, and the integration of Precision Livestock Farming (PLF) technologies (Aquilaniet al., 2022). Collectively, such advancements aim to optimize productivity, enhance animal welfare, and support climate-resilient and resource-efficient livestock farming.

With the widespread availability of smartphones, internet connectivity, and enhanced computational capabilities, the adoption of advanced technologies in animal husbandry has accelerated. Manual practices are increasingly inadequate for the demands of modern livestock production. Technologies such as sensors, artificial intelligence (AI), and the Internet of Things (IoT) are now transforming animal farming by enabling real-time monitoring and informed decision-making (Wolfert et al., 2017).

In the context of smart dairy farming, wearable sensors on animals gather health and productivity data in real time. AI, computer vision (e.g., YOLO v9), and automated sensor systems assess barn environments and monitor animal behaviors. These technologies enable cost-effective, non-invasive, and efficient health surveillance systems (Siberski-Cooper et al., 2023). As IoT continues to revolutionize agriculture, particularly dairy and livestock sectors, there is a growing need to review, adopt, and localize these technologies for Indian conditions. The use of sensors allows continuous data collection on animal and environmental indicators. When coupled with AI and machine learning (ML) or deep learning algorithms, these systems can identify anomalies, support early interventions, and assist in real-time decision-making (Neethirajan, 2023).

The deployment of such technologies enhances efficiency, animal health, and resource utilization, thereby reinforcing their importance in modern livestock farming (Tangorra et al., 2024). Depending on the herd size and sensor configurations, these systems can significantly boost managerial effectiveness, enabling standardization in feeding, thermoregulation, and production performance.Precision Livestock Farming (PLF) also termed Smart Livestock Farming is characterized by the application of modern AI and IoT systems for real-time monitoring of physiological, reproductive, behavioral, and health parameters (Silva et al., 2023). Early sensors focused on economically significant traits like temperature, rumination, body condition score, feed intake, and milk production (Neethirajan et al., 2017). Recent advances in biosensors have shifted the focus toward welfare indicators, enabling objective assessment of animal behavior and living conditions. These advancements collectively address concerns related to industrial livestock production by promoting sustainable and welfare-centered farming. Figure 1 illustrates the major livestock management areas where sensor-based technologies can be applied.



Fig 1: Different types of sensor technologies used in animal husbandry

At present, the AICRP-MAH cooperating centers are dedicatedly working on needful technologies using sensors as per the four pillars of livestock management. In this paper, technologies developed by the centres are briefly presented.

Livestock Population

As per Livestock census (2019), total livestock population in the country is 536.76 million. Of which, population of cattle (including milch cattle), buffaloes, goat, sheep, pigs, mithun, horses & ponies, camel, donkeys, and yaks are 193.46, 109.85, 148.88, 74.26, 9.06, 0.39, 0.34, 0.25, 0.08, 0.06 million, respectively. The livestock population in rural area is 95.78%. Male cattle population is 24.58% in year 2019 as compared to 35.58% in year 2012. Total Bovine population (Cattle, Buffalo, Mithun and Yak) is 303.76 million. Backyard and commercial poultry were 317.07 and 534.74 million, respectively. Total livestock including poultry birds were 1388.562 million in the country.As per Department of Animal Husbandry and Dairying, Government of India, country ranks number one in cattle & buffalo population. India is largest producer of milk (up to 23% of the world's milk annually), Buffalo meat, 2nd largest producer of goat meat, 2nd biggest exporter of poultry products and 3rd globally in production of eggs.As per https:// www.pib.gov.in/ Press Release Page.aspx PRID= 1935628, dairy being the single largest agricultural commodity employing more than 8 crore farmers directly in the country.

Recent Developed Technologiesfor Mechanising Animal Husbandry Sector

Following technologies for cattle and poultry have been developed by the Cooperating centres of AICRP on MAH,

i) Technologies for cattle

Sensor-based system for pregnancy detection in dairy animals

To identify the concentration of Abscisic Acid (ABA) in animal urine, a sensor-based detection system was developed at UAS Raichur centre using a red, green and blues(RGB) sensor. This system operates by detecting variations in blue color intensity, which indicates the presence of ABA. In the standardized procedure, urine samples were treated with a synthetic dye that reacts with ABA, resulting in a color change from white to blue. The RGB sensor quantified the intensity of the blue coloration, and the data were recorded for analysis. This method allows for a non-invasive and efficient approach to monitor ABA levels, contributing to early pregnancy detection in dairy animals.

IOT-based monitoring and early infection detection in dairy cattle using thermography

An IoT-based real-time monitoring and early infection detection system was developed at ICAR-CIAE, Bhopal centre. The system features both handheld and continuous monitoring configurations for real-time thermal profiling of cattle. It utilizes a BCC contactless IR temperature sensor, DHT22 humidity and temperature sensor, Arduino UNO R4, NodeMCU ESP8266 Wi-Fi board, and a 16×4 LCD display via I2C interface. All sensors were integrated through embedded C programming to measure and display body surface temperatures and environmental parameters. The embedded code initializes the sensors, captures real-time temperature and humidity data, and either displays it on an LCD or transmits it wirelessly. The program uses an instance of the Adafruit MLX90614 IR temperature sensor and ultrasonic distance sensing for precise cattle surface targeting. IR temperature readings from the neck dewlap region have the highest correlation (R^2 = 0.96) with rectal temperature, with minimal variability and tight agreement in Bland-Altman and distribution plots.

Sensor based non-invasive type respiration rate monitor

IGKV Raipur centre developed the sensor based non-invasive type respiration rate monitorfor accurate, continuous and long-term respiration rate monitoring in cattle. The machine consists of sensor (flex type), amplifier, microcontroller and display. The collected data was validating with the help of reference methods i.e. counting of flank movement and counting of breathe in front of nostril with hand.A 4-digit 7-segment display is used in this study as counter. This counter or timer is connected to an Arduino as a display. TM1637 module display is used in this study which have only four connections in total - two for power and two for controlling the display.A nylon belt of size 3 m in length and 35 mm width with buckle is used to hold the device around cattle body. Developed device is fixed on the belt and belt is tightening around the animal body. This ensures that the device can be installed at a desired place while taking respiration rate.

Sensor-based walk-in type mechanized washing system for cattle

A prototype of a sensor-based mechanized washing system has been developed by GBPUAT, Pantnagar centre to facilitate the continuous washing and cleaning of cattle when the atmospheric temperature exceeds 35°C. The sensor detects when an animal reaches the washing station's sensing area and sends an output signal to turn on the control box, which is the next component of the system that includes an SMPS, timer, relay, and contactor. The timer relay is triggered upon receiving the sensor's output signal. A 2.24 kW electric motor receives electricity from the contactor, which is activated by the relay. After that, the electric motor powers the two-stage plunger pump. Water is delivered by the pump to the washing station via 12.5 cm GI pipes. It has twenty-seven flat-fan-style nozzles.These nozzles atomize the water into fine droplets and distribute evenly over the cattle's body. After the set duration on the timer, the pump's power supply is automatically cut off.

Batch type cattle washing unit

A batch type cattle washing unit developed by VNMKV, Parbhani centreis suitable for batch type complete cleaning of cattle. This unit is fitted on an RCC platform. The rectangular boom moving and scrolling at top and fitted with seven hollow cone nozzles, one from top side of animal, two each from upper side, middle and lower side of animal. Two gates are provided in frame to enter and exit the animal comfortably. The HTPE pump of 2.24 kW capacity is used for water supply. Animalrequires 50% less labor, 76-88% less time, and 2.15 times (50%) more effective in ectoparasite removal as compared to traditional practices during washing with the developed system. Tnus, water usage is reduced by 67-72% (Singh et al., 2025).

Cattle grooming unit

Abatch type grooming unit developed by VNMKV, Parbhani centre has two brushes (375 mm in diameter and 600 mm in length) which is powered by a 1.4kW electric motor. The brushes are positioned in a horizontal and vertical (making L-shape) direction to groom the animal's dorsal and lateral sides. The brush height can be adjusted to match the animal's size, allowing the bristles, which are 2 mm thick, to effectively groom the animal's body. Two infrared proximity sensors, with a range of 1-3 meters, are placed near the brushes and are controlled by a panel. It was also observed that after the grooming operation, skin infections decreased by 3-4%, draftability improved by 15-16%, and the overall impact increased by more than 33%. This demonstrates the positive effects and benefits of

the grooming operation.

Portable milk pouch packing

MPUAT Udaipur centre adopted an available milk pouch packing machine and required modifications were incorporated for operation by using solar power. The milk pouch packing machine consists of feed head (funnel), control panel, sealing unit, heating element, pouch stand and trolley stand. The power requirement of portable milk pouch packing machine was found to be 260 watts. The output capacity of portable milk pouch packing machine was found to be 150-175 pouch per hour (500 ml capacity) depending upon the skill of persons for feeding and packing.

Animal feed pelletizer

UAS Raichur developed a compact feed pelletizer (680×320×1060 mm, 60 kg) which is powered by a 1.5 kW motor, having a 5 kg hopper and 98.5 kg/h output. It produces 6, 9, and 12 mm pellets suitable for poultry and dairy feed. Trials showed higher body weight, lower feed intake, better FCR, and reduced mortality and feed wastage (0.56%) in pellet-fed poultry compared to mash-fed. The machine is suitable for small farmers, offering efficient, clean, and cost-effective feeding (Singh, 2023).

Feed mixer machine

UAS Raichur centre developed the feed mixer machine suitable to the dairy farmers. This machine was powered by 0.75 kW electric motor whichconsists of stationary drum in which rotating arm assembly revolves at the speed of 45 rpm and power transmission system provision was also made. Maize, soybean meal, common salt, dicalcium phosphate, mineral mixture, DL-methionine, vitamin premix, salinmycin, hepatocare and BMD were the ingredients for the preparation of poultry feed as per recommended ratios. The feed ingredients were grinded and properly mixed inside the feed mixer machine. Machine was designed to mix the feed with hopper capacity of 50 kg/batch. The mash type poultry feed was used for conducting the feeding trials. Data revealed that the overall body weight, cumulative feed intake and cumulative FCR reported to be higher as compared to the feed mixture prepared manually. The mortality of the birds was noted minimum (4 %) than manual feed mixture (5.60 %). 95 % uniformity was observed in the average weight of birds in 12th week, which was significantly higher as compared to 82 % reported for the manually prepared feed mixture. This is capable to increase the milk production with more fat and solids when mash type feed was prepared as per required feed ingredients for animal. It also improves the reproduction efficiency. Machine is more helpful and beneficial for small level entrepreneurs, poultry farms owner as well as small dairy farmers (Singh, 2023).

Mechanised cleaning system for dairy barn

GBPUAT Pantnagarcentre developed the cattle dung collection machine for cleaning the dairy farm.Major component consists of frame, inclined platform, DC motor, dung collection box, electronic controller. The machine exhibits a cleaning capacity of 2300 m2/h (0.23 ha/h) for barnyard cleaning, while a similar task that would require 22 man-hours. This technology significantly saves both labour and time. The weight of the machine is 135 kg. The machine operates for two hours on a full charge of battery. Dung collection capacity and cleaning efficiency were observed to be 4000 kg/h and 97%, respectively.

Cattle dung dewatering machine

IGKV, Raipur centre has developed a low-cost cattle dung dewatering machine based on the properties of dung to get rid of unhygienic and tedious traditional method of drying of cattle

dung. Major components included like, base frame, upper and lower hopper, main cylinder, screw press, outer unit and power transmission system. A 5 hp electric motor is used to provide power in the machine through belt drive system. The average capacity of the cattle dung dewatering was found to be 122 kg/h while the average dewatering rate was reported as 93.61 kg/h.

Improved animal housing structure for draught and milch animals

A comfort animal housing structure was designed and developed by the MPUAT Udaipur center to provide an optimum environment to the animals for achieving the higher growth, improved feed utilization efficiency and optimum milk production with proper welfare living conditions. A low-cost comfort housing system for dairy animals is comprised of various components to facilitate them such as foggers, cement sheet with thatched roof, open area and plantation. The designed housing has the provision of all time availability of drinking water and fodder. Developed housing system is the combination of loose, open and conventional housing systems. The pulse rate and respiration rate were lower in animals during rainy season reared in loose housing system, comfort housing system as compared to conventional and open housing system. During winter, the data on dry matter intake (kg/day) was higher in animals reared under comfort housing system. This was significantly lower in animals reared in open housing. The milk yield (litres/day) during winter was higher in animals reared under comfort housing system during winter as compared to other housing systems. The dry matter intake (kg/day) during summer season was significantly higher in animals reared under comfort housing system as compared to conventional, open housing and loose housing systems. The animals in all the housing system maintained their physiological parameters but were more comfortable in comfort housing system as compared to others during summer season. There was significant difference between the treatments for milk yield which was significantly higher in animals reared under comfort housing system (11.87 litres) as compared to conventional (8.90 litres), open housing system (7.94 litres) and loose housing system (11.46 litres). Developed comfort housing system was found more comfortable with better physiological parameters as compared to others.

Animal lifting device

Animal lifting device has been developed by ICAR-CIAE Bhopal, ICAR-NRC Bikaner and VNMAU Parbhani centre. This device is helpful in many causes for a downer cow syndrome over which pre-calving and post calving conditions, hind leg dislocation and fracture of leg due to slippery floor, sick animals or which is suffering from illness and disability in standing. It was designed in such a way that it may need 2-3 people to lift the cattle instead of 6-8 people in traditional method.

Major components are superstructure, supporting frame, gear box, transportation wheel and supporting canvas. The height of the structure is kept to 2340 mm. Trials conducted in gaushalas which clearly indicated its benefit to recover the sick animals with the developed device. This device can lift up to 500-800 kg body weight of animals. Per cent recovery of animal is observed to 60-65%.

ii) Poultry farming

Poultry farm monitoring device for early detection of respiratory disease

This device was developed by OUAT, Bhubaneswar Centre. An attempt is made to develop an IoT based device which can analyse the voice produced in a flock of birds. The voices

of birds in various stages of development have been recorded in OUAT Poultry farms. The recorded sounds have been uploaded to the cloud and analyzed. Voices of some unhealthy birds were also recorded of 3 min each. These recordings were cut into samples of 30s resulting in a total of 1800 samples. The voices of the healthy birds have been standardized and classified using Convolutional Neural Networks and Efficient NetB3. The prediction scores of 95.5% have been achieved for healthy birds and score of 92.7% has been for unhealthy birds.

Controller-based feed dispensing system for poultry

A controller-based feed dispensing system for poultry was developed by ICAR-CIAE Bhopal centre. This system was tested for different types of poultry feed (Pre-starter and finisher). Data revealed that the discharge output ranged from 0.219 kg to 1.99 kg for week 1 to week 9 for pre-starter, whereas this value was found in the range from 0.261 to 2.38 kg for finisher-type feed. Developed systems can provide the feed precisely and reduce the wastage in the poultry farm. A computer vision-based bird identification system was also developed to count birds and determine the amount of feed to dispense. The system used the YOLOv7 object detection algorithm, which offered fast detection, high precision, and ease of deployment. The model achieved an overall precision of 83.6%, recall of 82.5%, and a mean Average Precision (mAP) value of 84.4%. These results demonstrate that the computer vision approach is effective in detecting birds and can be successfully integrated into an automatic feed dispenser for poultry. The system resulted in a 65-70% saving in time and a 65% reduction in feeding costs as compared to manual circular feeding methods. It ensured timely operations with less man-power and also helping in preventing disease transmission between birds and human.

Solar powered water sprinkling system in poultry

OUAT Bhubaneswar centre developed the solar powered water sprinkling system to control the temperature inside the poultry house through sensor. A temperature sensor system, integrated with a solar panel and a 0.5 hp DC motor-based water sprinkling system, operates four micro sprinklers on the poultry house roof. The sensor, set at 30°C, automatically activates the sprinkler system when the shed temperature reaches or exceeds 30°C, continuing until the temperature drops below the set threshold. In summer season, the inside ambient temperature of the poultry shed during 8.00 AM to 5.00 PM varied from 25 - 32ºC with a humidity range of 38 - 60 %. The temperature humidity index (THI) varied from 68 - 76. Whereas the out-side temperature during the corresponding period varied from 27 - 37ºC with a humidity range of 70-83 %. Findings revealed that the inside ambient temperature of the shed was 5-6ºC lower than the outside temperature during the noon in summer season. The relative humidity of outside air varied from 33 - 58 %. The THI of the poultry shed was found to be below the threshold limit of 74 throughout the day except from 1.00 PM to 3.00 PM during which it was 75 - 76 that comes under caution zone having mild heat stress indicating a better environment for the poultry birds due to continuous water sprinkling by the sensor based solar powered water sprinkling system.

Solar powered egg incubator for small farmers

IGKV Raipur center has developed a solar-powered egg incubator specifically designed for small farmers or the marginal farming community. The developed egg incubator consists of an axial fan, actuator, timer, temperature controller, relay, SMPS, thermometer, egg tray,

hatchery basket, heater, wheel, switches, frame, wall panel (plywood and whiteboard), battery, solar panel, etc. Developed solar power egg incubator were tested with Kadaknath birds and Quail birds with different trials in two different season. The temperature maintained for Kadaknath and Quail eggs in the incubator were 99º and 87º F, respectively. Fan and water pump working well and maintained the humidity about 65 %. Hatchability for Kadaknath and Quail birds were reported to be 68.70 and 60.48 %, which was quite higher than natural hatching process. Healthy fresh chick hatchout from the solar incubator was observed(Singh, 2023).

Poultry litter racker

UAS Raichurcentre has developed self-propelled litter racker machine which consists of blade assembly provided with rubber batons over the tines. It has been found that the ammonia accumulation was more in manual raking compared to machine raking. GBPUAT Pantnagar centre developed a battery assisted litter racking machine to automate the racking process in the poultry farm. The machine consists of a battery, frame, BLDC motor, raking tool and ground wheel. A garden rake helps in levelling of beds, crushing of clods, and aeration of soil. The ends are forged to make pointed edge for easy penetration. Amonia concentration was 33% less with the developed litter racker than manual stirred litter. The poultry litter agitator with vertical axis rotating element was developed at OUAT Bhubaneswar centre. The developed litter agitator was fitted with a DC motor (200 W), with two batteries connected in parallel supplying DC current to the motor for operating the stirring elements. The motor shaft is connected to the litter agitating shaft through belt and pulley arrangement. The motor shaft rotates at 2700 rpm and is reduced to 300 rpm of litter agitating shaft. A handle is provided at desirable height to control the forward movement of the machine by a gentle pushing force. Artificial Intelligence (AI) robot was developed to measure the ammonia and air quality data inside the poultry house which gives real time data to server. Robot fitted with ultrasonic sensor for sensing obstacles such as feeder, drinker, poultry birds, walls etc has been developed. The operator only took one hour to complete stirring the litter in a 220m2 poultry farm as compared to 2.5 to 3 hours in the existing method of raking with a bamboo stick. It was observed that the bulk density of poultry litter decreased from 0.46 g/cm3 to 0.31 g/cm3. There was a slight increase in ammonia inside the poultry house during litter agitation with the developed litter.

Study on different insulating materials for climate control in poultry housing

Polyethylene air bubble film laminated with one side pure aluminum foil and white poly on another side and air bubbles was installed in tin shed of poultry. Aluminum bubble wrap insulation sheet thickness of 8 mm and 12 mm were selected. All the birds were kept in cage system of housing. Findings concluded that both nutrient intake and digestibility coefficient improve when birds are housed in insulated pens compared to tin shed pens. Aluminum bubble wrap of 8 mm thickness is found economical for insulating the tin poultry shed.

Conclusion

The application of smart technologies particularly sensors, IoT, artificial intelligence, and computer vision has significantly advanced the mechanization of animal husbandry. Through the AICRP-MAH initiative, validated sensor-based systems have been successfully developed for feeding automation, infection and pregnancy detection, environmental control, and animal health monitoring. These innovations offer a

transformative pathway to sustainable and ethical animal husbandry systems in India and have the potential to significantly benefit smallholder farming communities.

There is great scope of artificial intelligence (AI)/ internet of things (IOT), drone, sensors, cameras etc for mechanizing the animal husbandry sector in the country. Livestock farmers can detect the onset of health issues often before clinical symptoms appear through facial recognition and monitoring health status. Modern technologies have the potential to improve livestock productivity, enhance their traceability, assist in disease prevention etc. This will also help the farmers to go on digital animal farming.

References

Aquilani, C., Confessore, A., Bozzi, R., Sirtori, F., & Pugliese, C. (2022).Review: Precision livestock farming technologies in pasture based livestock systems.Animal, 16(1), Article 100429. https://doi.org/10.1016/j.animal.2021.100429

Din M, Singh S P, Pagare V andNamdeo A (2024). Mechanization and profitability of small farms through efficient animal drawn implements. RASSA Jour of Sci for Soci. 6(1): 1-9, DOI: 10.5958/ 2583-3715.2024.00001.5

Food and Agriculture Organization of the United Nations. (1999). (FAO Animal Production and Health Paper No. 150). https:// www.fao.org/ 3/x2023e/x2023e00.htm

Lawal A T (2023). Recent developments in electrochemical sensors based on graphene for bioanalytical applications. Sensi and Bio-Sensi Res, 41, 100571.

Neethirajan, S. (2017).Recent advancement in biosensors technology for animal and livestock health management.Biosensors and Bioelectronics, 98, 398-407. https:// doi.org/ 10.1016/ j.bios.2017.07.015

Neethirajan S (2020). The role of sensors, big data and machine learning in modern animal farming. Sens and Bio-Sens Res, 29: 100367.

Neethirajan S (2023). Artificial intelligence and sensor technologies in dairy livestock export: charting a digital transformation. Sensors, 23(16): 7045

Rojas-Downing M M, Nejadhashemi A P, Harrigan T andWoznicki S A (2017). Climate change and livestock: Impacts, adaptation, and mitigation. ClimRisk Manage, 16: 145-163.

Siberski-Cooper C J, Mayes M S, Gorden P J, Hayman K, Hardie L, Shonka-Martin B N., andKoltes J E (2023). The impact of health disorders on automated sensor measures and feed intake in lactating Holstein dairy cattle. Fronti in AnimSci, 3: 1064205.

Singh S P (2023a). Instrumentation, Technologies and Application of Sensors in Animal Husbandry Mechanization.CIAE/UAE/TB/2024/372.AICRP on Increased Utilization of Animal Energy with Enhanced System Efficiency. ICAR - Central Institute of Agricultural Engineering. NabiBagh Bhopal, Madhya Pradesh (India).

S P (2023b). Research Highlights 2023-24. AICRP on Increased Utilization of Animal Energy with Enhanced System Efficiency.Tech. Report No.CIAE/UAE/TR/2023/364.ICAR-Central Institute of Agricultural Engineering, Bhopal.

Silva, F. G., Conceição, C., Pereira, A. M. F., Cerqueira, J. L., & Silva, S. R. (2023).Literature Review on Technological Applications to Monitor and Evaluate Calves' Health and Welfare.Animals, 13(7).

Singh S P, Pagare V and Patle R (2025). Research Highlights 2024-25. AICRP on Mechanization of Animal Husbandry.Technical Report No.CIAE/MAH/TR/2025/391. ICAR-Central Institute of Agricultural Engineering, Bhopal

Tangorra F M, Buoio E, Calcante A, Bassi A and Costa A. (2024). Internet of Things (IoT): Sensors application in dairy cattle farming. Animals, 14(21): 3071.

Wolfert S, Ge L, Verdouw C andBogaardt M J (2017).Big data in smart farming-a review. AgrilSyst, 153: 69-80.

Next Renewable Energy Technology for Carbon Footprint reduction in Agriculture

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Introduction

Agriculture is an inevitable land-use change for human survival, and is spread over 40% of land across the globe. India being largely an agrarian country, agriculture plays a vital role in the Indian economy, with 157.35 million hectares under cultivation and over 58% of rural households depending on agriculture for their principal livelihood. Agriculture and its allied sectors contributed 16% toward the gross domestic product (GDP) in 2024. Among the various production processes responsible for release of GHGs to the atmosphere, agriculture accounts for 10-12% of GHG emission globally and 21% in India, contributing about 25, 50, and 70 % of CO2, CH4, and N2O, respectively.

Globally, agriculture remains the primary source of food for the population but is highly dependent on fossil fuels to operate farm machinery and support intensive farming practices. This reliance results in significant greenhouse gas (GHG) emissions, making agriculture the second-largest contributor to anthropogenic GHG emissions after the power sector, as shown in Fig. 1.

Transitioning to renewable energy resources such as biofuels, solar, wind, biomass, geothermal, small-scale hydro, and wave energy, they alloffer a viable pathway to reduce environmental impact. Among these, biofuels are particularly promising as low-carbon alternatives to conventional fuels, notably in reducing emissions from the transport and agricultural sectors. To ensure the sustainability of these alternatives, it is essential to assess the carbon footprint (CF) of each fuel type. CF has become a key metric for evaluating environmental impact and is increasingly used to guide sustainable decision-making in agriculture. Its measurement enables the comparison of emissions across agricultural practices and identifies opportunities for improving

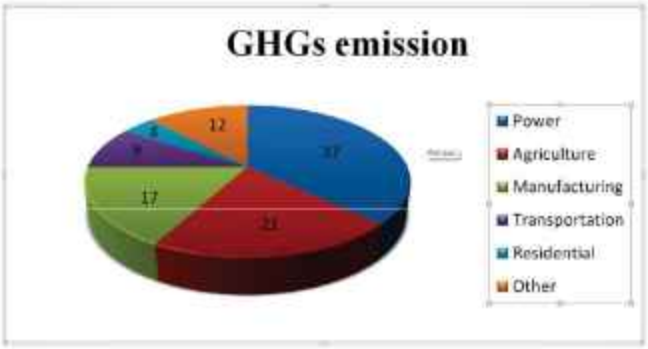


Fig 1: Emission of GHGs in India

environmental performance.

Numerous studies have shown that the use of alternative fuels can substantially reduce dependency on fossil fuels. In addition to environmental gains, bioenergy systems offer socioeconomic and technical advantages, supporting multiple UN Sustainable Development Goals (SDGs). Specifically, SDG 2ending hunger and promoting sustainable agriculturecan be advanced through bioenergy-driven income generation and improved food security in rural communities. Revenues from bioenergy initiatives can enhance livelihoods, support better nutrition, and contribute to resilient agricultural systems.

Solar Energy

The solar energy, inexhaustible power of the sun

leads among the renewable technologies in the world. The harnessing of sunlight for different form of energy has seen remarkable global advancements. The technological innovation in solar photovoltaic has seen unprecedented levels of efficiency of solar cells from monocrystalline solar cell to perovskite solar cellsoffering cost-effective alternatives with high conversion rates. Recent research and developments in the solar cell focus on enhancing the efficiency using novel materials and improved manufacturing processes for cost reduction and to address the intermittent nature of solar power. One of the recent breakthroughs in solar technology is the rise of perovskite solar cells. Perovskite materials are natural mineral composed of oxides of calcium and titanium found to exhibit exceptional light-absorbing properties and can be processed at lower costs compared to traditional silicon-based solar cells. This innovation has the potential to revolutionize the solar industry by providing a cost-effective alternative with high conversion rates. Innovations in solar tracking systems, which optimize the orientation of solar panels to follow the sun's path throughout the day, increase energy capture efficiency.

The thermal application of solar is another important route to harness the solar energy. Various research and developments have been taken place to extract the power of sun for thermal energy as well as electrical energy (Powell et al. 2017, Wang et al, 2021). The solar power can be concentrated through mirrors or lenses onto a small area, generating high temperature heat that can be converted into electricity energy. In these systems the operating temperature is limited by the solar salt heat transfer fluid at565 C, leading to limited design efficiency of 42-45 %. Thus key areas in concentrated solar power technologies includes innovation in cost effective heat transfer fluid and thermal energy storage materials. Recent years, solid particle receivers having potential for temperatures close to 1000 C invited great interestto overcome current working temperature. Concentrated Solar Power (CSP) technologies found to have potential to integrate with thermal energy storage for harnessing solar energy during off sunshine hours. The overall energy conversion efficiency could be enhanced. Few research and developmental research efforts are listet below

Next-Generation solar technologies

Perovskite Solar Cells

- Higher efficiency compared to silicon-based cells (up to 30%).
- Lightweight and flexible, making them ideal for diverse applications.
- Challenges: Stability and degradation issues.

Bifacial and Transparent Solar Panels

- Enhanced sunlight capture
- Increase energy output by 10-20% compared to monofacial panels.
- Potential to revolutionize urban energy generation.

Solar Paint & Solar Skins

- Solar paint embedded with photovoltaic nanoparticles can generate electricity.
- Aesthetic integration for rooftops and vehicles.

Agrivoltaic

- Increase area for solar installation.
- Reduction of carbon footprint from agriculture.

Manufacturing Expansion: Domestic solar PV manufacturing to become a global RE manufacturing hub

Advanced Solar Storage

- ❖ Solid-State Batteries: Higher energy density, safer, and longer lifespan.
- ❖ Thermal Energy Storage: Molten salt technology for application like solar refrigeration.

Agri Voltaic System

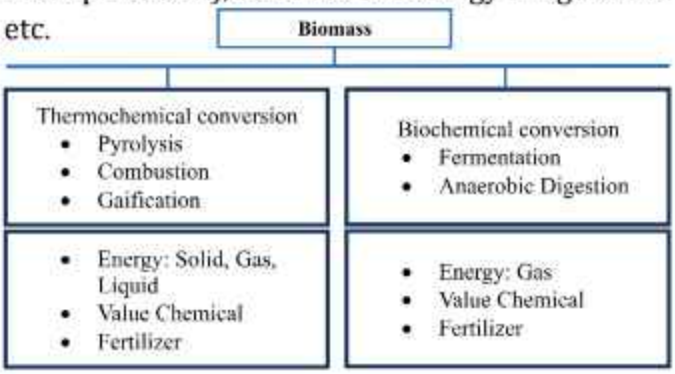
The large-scale deployment of photovoltaic (PV) power generation is a critical component of global strategies aimed at reducing greenhouse gas emissions and mitigating climate change. However, one of the key limitations of expanding PV infrastructure is its significant land requirement, which poses challenges in regions facing growing competition for land due to urbanization and increasing food demand. Agrivoltaic systems, which integrate crop production with solar energy generation on the same parcel of land, offer a promising solution to this challenge. By cultivating shade-tolerant crops beneath solar panels, farmers can maintain agricultural productivity while simultaneously generating clean energy. This dual-use model not only enhances land-use efficiency but has also been shown to improve economic returns by more than 30% compared to conventional farming, due to the added value of solar electricity.

Moreover, agrivoltaics can provide additional benefits such as reduced water evaporation, microclimate regulation, and protection against extreme weather events, potentially improving crop resilience in arid and semi-arid regions. However, despite these advantages, certain challenges persist. The initial installation costs of agrivoltaic systems are relatively high, and the design must be carefully optimized to balance light availability for crops with solar panel efficiency. Additionally, not all crop types are suitable for shaded environments, and in some cases, the infrastructure may complicate farm machinery operations or reduce yield if not properly managed. Nonetheless, with appropriate crop selection and system design, agrivoltaics holds significant potential as a sustainable and economically viable strategy for harmonizing food and energy production on limited land resources.

Biomass energy

Biomass has been used as primary source of energy for centuriesworldwide. India is one of the largest producers of biomass and has gained increased attention to provide renewable energy source for different form of energy including solid, liquid and gas. The biomass can be converted into a variety of useful forms, including fuel for vehicles, heat, and power through various processes. The conversion routes are presented below

The advancements in various process have been done for increased cost effective conversion of biomass in different form of energy. But the scientific community is still facing challenges related to competitive cost of biomass energy, long term sustainability and scale up issue. Out of all conversion technologies, India has significant achievements in installation of large scale plants for production of Compressed Biogas(CBG) through biochemical route. The Govt of India has launched different schemes like SATAT (Sustainable Alternative Towards Affordable Transportation), National Bioenergy Programme etc.



As of now 82 CBG plants have been commissioned in India, and 2026 potential investors have been issued a letter of intent (LOI) for setting up similar plants as of March 2024. Most of these plants are designed to operate on mixed feedstock(Singh et al. 2023). Although there is good progress in setting up of these plants, but most of them are under operation at their lower level of capacities due to various associated challenges including Inadequate supply chain management, high investment cost and lack of public awareness. The other conversion route for conversion of biomass to bio energy is still under laboratory stage.

Next-generation biomass energy technologies offer a transformative approach to reducing greenhouse gas (GHG) emissions in the agriculture sector by converting agricultural residues, livestock waste, and other organic materials into clean, renewable energy. Unlike traditional biomass combustion, advanced methods such as biomass gasification, torrefaction, pyrolysis, and anaerobic digestion enhance energy efficiency while minimizing environmental pollution. These technologies produce cleaner fuels like biochar, syngas, bio-oil, bio-CNG, and biogas, which can replace diesel and other fossil fuels used in tractors, irrigation systems, and agro-processing units. Notably, biochar, a stable carbon-rich product from pyrolysis, not only acts as a soil amendment but also sequesters carbon, thereby reducing CO? emissions long-term. Similarly, bio-CNG from anaerobic digestion of crop waste and manure significantly cuts CH? and N?O emissions while providing decentralized energy solutions. Integration of carbon capture and utilization (CCU) with these processes further enhances their climate mitigation potential. By promoting waste-to-energy conversion, energy self-reliance, and reduced dependency on fossil fuels, next-generation biomass energy plays a critical role in achieving low-carbon, climate-resilient agriculture and supports national goals related to clean energy, sustainable farming, and carbon neutrality.

Ethanol

Ethanol, a biofuel produced via fermentation of biomass such as sugarcane, corn, and increasingly, lignocellulosic residues like crop stubble and agro-waste, offers a low-carbon alternative to fossil fuels. Although its combustion emits CO?, this is largely offset by the carbon absorbed by the feedstock during growth, creating a near carbon-neutral cycle.In agriculture, ethanol can replace diesel and petrol in tractors, irrigation pumps, and transport vehicles, either in pure form or blended (e.g., E10, E85). This switch can reduce greenhouse gas (GHG) emissions by 34-65% over the fuel's life cycle (DOE, 2020).

Second-generation ethanol, derived from non-food biomass such as wheat straw, rice husk, and bagasse, enhances sustainability by reducing food-fuel conflicts and promoting waste utilization. It also aligns with circular bioeconomy goals and integrated waste management systems.In India, initiatives like the Ethanol Blended Petrol (EBP) Programme aim to reach 20% ethanol blending by 2025, supporting rural decarbonization and offering additional income streams for farmers through residue sales (MoPNG, 2023).However, challenges such as feedstock logistics, land use, water demands, and high processing costs hinder large-scale adoption. Investment in advanced biorefineries, decentralized production, and enabling policies is essential to make ethanol a key player in sustainable agricultural energy.

Bio-CNG

Bio-CNG is a purified form of biogas, produced from anaerobic digestion of organic waste such as crop residues, animal dung, agro-industrial

waste, and other biodegradable materials. The raw biogas, containing 50-60% methane, is upgraded to over 90% methane concentration after removing impurities like CO?, H?S, and moisture, making it comparable in performance to conventional CNG. In agricultural applications, Bio-CNG can be used to power tractors, irrigation pumps, and rural transport vehicles, offering a clean substitute to diesel and petrol. Unlike fossil fuels, Bio-CNG is carbon-neutral as the methane used originates from biomass decomposition, which would otherwise release GHGs into the atmosphere. The use of Bio-CNG reduces GHG emissions by up to 75-90% compared to conventional fuels (MNRE, 2024).

To further enhance its climate benefits, coupling Bio-CNG production with carbon capture and utilization (CCU) can sequester the CO? removed during the biogas upgrading process. This captured CO? can be repurposed for greenhouse cultivation, food processing, or industrial applications, effectively closing the carbon loop and minimizing net emissions. India has recognized the potential of this technology through initiatives like the Sustainable Alternative Towards Affordable Transportation (SATAT) scheme, aiming to establish thousands of Compressed Biogas (CBG) plants across the country, many of which will source feedstock directly from agricultural and livestock sectors. This not only reduces rural emissions but also creates income opportunities for farmers by enabling them to supply agri-residues and dung for energy production.

Biohydrogen

Biohydrogen is an emerging renewable energy technology with significant potential to reduce the carbon footprint of agriculture by offering a clean, zero-emission alternative to fossil fuels. Produced biologically through processes such as dark fermentation, photofermentation, and photolysis using agricultural waste, crop residues, or animal manure, biohydrogen not only helps manage organic waste but also supports the circular bioeconomy. Its application in agriculture ranges from powering fuel cell-based tractors and irrigation systems to generating clean electricity for cold storage and greenhouse operations in off-grid rural areas. Unlike conventional hydrogen derived from fossil fuels, biohydrogen is renewable and environmentally benign, emitting only water upon combustion. It contributes to the decarbonization of farm operations by reducing emissions of CO2, CH4, and N2O. Moreover, it aligns with national strategies like India's National Green Hydrogen Mission, which promotes clean hydrogen production and rural energy transformation. Despite current challenges such as low yield, high purification costs, and lack of infrastructure, investments in bioreactor technologies, research, and supportive policies could make biohydrogen a viable solution for sustainable and climate-smart agriculture.

Renewable energy Technology for future

The renewable energy offers a great potential to provide energy security in India. Several studies in different sectors have pointed the options for getting advanced form of renewable energy. The options explored under research and developments are hydrogen, fuel cell, energy storage material, Batteries and super capacitor for future energy systems either as a storage medium or as a fuel or a fuel constituent to phase out fossil fuels in hard-to-abate sectors, including transportation and industry. Among these advancements, green hydrogen being carbon-free attracted the great interest of Govt and industries. The next-generation electrolyzers, such as solid oxide

electrolyzers (SOE) and anion exchange membrane (AEM) electrolyzers. SOE electrolyzers operate at high temperatures to increase the efficiency of electrolysis has been developed for cost effective production of hydrogen (Cozzolino and Bella, 2024). The biomass to hydrogen as a development of new sustainable and environmentally friendly energy technologieshave been extensively researched currently (Pal et al. 2022). Various routes including thermochemical, biological such as alcohols, glycerol, methane-based reforming, fermentation, enzyme and biocatalyst-based approaches, and biomass gasification have been proposed.Although the yield and production rates of hydrogen have shown significant improvement however research and innovation are needed to enhance H2 synthesis rates. Besides there are challenges associated with storage and transportation of hydrogen as a fuel. The bio material for energy storage system like batteries, super capacitors have been explored extensively (Saini et al. 2021). Some of the area for future research and development can be summarized below

- Carbon Capture and Storage from CBG Plants
- Torrefaction of biomass suitable for co-firing in large scale thermal plants
- Hydrogen production from biomass
- Carbon Nanotubes from biomass
- Biomass carbon for supercapacitor
- Solid state batteries
- Direct conversion of biomass into ethanol
- Bioenzematic Fuel Cells
- Artificial intelligence (AI) and machine learning (ML) for optimization of renewable energy system

Conclusion

The transition to renewable energy technologies in agriculture is not just a necessity for reducing carbon emissions but also a strategic move towards sustainable and resilient food systems. Technologies such as biofuels (ethanol, biodiesel), bio-CNG with carbon capture, solar-powered irrigation, wind energy, and biomass gasification offer viable alternatives to conventional fossil fuels, significantly lowering the sector's greenhouse gas (GHG) emissions. By integrating these innovations, agriculture can move toward a low-carbon and circular economy model, where waste is converted into energy, emissions are captured and reused, and dependence on non-renewable resources is minimized. These solutions also promote energy self-sufficiency in rural areas, improve farmer incomes, and support national and global commitments such as the UN Sustainable Development Goals (SDGs) and India's Net-Zero targets. However, to realize the full potential of these technologies, a multi-dimensional approach is required, combining policy support, financial incentives, infrastructure development, farmer awareness, and research and innovation. With sustained efforts and integrated strategies, renewable energy can play a transformative role in achieving climate-smart agriculture and ensuring long-term environmental and economic sustainability.

References

Al Mamun, M. A., Dargusch, P., Wadley, D., Zulkarnain, N. A., & Aziz, A. A. (2022).A review of research on agrivoltaic systems. Renewable and Sustainable Energy Reviews, 161, 112351.

Chateau, J., Dang, G., MacDonald, M., Spray, J., &Thube, S. (2023). A Framework for Climate Change Mitigation in India.

Cozzolino, R. and Bella, G. (2024) A review of electrolyzer-based systems providing grid ancillary services: current status, market, challenges and future directions Front. Energy Res Volume 12 - 2024https:// doi.org/ 10.3389/ fenrg.2024.1358333

Dinesh, H., & Pearce, J. M. (2016).The potential of agrivoltaic systems. Renewable and Sustainable Energy Reviews, 54, 299-308.

Jain, R., Panwar, N. L., Agarwal, C., & Gupta, T. (2025). A comprehensive review on unleashing the power of hydrogen: Revolutionizing energy systems for a sustainable future. Environmental Science and Pollution Research, 32(22), 13329-13359.

Mathur, S., Waswani, H., Singh, D., &Ranjan, R. (2022). Alternative fuels for agriculture sustainability: Carbon footprint and economic feasibility. AgriEngineering, 4(4), 993-1015.

Pal, D. B., Singh, A. and Bhatnagar A. (2022). A review on biomass based hydrogen production technologies. International Journal of Hydrogen EnergyVolume 47, Issue 3, 8 January 2022, Pages 1461-1480https:// doi.org/ 10.1016/ j.ijhydene.2021.10.124

Powell KM, Rashid K, Ellingwood K, Tuttle J, Iverson BD. Hybrid concentrated solar thermal power systems: A review. Renew Sustain Energy Rev 2017;80: 215-37.

Saini,S., Chand,P. Joshi, A. (2021) Biomass derived carbon for supercapacitor applications: Review Journal of Energy StorageVolume 39, July 2021, 102646

Sah, D., &Devakumar, A. S. (2018).The carbon footprint of agricultural crop cultivation in India. Carbon Management, 9(3), 213-225.

Singh, D, Tembhare, M. and Kumar S. (2023) Compressed biogas plants in India: Existing status, technological advances and challenges Biomass and Bioenergy 178 (2023) 106964 https://doi.org/10.1016/j.biombioe.2023.106964

Singhal, S., Agarwal, S., Arora, S., Sharma, P., &Singhal, N. (2017).Upgrading techniques for transformation of biogas to bio?CNG: a review. International Journal of Energy Research, 41(12), 1657-1669.

Wang W, Fan L, Laumert B. A theoretical heat transfer analysis of different indirectly-irradiated receiver designs for high-temperature concentrating solar power applications. Renewable Energy 2021;163:1983-93.

https://mopng.gov.in/files/TableManagements/annual202324.pdf

https://www.energy.gov/eere/bioenergy/biofuel-basics?nrg_redirect=362992

Private Minor Irrigation in the State of Uttar Pradesh: Challenges, Contribution, and Managing Irrigation Water for the Future

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Abstract

Private Minor Irrigation played a pivotal role in the extension of irrigation facilities in the State of Uttar Pradesh. About 79% of the net irrigated area is attributed to private minor irrigation works, and 81% of the irrigated area is from groundwater resources. The State had to pay the price in the form of declining groundwater levels and an increase in problematic blocks. The paper discusses how the State was able to increase the irrigated area in a short period, its overdependence on groundwater, the consequences thereof, remedial actions, and the desired orientation in approach for ensuring adequate irrigation water for the future.

1. Introduction

Today, the State of Uttar Pradesh, India, boasts of having more than 85% of its irrigated area, but in the early 1980s, this was not the case, and the State was struggling to increase its irrigated area. Though the State had rich water resources and had a large groundwater reservoir, its extraction and development were a challenge due to a financial resource crunch. On the other hand, most of the farmers in the State were small and marginal, having no spare money to develop an irrigation source on their own. Furthermore, due to the fragmentation of land holdings, their percentage was increasing. To meet the increasing food demand of a rising population, the challenge for the State in the eighties was how to enhance the irrigated area of the State. Another challenge was how to do it rapidly.

This paper discusses how the Private Minor Irrigation Programme helped to meet these challenges. Uttar Pradesh is the only State in India that has a separate department to implement the Private Minor Irrigation Programme. Under this programme, technical support and financial assistance are provided to the farmers to develop a minor irrigation water source. The farmers also contribute financially, and the developed source is owned, operated, and maintained by them, reducing the burden on the government exchequer.

2. The Schemes

Considering the high percentage of small and marginal farmers in the State and rich groundwater resources, the State Government specifically launched a shallow boring/tubewell scheme for Small and Marginal Farmers in 1984-85, because, without their active participation and cooperation, a rapid increase in net irrigated area was impossible. This scheme was named as "Free Boring Scheme". The government provided a certain amount of subsidy to construct a bore well and purchase a pump set. The farmers bore the remaining cost. The scheme became popular, and the government substantially increased the targets under the scheme in the consecutive years. The Minor Irrigation Department was unable to meet the increased targets as it was using the traditional sand pump boggy set technology for drilling, which was slow, the cost of the set and drilling was high, and the cost of transport was high due to the heavy weight. Furthermore, extra funds were required to

purchase additional boring sets to meet the targets. The department desperately needed a low-cost, fast, and simple drilling technology.

During the same time, an unknown local mechanic developed an indigenous drilling technology by combining the principles of percussion drilling and reverses circulation rotary drilling and named it "Pressure Boring Set". It was very cheap as casing pipe and tripod were not required, easy to transport due to its lightweight, drilling was very fast, and the cost of drilling was very low. The department studied the operation of this set, prepared a technical report, and decided to adopt it in its drilling programme. This escalated the construction of the bore well and substantially reduced the drilling time. The cost of lowering assembly was also reduced because its adoption allowed the use of PVC pipes in shallow borings [1].

With the help of this new indigenous technology, the department was able to achieve annual targets under the free boring scheme, which helped substantially in increasing the net irrigated area in the State. The progress of net irrigated area and number of borings is shown in Fig. 1 [1].

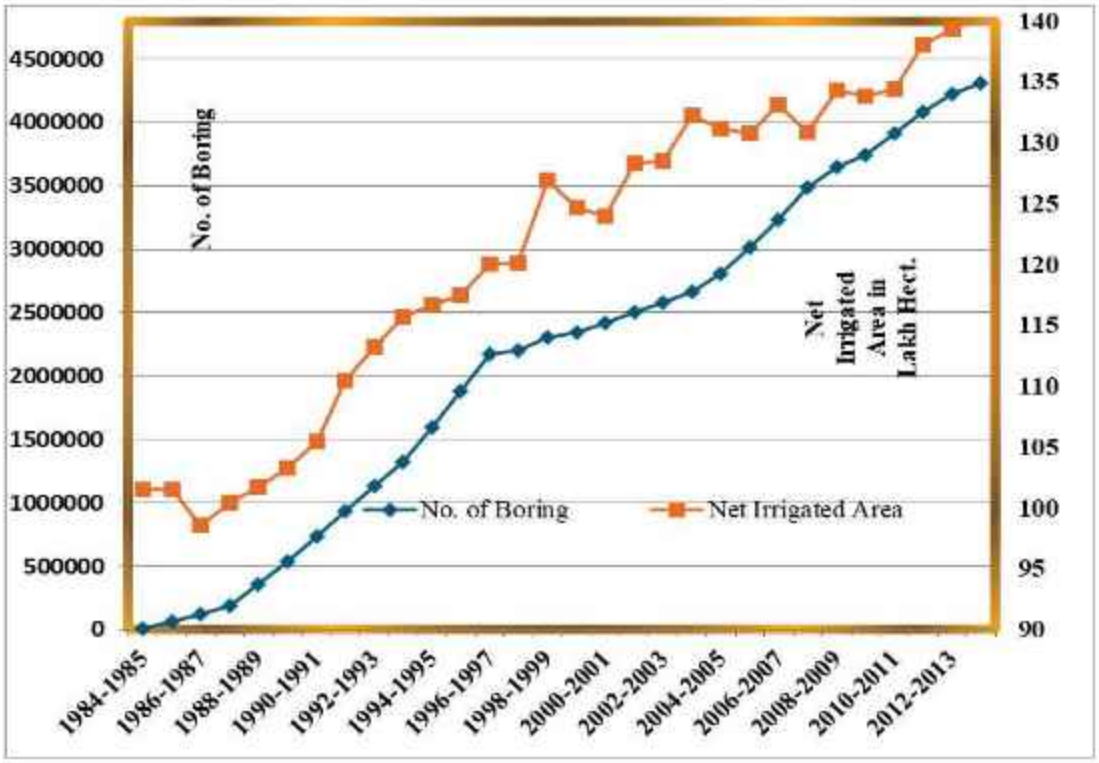


Fig 1: Progress of net irrigated are a and shallow borings [1]

The Free Boring Scheme changed the lives of millions of farmers, and after 40 years of its inception, this scheme is still popular among farmers.

After the success of the shallow boring scheme, the Medium Deep Tube Well, Deep Tube Well, and Community Blast Well schemes were also implemented under the Private Minor Irrigation Programme to cater to varying geohydrological conditions in the State. These schemes helped in substantially increasing the net irrigated area from private minor irrigation works. The progress of the net irrigated area from different sources is presented in Tables 1[2].

Table 1: Source -wise irrigated area in the state of Uttar Pradesh
(Note- Figures in the brackets are percentages)

S. no.	Name of source	Net irrigated area (million hectares)				
		1984-85	2002-03	2006-07	2011-12	2014-15
1	2	3	4	5	6	7
1.	Canals	3.331 (32.8)	2.630 (20.47)	2.614 (19.63)	2.555 (18.46)	2.482 (17.24)
2.	State tube wells	0.654 (6.20)	0.505 (3.93)	0.373 (2.80)	0.490 (3.54)	0.444 (3.08)
3.	Private tube wells	5.086 (50.08)	8.783 (68.37)	9.129 (68.57)	9.671 (70.03)	9.739 (67.68)
4.	Other sources	1.083 (10.15)	0.928 (7.22)	1.197 (8.99)	1.093 (7.91)	1.724 (11.98)
Total		10.154	12.846	13.313	13.809	14.389

It can be concluded from Table 1 that the major contribution to the net irrigation area is by private tube wells. Under private tube wells, most are shallow tube wells. Moreover, 79% of the net irrigated area is attributed to private minor irrigation works, and 81% of the net irrigated area is through groundwater sources [2].

With an increase in irrigated area in the State, total food production also increased about 86%, from 29.193 million metric tons in 1984-85 to 55.747 million metric tons in 2016-17 [2].

The above schemes under the private minor irrigation programme are still ongoing and very popular among the farmers. However, the success of these schemes made the irrigated agriculture in the State overdependent on groundwater. The farmers prefer these schemes as groundwater-based minor irrigation structures need a low initial investment, are an assured source of water, and they have full control over their operation and maintenance to plan their agricultural activities without fear of unavailability of irrigation water, a serious issue related to canal irrigation.

3. The Price and Remedial Action s

A plethora of anything is always fatal, and the same is true with irrigated agriculture in the State, which has become overdependent on groundwater over time. The price of it was declining groundwater levels, and a sharp increase in the number of problematic blocks (over-exploited, critical, and semi-critical blocks, or OCS blocks) in the State. The growth of OCS blocks is shown in Fig. 2 [3]

This trend was not only in Uttar Pradesh, but at the Country level, India became the epicentre of tube well irrigation in the World and became the largest extractor of groundwater. Its groundwater withdrawals surpassed the combined withdrawals of the United States and China as depicted in Fig. 3 [3].

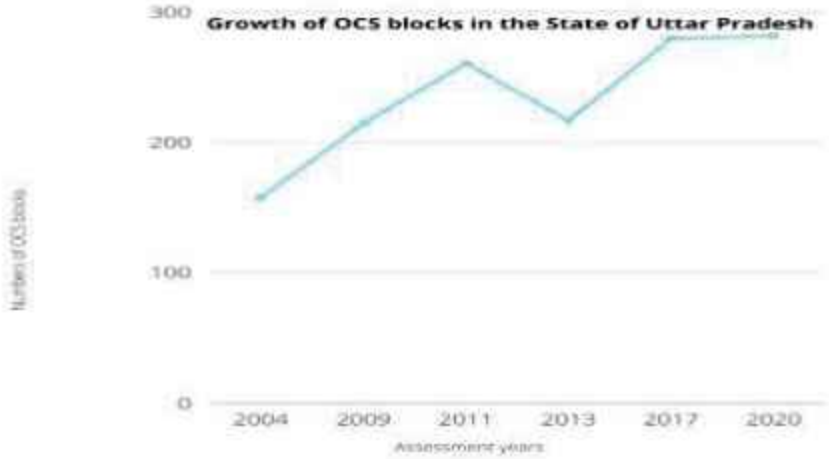


Fig 2: Growth of OCS blocks in the state of Uttar Pradesh [3]

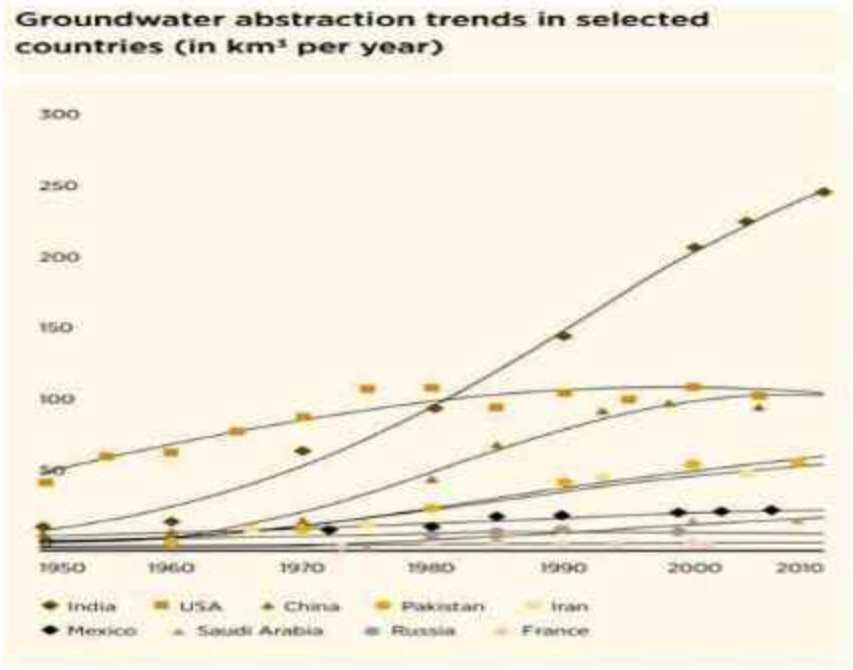


Fig 3: Groundwater abstraction in various countries over time [3]

By the beginning of the first decade of the 21st century, it became evident that tube well irrigation would not be sustainable without protecting and rejuvenating the precious groundwater resource. Thus, the efforts started for rainwater harvesting and groundwater recharge. Apart from issuing guidelines to all concerned departments to increase investment in rainwater harvesting and groundwater recharge in their ongoing schemes, the Minor Irrigation Department increased the allocation for its stone masonry check dam scheme and conceived a new scheme for redevelopment and management of traditional ponds (> 01 hectare). These

ponds were the backbone of our local surface and groundwater supply systems from times unknown, but due to heavy siltation, encroachment, and neglect over time, their capacity to store surface water and facilitate groundwater recharge has declined considerably. These ponds are available in every village of the State.

In the year 2003-04, the department was able to arrange funds for the scheme from the 13th Finance Commission. In the following years, the department was able to get funds for this scheme from the sustainability component of the drinking water mission. From 2015-16, the department launched a regular scheme for the Redevelopment and Management of large ponds. The department has developed 1,169 large ponds and 1,541 stone masonry gravity check dams between 2017-18 and 2024-25 in the State [4].

The department also implemented pilot schemes for artificial groundwater recharge, Rooftop Rainwater Harvesting, and Groundwater Recharge to demonstrate the technology. Now Rooftop Rainwater Harvesting and Groundwater Recharge is also a regular scheme.

Enhancing Water Conveyance Efficiency

To enhance water conveyance efficiency, the Minor Irrigation Department also introduced a portable HDPE quick-coupling pipe irrigation system in all its tube well schemes. In the Bundelkhand Region of the State, the department provided this to farmers under the Bundelkhand Package in a big way. The impact of this scheme was that the coverage under the pipe irrigation increased manifold, from 32.71% in 2013-14 to 45.72% in 2017-18 [2,5]. However, the coverage under sprinkler and drip irrigation is still a concern, only 0.34% and 0.11% respectively [5]. This indicates the need to re-examine the Micro Irrigation Scheme.

4. Climate Change and the Availability of Water

The impact of climate change started to be felt after 2000, and it became more prominent after 2010. The State witnessed a significant decline in average annual rainfall and the number of rainy days. The mean annual rainfall for the period 1989 to 2018 was 748.1 mm, 23.22% less than the long-term average annual rainfall of 974.4 mm. In the majority of districts, the number of rainy days declined to a range of 31.2-41.2 days, and in some western districts, rainy days were 27.

At the country level, there were negative deviations in annual rainfall in most states. In the states of Punjab, Haryana, and Uttar Pradesh, these were alarming, 17%, 19%, and 23% respectively. These are the states where forest cover is only 3.4%, 3.62%, and 6.15% and these are also the major contributing states to the food basket of the country [3].

The relation between rainfall and precipitation has been a debatable issue, but a consensus is again emerging now that vegetation and precipitation are closely related. An analysis of 5 years (2013-2017) of rainfall data in the Bundelkhand region of the State shows a strong correlation between negative deviations in the rainfall and forest cover [6].

Thus, rainfall is an unreliable source of water supply now, which will affect our local surface water and groundwater supplies in the future. There is a need to search for alternative sources of water supply.

5. Way Ahead

The State government's efforts to arrange water for irrigation are laudable, but with the looming danger of water scarcity due to climate change and increasing population, orientation in the approach is needed now. We can blunt the adversaries of climate change and population increase and ensure adequate water for irrigation in the future if we address the following issues urgently and effectively.

1. More attention is needed for the redevelopment and management of large ponds. The budgetary allocation for this is insufficient, and with the present level of allocation, it will take decades to redevelop all the ponds, approximately 20000. There is a need to adopt a more focused approach, i.e., map all such ponds, and redevelop them in a time-bound manner as water sanctuaries by providing sufficient funds.
2. With rainfall being an unreliable source of water supply, the search for alternative sources of water supply becomes a necessity for the future. Wastewater may be one such source, available throughout the year in the same quantity [3]. To tap this resource, special funding and projects are required to collect, filter, store, and transport it.
3. Forests play an important role in the hydrological cycle. Apart from attracting clouds, conserving water and soil, and controlling temperature, they increase moisture in the atmosphere by enhancing evaporation. The State's Forest cover is stagnant at around 6%, far below the recommended value of 33%. A substantial increase in the forest cover in a short period seems a herculean task unless we change our forest development strategies and adopt some innovative approaches.
4. The aquifer recharge and transfer of water through the aquifer system are standard techniques to solve water woes. These techniques have not been tried in the State yet. These techniques should be tried and demonstrated for large-scale adoption.
5. A considerable area in the State is waterlogged. Means it is surplus in groundwater. In these areas, the groundwater level can be lowered through the field drainage system, and drained water can be collected in sump wells and transferred to the water-scarce regions by pipelines.
6. Reliable and up-to-date information is the primary requirement to manage a resource. There are many discrepancies in the irrigation statistics. Either the available data are out-dated, or there are errors, disagreements, and mismatches. For example, the figures of ultimate irrigation potential have not been revised over the last several years, and the potential created by groundwater has far surpassed the ultimate irrigation potential. Regarding the waterlogged area, there is disagreement among different agencies. The unit net irrigated area by different private minor irrigation structures has also not been revised over the last several years [2]. So, there is a need to reconcile the irrigation statistics.
7. The State has several water laws and policies, such as the State Water Policy (1999), the Uttar Pradesh Participatory Irrigation Management Act 2009, Policy for Groundwater Management, Rainwater Harvesting, and Groundwater Recharge 2013, the Uttar Pradesh Water Management and Regulatory Commission Act 2014, the Uttar Pradesh Groundwater (Water Management and Regulation) Act 2019, etc. These are

either ineffective or inefficiently implemented [2]. There is a need to enact strong laws and develop an effective mechanism for their implementation.

8. The State also has a large static groundwater resource, which has not yet been assessed for future use. This resource needs to be quantified along with its quality assessment, so that it is available for use in times of need in the future.
9. The over-dependency of irrigated agriculture on groundwater can be reduced by increasing the share of surface water irrigation. It can be achieved by making our old age canal irrigation network more efficient by checking conveyance losses and improving surface water availability by encouraging more local surface water storage. Apart from this, it is now illogical to provide subsidies to farmers for the construction of tube wells in those districts where the net irrigated area is above 95% and most of the area is irrigated by tube wells. In such districts, these schemes should be discouraged, and the funds should be diverted for the redevelopment and management of large ponds to ease pressure on groundwater.
10. Water application efficiency in the State is still very low despite the increased use of pipe irrigation. The coverage under sprinkler and drip irrigation is negligible, though the Micro Irrigation Program was started 35 years ago. So, the Micro Irrigation Program needs to be redesigned specifically for the State's prevailing conditions and requirements. For drip irrigation, community farming can be encouraged because of the uneconomical land holdings of most farmers. For it, the concept of horticulture complexes can be tried. Special attention is needed on the design aspects of these systems as they are pressure systems, and even a slight variation in land slope can adversely affect their performance. A tailor-made design does not simply work for these systems.
11. Automation is another way of improving efficiencies. In the past few decades, information technology has revolutionized the way we do things and made our lives easier. But its adoption in the irrigation and agriculture sector is very sluggish. IOT, cloud, and sensor network-based irrigation systems supported by AI may substantially improve water application efficiency. But these systems are still confined to laboratory-level experiments and have yet to be field-tested. This is the right time to field-test these systems as the future is in AI, and if we do not adopt these technologies now, we will fall behind.
12. Agriculture is the biggest user of water in the State. By limiting the area under water-guzzling crops like wheat, paddy, sugarcane, we can reduce water use in agriculture and, in turn, pressure on water resources.

References

1. Chaurasia P. R. and Subhash. 2018. *"A Low*-cost Indigenous Intervention which has Revolutionized the Drilling Technology and Changed the Life of Millions of Farmers *in the State of Uttar Pradesh, India"*, Journal of Institution of Engineers (India), Series A, Volume 99, Issue 2, 2018.
2. http://doi.org/10.1007/s40030-018-0278-7

3. Chaurasia P. R. and Sinha R. S., "Water Development and Management in Uttar Pradesh , India: Past, Present and Future Perspectiv e", 2021, Notion Press, Chennai, India.
4. Chaurasia P. R. and Sinha, R. S. 2022, *"Over Dependency on Groundwater in India: Issues and Insights"*, International Journal of Industrial Marketing, ISSN 2162-3066, Nov 2022, Vol. 7, No. 1. https://doi.org/10.5296/ijim.v7i1.20399
5. "*Progress Reports"* (Minor Irrigation Department, Government of Uttar Pradesh, India).
6. "State-wise Report of 6th Minor Irrigation Census, Vol-2", 2023 (Government of India, Ministry of Jal Shakti, Department of Water Resources, River Development and Ganga Rejuvenation, Minor Irrigation (Statistics) Wing), pp 245.
7. Chaurasia P. R. and Chandra Subhash, "Bundelkhand Water Woes: Paradigm Shift is needed in the Strategy", Journal of the Institution of Engineers (India Series A), 102(1), 335-345, Jan 2021. https://dio/10.1007/s40030-020-00496-8

Road Map on Mechanization of Indian Agriculture

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Introduction

Economic growth in Indian agricultural sector lags behind growth in industry and services, creating an ever widening rural-urban income gap. The production and productivity in Indian agriculture cannot be enhanced by primitive and traditional practices of farming. Agricultural mechanization plays a key role in improving agricultural production and productivity in developing counties. The average farm size in India is small (1.08 ha) and small and marginal land holdings (less than 2.0 ha) account for 86% of land holdings. Mechanizing small and non-contiguous group of small farms is against 'economies of scale' for individual ownership of farm machinery. With continued shrinkage in average farm size, more farms will fall into the adverse category thereby making individual ownership of agricultural machinery progressively more uneconomical.

Status

The status of farm mechanization in India is analysed by the trend in growth of mechanically power-operated farm equipment over traditional human and animal power operated equipment. It was observed that there was a direct correlation between farm power availability and productivity during the past six decades. Haryana state of India has the highest tractor density per thousand hectare of net sown area of 96 tractors and followed by 79 tractors for Punjab against all India average of 43 tractors. The sale of transplanter, power weeder, combine harvesters, rotavator and thresher in India is growing at a compound annual growth rate (CAGR) of 50, 50, 28, 20 and 10%, respectively.

Challenges

The average farm power availability needs to be increased from 3.04 to 4 KW ha-1 by 2030 to assure timeliness and quality in the field operations. Therefore, India adopts a policy of selective mechanization under diverse conditions, which makes the agricultural mechanization challenging.

Solutions

- Mechanize small farms by popularizing high capacity farm machinery on custom hiring basis.
- Promote improved manual tools and animal drawn farm equipment on individual ownership basis in small farms because Indian farms have huge animal population.
- Provide subsidies to medium and large scale farmers to encourage them to buy and to apply advanced medium and high capacity machinery.
- Institutionalize high cost farm machinery (combine harvester, sugarcane harvester, potato combine, paddy transplanter, laser leveller, rotavator etc.) through custom service or rental model to reduce the cost of operation
- Promote robotics, automation; sensors and ICT based farm machinery application.
- Promote application of drones for pesticide applications, crop yield loss estimates and other such operations through custom hiring models.
- Establish farm machinery banks in low farm power availability region for

machines being manufactured elsewhere in the country.

- Ensure quality of machinery being sold and after sales support for farm machinery
- Promote mobile drying units for food grains, oilseeds and spices
- Promote solar assisted walk-in type driers for all sorts of crops and their derivatives
- Promote Agro Processing Centres on production sites and in village headquarters on individual ownership basis
- Promote incubation and custom hiring models for multiple crop processing facilities in a given production catchment area.
- Promote Public Private Partnership mode for medium to large scale storage facilities including cold storages and warehouses
- Promote Small and Medium scale manufacturers in various parts of the county for adoption of low cost machines, gadgets and equipment for which large companies are reluctant to promote.
- Promote training centres for creating manpower for repair and maintenance of farm machinery and equipment, drone operations, manufacturing skills for farm machinery, management of custom hiring centres and other such trades
- Initiate diploma programs in Agricultural Engineering in SAUs.

Government Initiatives

The Government of India has also taken initiatives and programmes like Rashtriya Krishi Vikas Yojana (RKVY), National Food Security Mission (NFSM), National Horticulture Mission (NHM), Gramin Bhandaran Yojana (GBY), Sub-mission on Agricultural Mechanization (SMAM), scheme on Promotion of Agricultural Mechanization and Machinery for In-situ Management of Crop Residue in the States of Punjab, Haryana, Uttar Pradesh and NCT of Delhi etc.

Focus Areas for R&D

Based on the present agricultural mechanization situation, to accelerate farm mechanization, the following major R&D activities for application of Sensors, AI, IoT and Robotics need fast tracked:

- Develop machinery for adoption of precision farming for improved input use efficiency of seed, fertiliser, chemicals and water
- Develop autonomous guidance and real time monitoring system for tractors, power tillers and self-propelled machinery
- Application of drones for spraying and crop health monitoring
- Automated soil sampling and nutrient assessment system
- Robotics for harvesting of coconut, black pepper etc.
- Agri-bot for protected cultivation
- IoT based controlled storage systems for food grains and pulses
- AI and IoT based smart irrigation systems for field and horticultural crops

Strategies

A. For ICAR/SAUs:

- Develop small and smart multi-crop and multi-purpose machines and implements for small farmers
- Develop energy efficient large - versatile multi-crop and multi-purpose machines

and implements for simultaneous operations in different cropping systems and land configurations

- Develop high value products from agro produce and by-products for domestic and export
- On-farm processing and value addition techniques for enhancing farmers' income
- Industry partnership to improve/ facilitate commercialization and adoption of developed technologies /machines/ processes/ products.
- FastTrack R&D on artificial intelligence, IoTs, robotics, drones, automation, block chain, etc.
- Use social media platforms for promotion of technologies
- Entrepreneurship training/certification course for rural youth for establishment of CHCs, machinery operation and safety, repair and maintenance etc.
- Promote CHC based Agro Processing Centres in rural area
- Prepare machinery packages for small farm mechanization starting from primary cultivation to harvesting, primary processing and packaging machines for various crop rotation/agro-climatic type of areas for the whole country
- Promote "Mobile Repair and Maintenance Vehicles" in rural areas
- Promote small to medium manufacturers for agricultural machinery

B) For DA & FW:

1. Facilitate assessment of agricultural Mechanisation, farm accidents, post harvest losses, etc. every 5 years; and publish yearly mechanisation databank.
2. Facilitate Linking, monitoring and upkeep of mobile apps developed by different institutes and SAUs into single FARMs app.
3. Initiate development of BIS codes for precision machines, drones, autonomous agricultural vehicles.
4. Equipment testing centres for testing of precision machines, drones, autonomous agricultural vehicles.
5. Facilitate regular Government-Industry-Institute-Stakeholder interface meetings

Way Forward

Agriculture is viewed in a holistic manner addressing to production agriculture as well as secondary agriculture. Further planning has to be different from other plans considering the major emphasis on "Aatma Nirbhar Bharat". Major concern to improve agricultural growth is to increase income of the farmers to make agriculture a profitable enterprise.

Climate Change - An Overview

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The climate change is a reality during twenty first centuary though some people still opine this as climatic variability. The term climatic variability is that inherent deviation from within the normal climate of that region which gets nullified over a short period. It is linked with the term probability, which conforms that a parameter of certain magnitude is expected to repeat at certain period of time. The word climate change is a shift in the climatological parameters from a large term average (of normally 30 years) of recorded data. The global climatological data analysis clearly indicates the climate change. The changes observed in easily measurable parameters i.e. the temperature and solar radiation (radiative force) clearly show a significant change over time in the recorded instrumental data since 1850. The 100 years linear trend (1906-2005) of 0.74 C (0.56 to 0.92 C) temperature has been reported (FAR, IPCC), which is larger than 0.6 C (0.4 to 0.8 C) C reported during 1901-2000 (TAR, IPCC). Further, 11 of the 12 years (1995-2006) rank among the twelve warmest years in the instrumental record of global surface temperature since 1850. These are 1998, 2005, 2003, 2002, 2004, 2006, 2001, 1997, 1995, 1999, 1990, and 2000 in the order of decreasing rank. The last 50 year period shows an increasing rate of 0.128 0.026 degree per decade whereas last 100 year period shows an increase rate of 0.074 0.018 degree per decade in the temperature (Fig.1, IPCC). Consequent to the increasing trend in temperature is the observed rising sea level due to melting of polar ice, glaciers and thermal expansion of sea water. The global average sea level has risen on an average rate of 1.8 (1.3 to 2.3) mm per year since 1961 and at the rate of about 3.1 (2.4 to 3.8) mm per year since 1993. If the sea level continues at this rate then Maldives, Lakshadweep Islands and similar other coastal areas are likely to be inundated. However, some area in temperate region is likely to be available for cultivation as snow line is expected to go up due to receding of the glaciers. The hypotheses are many and the scientists are trying to be precise in their computations. The temperature increase is widespread over the globe and is greater at higher northern latitudes.

This is the global record of climate change. We, however, have witnessed the following changes in the climate in our vicinity;

1. Shift in the precipitation season-delayed or early monsoon, unexpected rain/snow fall,
2. High intensity of precipitation,
3. Increased / decreased number of rainy days/ snowfall days,
4. Higher/lower annual rainfall,
5. Some regions known for low rainfall receiving higher rainfall and vice-versa,
6. Prolonged dry spell,
7. More warmer days,
8. Less cold nights/higher night temperature during winter,
9. More frequent drought,
10. More frequent floods,
11. Melting of snow bound areas/glaciers at faster rate.

The above changes are being observed by every one in different parts of the world. This unexpected change in the climate is affecting our day to day life, disturbing transport, bringing more ill health and asking for more additional artificial energy and so on. Now these changes/problems may be due to climate change or due to climate variability, but we have to find out suitable solutions to these problems in order to avoid a quiet possible diminishing world.

The change in the climate is also observed in some of the biological processes as;

1. Seasonal changes in the in the stream / river flow (reduction in the discharge during non-rainy period and increase in the discharge during the rainy season; increase in the dry flow days of the stream)
2. Change in the flowering time of plants
3. Change in the maturity time of the plants
4. Change in the intensity of insects
5. Change in the biological behaviour of the animals, birds, insects etc.
6. Observation of new types of insects
7. Migration of plants and insects from one climatic zone to others
8. More and new occurrence of diseases
9. Declining agricultural production, and so on

What we are not able to visualize at local level, is termed as macro or global observations. These are;

1. Melting of glaciers
2. Decrease in the snow bound area at the poles and glacier
3. Sea level rise

The projections for future are still worse than these tiny changes being observed by individuals. It is projected that the global temperature may even rise by 1.1 to 6.4 C during twenty first century. Now we are tired with the observed sea changes as referred above due to temperature change of only the magnitude of 1.8 (1.3 to 2.3) mm per year since 1961 and at the rate of about 3.1 (2.4 to 3.8) mm per year since 1993. The projected change in the temperature of 1.1 to 6.4 C is likely to cause the sea level rise of about 18 to 59 cm by the end of the century (IPCC). There is a confidence level of over 90 percent that there will be more frequent warm spells, heat waves and heavy rainfall during twenty first century. There is a confidence level of more than 66 percent that there will be an increase in droughts, tropical cyclones and extreme high tides. The Soil and Water Conservation Society (2003) reported increase in soil erosion ranging from 4% to 95% and increase in runoff from 6% to 100% may already be evident on cropland in some locations.

History of knowledge of Climate Change

The change in the climate change is not new to the human kind. The globe is said to have witnessed this several times in past. There are record in the old literature of all the religions throughout the world and geological and other evidences too. In the present time, the concept of Climate Change was brought some time in the middle of twentieth centaury. However it got momentum during the last quarter of the twentieth century when World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP) constituted a panel named as Intergovernmental Panel on Climate Change (IPCC) during 1988 to evaluate the risk of climate change caused by human activity and to suggest the causes of climate change, it's possible effect over the globe and mitigation strategies to combat the adverse eventualities of climate change. The first assessment report (FAR) by IPCC was submitted during 1990, second (SAR) during 1995, third (TAR) during 2001 and fourth (FAR) was submitted during 2007. The fifth (FAR) was

published in 2014. People from over 130 countries contributed to the IPCC fourth assessment report. These people included more than 2500 scientific expert reviewers, more than 800 contributing authors, and more than 450 lead authors. Dr. R.K. Pachauri (the then Director General, TERI - The Energy and Resources Institute, New Delhi, India) was the chairman of IPCC. He served as the IPCC Chairman from 2002 to 2015. Ninety-seven scientists and urban practitioners from five continents have been selected by the Intergovernmental Panel on Climate Change (IPCC) as Authors, Coordinating Lead Authors, and Review Editors for the upcoming Special Report on Climate Change and Cities (SR-Cities), set for release in March 2027.

The scientists from these countries sit together under IPCC and debate the above. The scientific committee of the world through IPCC is anonymous about the fact that the main cause of climate change is due to global warming created by accumulation of green house gases in our atmosphere such as carbon dioxide, methane, nitrous oxide and few others. The emission of these gases due to anthropogenic activities is much higher than the absorption capacity of ocean, vegetation and the atmosphere. The accumulation of these gases in the atmosphere is increasing the global temperature and bringing changes in other climate related parameters, which ultimately triggers the evaporation from the ocean and other water bodies like lakes, reservoirs, rivers, etc. It also increases the evapo-transpiration from the vegetation.

Possible causes of climate change

Following gases in the atmosphere are said to be main cause for global warming;

1. Carbon dioxide (CO2)
2. Methane (CH4)
3. Nitrous Oxide (N20)
4. Ozone (O3)
5. Water vapours (H2O)
6. Synthetic halocarbons (The following are mostly produced by chemical industries)
   - (i) Chlorofluorocarbons (CFCs)
   - (ii) Hydro fluorocarbon
   - (iii) Perfluorocarbons
   - (iv) Halons
   - (v) Sulphur hexafluoride

Carbon dioxide concentration which was about 280 ppm (parts per million) during 1750 was about 379 ppm during 2005. Methane concentration has increased from 715 ppb (parts per billion) during 1750 to 1774 ppb during 2005 and nitrous oxide concentration has increased from 270 ppb during 1750 to 319 ppb during 2005 (Fig 2, IPCC).

The increased CO2 concentration (this is the basic/primary climatic parameter, which has been universally accepted to increase substantially and which triggers other climatic parameters viz. temperature, rainfall, humidity and sunshine hours etc. to vary both: temporally and spatially) is responsible for causing changes in temperature and rainfall - the crucial climatic parameters for evapo-transpiration, runoff and soil loss. The climate change is visualized as a result of global warming. And the global warming is due to the increased concentration of green house gases (Carbon Dioxide, Methane, Nitrous Oxide and other Chlorofluorocarbons (CFCs)).

Global summary of large stationary CO2 sources with emissions of more than 0.1 million tonnes of CO2 emissions of green houses gases are given in Table:1. The major source of CO2 is power sector (10,539 932 Mt yr-1) followed by cement production (932 Mt yr-1), iron and steel industry (645 Mt yr-1) and petrochemical industry (379

Mtyr-1).

Climate Change in India

The mean surface temperature in Tropical Asia has increased 0.3 - 0.8°C over the past 100 years, although there has been no trend in mean rainfall for the past thirty years in the area. There is also no discernible change in the number, frequency, or intensity of the tropical cyclones over the past 100 years, although some decadal patterns do exist (McLean et al., 1998). Temperature predictions for India due to anthropogenically-caused climate change for the year 2040 versus 1980 are for a 0.7°C and 1.0°C increase for maximum and minimum surface air temperatures, respectively. However, this warming will be less prominent during the monsoon season. Winter diurnal temperature range is predicted to decrease (McLean et al., 1998). With a doubling of pre-industrial levels of CO2 in the atmosphere, the United Kingdom Meteorological Office (UKMO) GCM predicts a temperature increase for India of 16.2%, the Goddard Institute for Space Studies (GISS) GCM predicts an increase of 10%, and the Geophysical Fluid Dynamics Laboratory (GFDL) GCM predicts an increase of 23.5%.Some recent studies, however, have indicated that the GCMs temperature predictions are too high (Dinar et al., 1998).

Each of these three models predicts an increase in precipitation with a doubling of CO2 levels from pre-industrial levels, but they predict differing magnitudes of increase at different times of the year (Dinar et al., 1998). The IPCC predicts that there will be an increase in the magnitude and frequency of extreme rainfall events in tropical Asia, but that due to the effect of sulfate aerosols, the mean summer monsoon rainfall in India will decrease by 0.5 mm/day. There is some uncertainty as to how much anthropogenic aerosols are being emitted, thus limiting the confidence of these predictions (McLean et al., 1998).

Soil moisture is also supposed to be altered due to changes in precipitation, runoff, percolation, evaporation and rainfall distribution. However, soil moisture is very hard to predict due to the many factors involved and the uncertainty associated in making any climate change prediction (Dinar et al., 1998).

The CO2 emissions by fuel type for the year 2000-01 in India is given in Table; 2, Anonymous (2006). The total emissions of CO2 from India during 2000-01 have been estimated at 880 million tones. The main source is coal with 550 million tonnes, followed by high speed diesel with 114 million tones and natural gas (59 million tones).

Effect of Climate Change over Run off and Soil loss on Watershed basis

Tripathi and Sharda (2007) and Tripathi et.al. (2007) studied the effect of changed rainfall during 21st century on run off and soil loss on 7 watersheds of the country representing different agro-ecological regions .they concluded that the annual and monsoon rainfall is projected to change by 3.4 to 46.9% and -8.9 to 42.2% respectively. The annual and monsoon rainy days are also projected to change by -2.8 to 86.7% and -16.0 to 91.4% respectively. The annual and monsoon run off is projected to change between 55.9% to 1211.1% and 48.0 to 350.00% respectively. The pre-monsoon, post-monsoon and winter monsoon rainfall & runoff will be beneficial for crop production, soil moisture storage and surface and sub-surface water harvesting with slight adoption of soil and water conservation measures on watershed basis. However, the monsoon rainfall & runoff will be much damaging leading to flood and loss of not only the soil fertility but movement of soil from

field to unwanted locations namely drainage network and water storage structures reducing their carrying capacity and storage capacity respectively. The frequency of land slide and slips will also be on higher side. The annual runoff of the magnitude of over 300 mm is projected to increase between 26.1 to 200% thus increasing the frequency of flood. The annual runoff of less than 50 mm is expected to reduce by 10 to 100% thus increasing the frequency of drought. It is very likely that high intense rainstorm may be very common leading to frequent drought and flood .The soil loss is expected to increase by 3.7 to 757%. The most feasible and relevant mitigation measure will be to adopt the watershed management programme more earnestly in combination of planting the permanent vegetation i.e. tree, shrubs & grasses in 10-70% of the total watershed area of about 500 ha, maintaining atleast 10% of cultivated land of individual farmer under agro/horti/forestry, 10-15% of common land under social forestry and another 15-70% of undisturbed forest in every watershed of about 500 ha depending on its location in plain/hilly/mountainous region.

Sources of major green house gases (GHGs)

1. Carbon dioxide (CO2): Carbon dioxide, though constitutes only about 0.04% of the air, but is the most harmful gas if it increases by a fraction just like small quantity of salt in the water.

Source of CO2

- The increase is primarily due to combustion of fossil fuel in steam generators (Power generation)
- Industrial furnaces
- Residential and commercial buildings
- In cement production,
- Vehicles (Transportation),
- In changes in tropical land use, and
- During the combustion of biomass

2. Methane (CH4): The increase of methane in the atmosphere is closely linked to the world's growing population and its growing demand for food.

Source of CH4

- In the increasing numbers of cattle and sheep,
- Increasing hectares of rice paddies, and
- Emitted during the process of oil drilling & coal mining from leaking gas pipelines.

3. Nitrous oxide (N2O): Nitrous oxide is also one of the important green house gases which have its share in the green house gas concentration.

Sources of N20

- Fossil-fuel combustion,
- Biomass burning,
- Use of fertilizer, and
- In the phenomenon of lightening

Engineering solutions to combat climate change

Combating climate change requires the commercialization of low emission technologies in various sections of application. The engineering fraternity has a special role to play to neutralize the adverse effects on the climate. Efforts should continue for producing power using solar photovoltaic, second generation bio-fuels, fourth generation nuclear fuels and developing smarter grid capacity for transmission. Conservation of water, efficient management of solid wastes and generating wealth from them by recycling process, figuring out the hot spots of energy consumption and associated CO2 emissions are some of the key areas where the engineers can apply their specialized knowledge for combating climate change.

Growth without GHG emission is the need of the day. Application of green technologies, phasing out GHG producing sources and combating the existing effects on climate are the areas of emphasis if the globe is to be saved from extinction.

Conservation of natural resources by adopting strategies for reducing, reusing, recycling and applying engineering solutions for combating emission of GHG is the need which requires addressing by engineers.

The sectors which need attention of engineers in mitigating emissions of gases can be grouped under;

A. Reducing emissions

B. Carbon Capturing and storage (CCS)

C. Obstructing the sunrays from coming to the earth

A. Reducing emissions : The major sectors where emissions can be reduced are;

1. **Energy:** Production, transmission and utilization,
2. **Transport:** Based on using renewable energy, efficient and attracting masses to travel together,
3. Residential and commercial buildings,
4. Industry,
5. Waste management,
6. Agriculture, and
7. Forest

B. Carbon capturing and storage (CCS) : This is the most favoured mitigation strategy considered by the scientists. Some of the options are;

1. Engineers say a forest of 100,000 "artificial trees" could be deployed within 10 to 20 years to help soak up the world's carbon emissions. These tree capture and store CO2 through a filter which then could be stored in the sea.
2. Physicist Freeman Dyson estimates that by annually increasing topsoil by just a tenth of an inch over land that supports vegetation, we could offset all human carbon emissions.
3. The gases can be stored at deep sea through abandoned natural oil extracting deep wells in the sea by piping the gases from the major sources.
4. By planting millions of tress which will store the atmospheric CO2 through the process of photosynthesis.

C. Obstructing the sunrays from coming to the earth : Some of the hypotheses on which scientists working are;

1. Reduction of incoming solar radiation by reflecting sunlight back into space by installing reflective roofs.
2. Install "algae based photo-bio-reactors" on buildings. These would be transparent containers containing algae which would remove carbon dioxide from the air during photosynthesis.
3. Spraying sulfur dioxide in the sky at above 65,000 ft which could become red and then prevent the sunrays coming to the globe surface to keep it cold.
4. By spraying the churned sea water, which could envelop the sky (taken to the clouds by wind) with white coloured paint surface. This envelop will send the sun rays back to the sky. This is somehow similar to the natural condition created after a volcano eruption.
5. Erecting vented building-size structures that contain grids coated with a chemical solution. As air flows through the vents, the

solution would bind to the carbon-dioxide molecules and trap them.

6. Creating colossal blooms of oceanic algae. Adding artificial nutrients like iron or nitrate would accelerate the growth of the oceanic algae / planktons which will sink to the ocean floor along with the CO2 when they die.

Some facts about the global source of sector-wise emissions and their possible reduction measures:

(i) Energy Sector

1. Around 40% of global primary energy was used as fuel to generate 17,408 TWh of electricity in 2004.
2. Electricity generation had an average growth rate of 2.8% per year since 1995.
3. It is expected to continue growing at a rate of 2.5 - 3.1%/ per year until 2030. In 2005,
1. 40% of world electricity production was by hard coal and lignite fuels
2. 20% with natural gas ,
3. 16% with nuclear,
4. 16% by hydro,
5. 7% by oil and
6. 2.1% by other renewables

Non-hydro renewable energy power plants have expanded substantially in the past decade with wind turbine and solar PV installations growing by over 30% annually. However, they still contribute only a small portion of electricity generation.

(ii) Transport Sector

In 2004, Transport energy use amounted to 26% of total world energy use and the transport sector was responsible for about 23% of world energy-related GHG emissions.

(iii) Residential and Commercial Buildings sector

In 2004, emissions from the buildings sector including through electricity use were about;

1. 8.6 GtCO2
2. 0.1 GtCO2- eq N2O
3. 0.4 GtCO2-eq CH4 , and
4. 1.5 GtCO2-eq halocarbons (including CFCs and HCFCs).

Using an accounting system that attributes CO2 emissions to electricity supply rather than buildings end-uses, the direct energy-related carbon dioxide emissions of the building sector are about 3 Gt/yr.

Measures to reduce greenhouse gas (GHG) emissions from buildings:

1. Reducing energy consumption and embodied energy in buildings,
2. Switching to low-carbon fuels including a higher share of renewable energy,
3. Controlling the emissions of non-CO2 GHG gases,
4. Design of buildings should be to reduce heating, cooling and lighting loads and utilize active solar energy and other environmental heat sources and sinks,
5. Increase efficiency of appliances, heating and cooling equipment and ventilation,
6. Implement commissioning and improve operations and maintenance
7. Change behaviour,
8. Utilize system approaches to building design, and
9. Consider building form, orientation and related attributes.

(iv) Industry Sector

Industrial sector emissions of greenhouse gases (GHGs) include:

1. Carbon dioxide (CO2) from energy use,
2. From non-energy uses of fossil fuels, and
3. From non-fossil fuel sources (e.g., cement manufacture); as well as non-CO2 gases. Total industrial sector GHG emissions were estimated to be about 12 GtCO2-eq/yr in 2006.

In 2004, approximately 85% of the industrial sector's energy use was in the industries of;

1. Energy-intensive,
2. Iron and steel,
3. Nonferrous metal,
4. Chemicals and fertilizers,
5. Petroleum refining,
6. Minerals (cement, lime, glass and ceramics), and
7. Pulp and paper.

Mitigating Options in Industrial sectors:

A. Through existing technologies

1. By designing facilities that are resistant to projected changes in weather and climate,
2. Relocating plants to less vulnerable locations,
3. Diversifying raw material sources, especially agricultural or forestry inputs, and
4. By mitigating their own emissions and developing low-emission products.

B. Through new and lower-cost technologies

1. Development of an inert electrode to eliminate process emissions from aluminum manufacture,
2. Use of carbon capture and storage in the ammonia, cement and steel industries, and
3. Use of hydrogen to reduce iron and non-ferrous metal ores.

IEA (2006a) reports:

'The energy intensity of most industrial processes is atleast 50% higher than the theoretical minimum determined by the laws of thermodynamics. Many processes have very low energy efficiency and average energy use is much higher than the best available technology would permit."

This provides a significant opportunity for reducing energy use and its associated CO2 emissions.

The major factors affecting energy efficiency of industrial plants are:

1. Choice and optimization of technology,
2. Operating procedures and maintenance, and
3. Capacity utilization that is the fraction of maximum capacity at which the process is operating.

(v) Waste Management Sector

Waste generation is closely linked to;

1. Population,
2. Urbanization, and
3. Affluence.

Post-consumer waste is a small contributor to global greenhouse gas (GHG) emissions (<5%) with total emissions of approximately 1300 MtCO2-eq in 2005. The largest sources are;

1. Landfill methane (CH4),
2. Wastewater CH4, and
3. Nitrous oxide (N2O)
4. In addition, minor emissions of carbon dioxide (CO2) result from incineration of waste containing fossil carbon (plastics, synthetic textiles).

(vi) Agriculture Sector

Forty to fifty per cent of the Earth's land surface is

occupied by agricultural lands (lands used for agricultural production, consisting of cropland, managed grassland and permanent crops including agro-forestry and bio-energy crops). Agriculture accounted for an estimated emission of 5.1 to 6.1 GtCO2-eq/yr in 2005 (10-12% of total global anthropogenic emissions of greenhouse gases (GHGs)).

The most prominent options for mitigation of GHG emissions in agriculture are;

1. Improved crop and grazing land management (e.g., improved agronomic practices, nutrient use, tillage, and residue management),
2. Restoration of organic soils that are drained for crop production and restoration of degraded lands,
3. Lower but still significant mitigation is possible with improved water and rice management,
4. Set-asides, land use change (e.g., conversion of cropland to grassland) and agro-forestry,
5. As well as improved livestock and manure management.
6. Many mitigation opportunities use current technologies and can be implemented immediately, but technological development will be a key driver ensuring the efficacy of additional mitigation measures in the future (high agreement, much evidence).

Some of the summarized key mitigation technologies and practices by various sectors are listed in Table: 3 and few of the sector-wise emission mitigation strategies are listed in **Table: 4.**

The water and air are our life line. If these two basic needs are not available to every one proportionally and qualitatively then we can only be happy today but not tomorrow.

Let us give our best to make not only ours life comfortable but others too. Remember if others are comfortable then only we are comfortable but if we think that if our life is comfortable then every ones life will be comfortable then we are completely mistaken.

References

Anonymous. (2006). Greenhouse Gas Mitigation in India: Scenarios and opportunities through 2031. The Energy and Resources Institute (TERI), New Delhi, India

Dinar A, Mendelsohn R, Evenson R, Parikh J, Sanghi A, Kumar K, McKinsey J, and Lonergan S. 1998. Measuring the Impact of Climate Change on Indian Agriculture.

Washington, DC: World Bank.

IPCC website; Assessment Reports (Working Group I ,II and III of First ,Second ,Third and Fourth Assessment reports.

McLean RF, Sinha SK, Mizra MQ and Lal M. 1998. Chapter 11: Tropical South Asia. In: The Regional Impacts of Climate Change: An Assessment of Vulnerability: A Special Report of IPCC Working Group II. [Eds: Watson RT, Zinyowera MC, and Moss RH] Cambridge: Cambridge University Press. pp. 381-407.

Tripathi KP and Sharda VN. 2007. Rainfall, Runoff and Soil Loss in selected watersheds of India during 21st century. Paper presented at the "Workshop on "Climate change and its impact on farming systems and natural resources" held at Y.S. Parmar University of Horticulture and forestry, Solan (H.P.) held during March 02-03.

Tripathi KP, Sharda VN, Shahid Ali, Md, and Mudgal Ashish. 2007. Impact of Climate change on Rainfall, Rainy days, Run off and Soil Loss in

Selected Watersheds of India during 21st Century. Paper presented at the National conference on "Impacts of Climate Change with Particular Reference to Agriculture "Organized at ACRC, CSCMS, TNAU, Coimbatore during Aug. 22-24.

Williams JR, Sharpley AN (Eds.), (1989) EPIC-Erosion/Productivity Impact Calculator: 1. Model documentation, USDA Technical Bulletin No. 1768.

Zhang XC, Nearing MA, Garbrecht JD and Steiner JL. 2004. Downscaling monthly forecasts to simulate impacts of climate change on soil erosion and wheat production. Soil Sci. Soc. Am. J. 68:1376-1385.

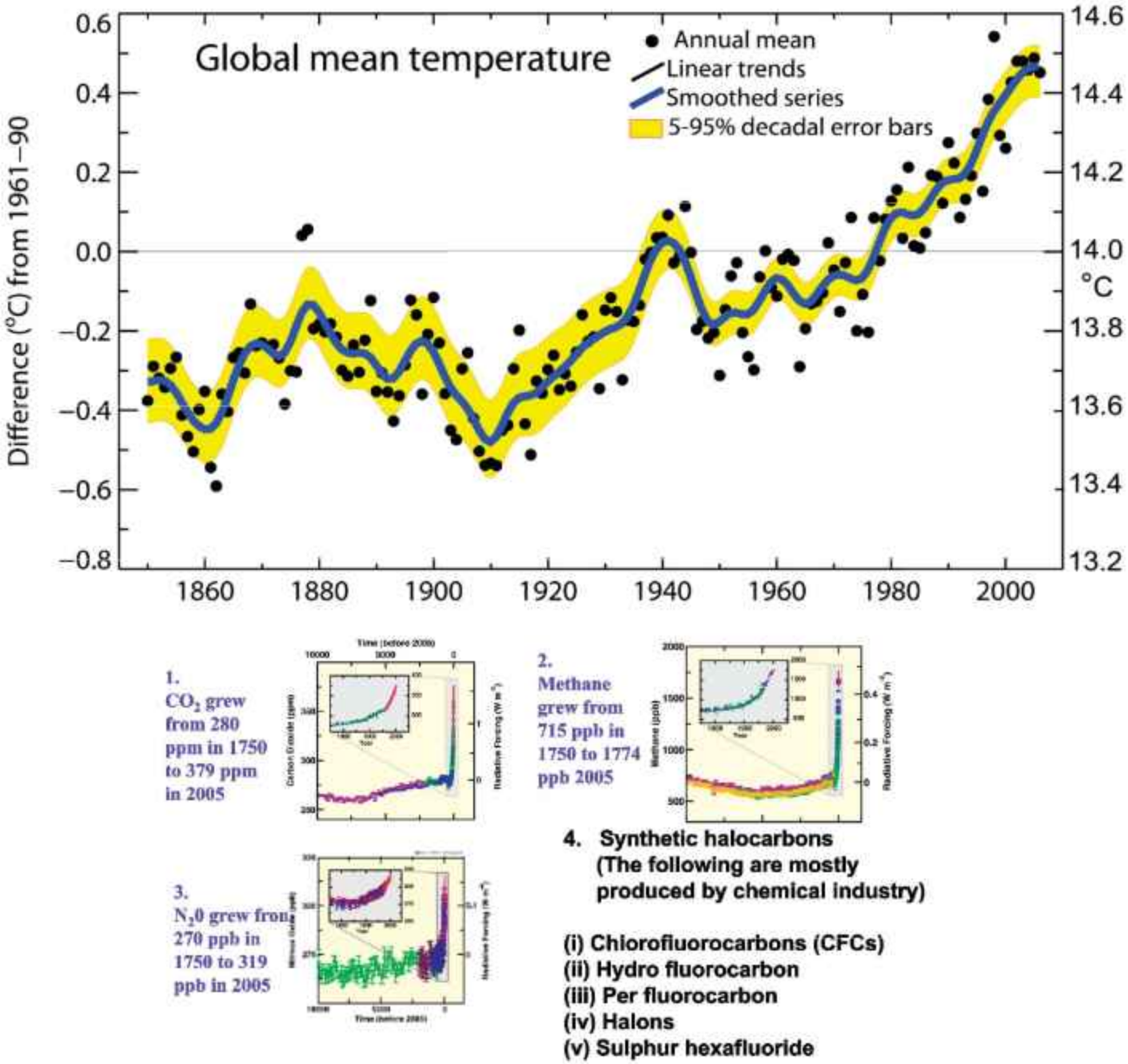


Fig 2: Increase in the concentration of some of the green house gases in the near past

Table 1: Profile by process or industrial activity of worldwide large stationary CO_2 sources with emissions of more than 0.1 Million tonnes of CO_2 ($MtCO_2$) per year

Process	Number of sources	Emissions ($MtCO_2\ yr^{-1}$)
Bio-ethanol & Bio-energy	303	91
Biomass		
Cement Production	1,175	932
Fossil Fuels		
Iron and Steel Industry	269	645
Oil & Gas Processing	Not available	50
Other Sources	90	33
Petro-chemical industry	470	379
Power	4,942	10,539
Refineries	638	798

Source: Special report on Carbon dioxide Capture and Storage (2005), Summary for Policy Makers and Technical Summary, IPCC, WGIII

Table 2: CO_2 Emissions by fuel type for the year 2000-01 in India

Fuel	CO_2 Emissions (million tonnes)
Coal (Including all types of coal and lignite)	550
Natural gas	59
Liquefied Petroleum gas	19
Naphtha	27
Motor Gasoline	21
Aviation Turbine Fuel	7
Kerosene	34
High speed Diesel	114
Light Diesel Oil (Including other Petroleum Products)	29
Fuel Oil	20
Total	880

Source: Anonymous. (2006) . Greenhouse Gas Mitigation in India: Scenarios and opportunities through 2031. The Energy and Resources Institute (TERI), New Delhi, India

Table 3: Key mitigation technologies and practices used by different sectors (Sectors and technologies are listed in no particular order. Non-technological practices, such as lifestyle changes, which are cross cutting, are not included in this table)

Sector	Key mitigation technologies and practices currently commercially available	Key mitigation technologies and practices projected to be commercialized before 2030
Energy supply	Improved supply and distribution efficiency; fuel switching from coal to gas; nuclear power; renewable heat and power (hydropower, solar, wind. geothermal a nd bioenergy); combined heat and power; early applications of Carbon Capture and Storage (CCS, e.g. storage of removed CO_2 from natural gas).	CCS for gas, biomass and coal -fired electricity generating facilities; advanced nuclear power; advanced renewable energy, including tidal and waves energy, concentrating solar and solar PV.
Transport	More fuel efficient vehicles; hybrid vehicles; cleaner diesel vehicles; bio - fuels; modal shifts from road transport to rail and public transport systems; non-motorised transport (cycling, walking); land -use and transport planning.	Second generation biofuels; higher efficiency aircraft; advanced electric and hybrid vehicles with more powerful and reliable batteries.
Buildings	Efficient lighting and day lighting; more efficient electrical appliances and heating and cooling devices; improved cook stoves, improved insulation; passive and active solar design for heating and cooling; alternative refrigeration fluids, recovery and recycle of fluorinated gases.	Integrated design of commercial buildings including technologies, such as intelligent meters that provide feedback and control; solar PV integrated in buildings.
Industry	More efficient end -use electrical equipment; heat and power recovery; material recycling and substitution; control of non-CO_2 gas emissions; and a wide array of process -specific technologies	Advanced energy efficiency; CCS for cement, ammonia, and iron manufacture; inert electrodes for aluminium manufacture.
Agriculture	Improved crop and grazi ng land management to increase soil carbon storage; restoration of· cultivated peaty soils and degraded lands; improved rice cultivation techniques and livestock and manure management to reduce CH_4 emissions; improved nitrogen fertilizer application techni ques to reduce N_2O emissions; dedicated energy crops to replace fossil fuel use; improved energy efficiency.	Improvements of crop yields.

Forestry / forests	Afforestation; reforestation; forest management; reduced deforestation; harvested wood product m anagement; use of forestry products for bioenergy to replace fossil fuel use .	Tree species improvement to increase biomass productivity and carbon sequestration. Improved remote sensing technologies for analysis of vegetation/ soil carbon sequestration potential and mapping land use change.
Waste management	Landfill methane recovery; waste incineration with energy recovery; composting of organic waste; controlled waste water treatment; recycling and waste minimization.	Biocovers and biofilters to opt imize CH_4 oxidation.

Note: Selected sectorial policies, measures and instruments that have shown to be environmentally effective in the respective sector in at least a number of national cases.

Table 4: Few of the sector-wise emission mitigation strategies

Sector	Policies, measures and instruments shown to be environmentally effective	Key constraints or opportunities
Energy supply	Reduction of fossil fuel subsidies	Resistance by vested interests may make them difficult to implement
	Taxes or carbon charges on fossil fuels	
	Feed-in tariffs for renewable energy technologies	May be appropriate to create markets for low emissions technologies
	Renewable energy obligations	
	Producer subsidies	
Transport	Mandatory fuel economy, biofuel blending and C O_2 standards for road transport	Partial coverage of vehicle fleet may limit effectiveness
	Taxes on vehicle purchase. registration, use and motor fuels, road and parking pricing	Effectiveness may drop with higher incomes
	Influence mobility needs through land use regulations, and infrastructure planning	Particularly appropriate for countries that are building up their transportation systems
	Investment in attractive public transport facilities and non - motorised forms of transport	
Buildings	Appliance standards and labelling	Periodic revision of standards needed
	Building codes and certification	Attractive for new buildings. Enforcement can be difficult
	Demand-side management programmes	Need for regulations so that utilities may profit

	Public sector leadership programmes, including procurement	Government purchasing can expand demand for energy- efficient products
	Incentives for energy service. companies (ESCOs)	Success factor: Access to third party financing
Industry	Provision of benchmark information	Maybe appropriate to stimulate technology uptake. Stability of national policy important In view of international competitiveness
	Performance standards	
	Subsidies, tax credits	
	Tradable permits	Predictable allocation mechanisms and stable price signals important for investments
	Voluntary agreements	Success factors include: clear targets. a baseline scenario, third party involvement in design and review and formal provisions of monitoring. close cooperation between government and industry
Agriculture	Financial incentives and regulations for improved land management, maintaining soil carbon content, efficient use of fertilizers and irrigation	May encourage synergy with sustainable development and with reducing vulnerability to climate change, thereby overcoming barriers to implementation
Forestry/ forests	Financial incentives (national and international) to increase forest area, to reduce deforestation, and to maintain and manage forests	Constraints include lack of investment capital and land ten ure issues. Can help poverty alleviation
	Land use regulation and enforcement	
Waste management	Financial incentives for improved waste and wastewater management	May stimulate technology diffusion
	Renewable energy incentives or obligations	Local availability of low-cost fuel
	Waste management regulations	Most effectively applied at national level with enforcement strategies

Note: a) Public RD & D investment in low emissions technologies have proven to be effective in all sectors

Development of a Utility Machine for Sugarcane Juice and Jaggery

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Abstract

In India, sugarcane is processed for making sugar, jaggery (gur) and khandsari. Out of total sugarcane production, about 20 per cent is used for jaggery and khandsari. For quality jaggery making, sugarcane needs to be cleaned before crushing. A sugarcane cleaner-cum-washer (SC-c-W) has been developed at ICAR-Indian Institute of Sugarcane Research (IISR), Lucknow for cleaning and washing of sugarcane prior to crushing for jaggery making. The unit consists of six rollers; two feed rollers having rubber flaps for gripping and cane feeding and four scrapping rollers (two sets of two rollers each) having steel wire brush for removal of impurities sticking to sugarcane stalks. Water spray arrangement has also been provided at two places for washing of canes. The unit was evaluated for its performance. Three combinations of roller speed were evaluated. It was found that the best combination of roller set was that in which upper scrapping rollers moved with 50.63 and 75.95 rpm and lower rollers moved with 60 and 90 rpm in 1st and 2nd set respectively. It was due to differential speed of rollers which gave best rubbing and scrapping action. The capacity of machine was found to be 1000-1100 kg canes/h with 3-4 canes feeding in single pass. Impurity removal increased with number of cane feeding at a time and maximum (4.338g) impurity was removed with 3-cane feeding. SC-c-W, when used with water spray, appeared giving better results based on visual observation of cleaned canes.

Keywords: Sugarcane, Jaggery, Sugarcane cleaner-cum-washer, Sugarcane juice

Introduction

In India, sugarcane is processed for making sugar, jaggery (gur) and khandsari. Out of total sugarcane production, about 20 per cent is used for jaggery and khandsari. There are lots of impurities sticking to sugarcane stalk like trash, wax, gum, dust, roots, dry leaves, soil particles, chlorophyll and other colour compounds etc. All these unwanted materials go into the sugarcane juice in jaggery making as mostly sugarcane is crushed directly. Although sugarcane juice clarification is performed using vegetative clarificants; yet it is advisable to clean cane prior to crushing for sugarcane juice and jaggery.

A sugarcane cleaner-cum-washer (SC-c-W) has been developed at ICAR-Indian Sugarcane Research Institute (ISRI), Lucknow for cleaning and washing of sugarcane prior to crushing for jaggery making so that impurities sticking to sugarcane stalk are removed. This machine was evaluated for its performance in terms of quantity of impurities removed, speed of rollers, capacity of machine (number of cane feeding at a time) etc. For comparison, canes were cleaned manually also and jaggery was prepared. Colour values and other parameters of juice and jaggery were determined and compared.

Materials and Methods

The paper deals with performance evaluation of sugarcane cleaner-cum-washer (SC-c-W) developed at ICAR-Indian Sugarcane Research Institute, Lucknow (U.P.).

Description of machine

The machine consists two feed rollers having rubber flaps for gripping and feeding of canes and four scrapping/scratching rollers (two sets of two rollers each) having steel wire bristles (40 mm length, 1.5 mm diameter) for removal of impurities sticking to canes. The size of upper and lower feed rollers are

30 cm x 88 cm (L x D) and 30 cm x 56.8 cm respectively whereas the size of scrapping rollers is 30 cm x 57 cm. Upper and lower rollers move in opposite direction thus giving forward movement to the cane. Steel wire bristles have been provided on scrapping/scratching rollers for scrapping/scratching of impurities from cane stalk surface. All these rollers are mounted on 40 mm angle iron frame. Suitable power transmission arrangement having gear box, spur gears, chain-sprocket etc. for transmitting power from electric motor (1 h.p., 1425 rpm) to different components. The speed and direction of movement of all the rollers are mentioned in table 1.

A washing unit with water pump (0.50 h.p., 2780 rpm self-priming monoset pump-Crompton Greaves Ltd. Co.) and water spray arrangement is used for washing of canes. The whole machine is shown in Fig. 1.

Table 1 : Speed and direction of movement of rollers of SC -c-W

Speed of motor	Direction of rollers		Speed of feed rollers (rpm)		Speed of 1st set of scrapping rollers (rpm)		Speed of 2nd set of scrapping rollers (rpm)	
1425 rpm	Upper	Forward	Upper	15	Upper	50.63	Upper	75.95
	Lower	Backward	Lower	15	Lower	60	Lower	90



Fig 1: Sugarcane cleaner -cum-washer

Change of speed of different scrapping /scratching rollers

Chain-sprocket system was used to change speed of scrapping/scratching rollers. Three speed combinations (roller sets) were used. Sprocket with 54 teeth and 64 teeth was fixed in the first and second combination speed sets respectively. System with all scrapping/scratching rollers moving with different speed was taken as the third combination. Speed and direction of rollers in all the roller sets are given in table 2.

Table 2 : Speed and direction of rollers in different roller sets

Roller set	Position of rollers	Direction of rollers	Speed of feed rollers (rpm)	Speed of 1st set of scrapping rollers (rpm)	Speed of 2nd set of scrapping rollers (rpm)
I	Upper	Forward	15	50.63	75.95
	Lower	Backward	15	50.63	75.95
II	Upper	Forward	15	60	90
	Lower	Backward	15	60	90
III	Upper	Forward	15	50.63	75.95
	Lower	Backward	15	60	90

Cleaning of sugarcane in sugarcane cleaner -cum-washer

Three samples each of single cane, two canes and three canes were taken for all selected combinations of roller sets. These canes were cleaned in sugarcane cleaner-cum-washer in single, two and three passes and time of operation was recorded for each case. The removed impurities were weighed each time. These cleaned canes were crushed in sugarcane crusher to see the effect of impurities removal.

Visual observation of sugarcane juice and its L, a*, b* values

Sugarcane juice obtained from uncleaned, manually cleaned and cleaned with SC-c-W was filled in tumbler glass and kept at place with good lighting for visual observation.

Jaggery making from uncleaned, manually cleaned and juice obtained from SC -c-W

Jaggery was prepared from uncleaned, manually cleaned and juice obtained from SC-c-W using IISR developed jaggery making protocol. Density and hardness of jaggery samples were determined using standard procedures.

Results and Disc ussion

Effect of roller set s and number of canes on impurity removal

Effect of roller sets on impurity removal for single pass for single, two and three cane feeding is shown Fig. 2.

Maximum impurity was removed in case of roller set III and minimum with roller set I as evident from Fig.2. With increase in number of cane feeding, impurity removal increased due to more resistance provided by canes and thereby giving more time for cleaning.

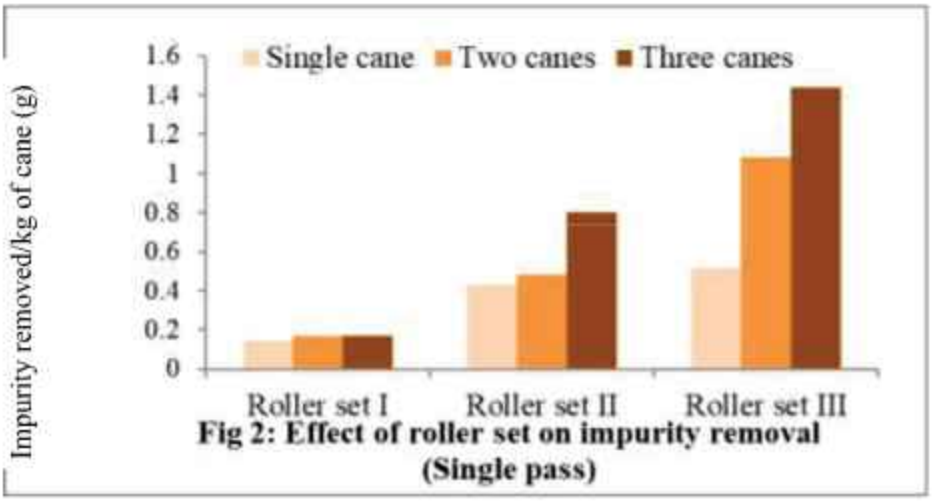


Fig 2: Effect of roller set on impurity removal (Single pass)

Effect of roller set on capacity

Effect of roller set on capacity of SC-c-W for all the cases of cane feeding in single pass is shown in Fig. 3.

It may be observed that capacity increased with number of cane feeding. With different roller sets it ranged from 124.61 kg/h to 615.32 kg/h. Capacity of SC-c-W in roller set I was found to be 124.61, 290 and 409.69 kg/h for single, two and three canes respectively. In roller set II, it was found to be 179.73, 383.99 and 548.58 kg/h while in roller set III, it was 190.18, 389.89 and 615.32 kg/h in all the case of cane feeding.

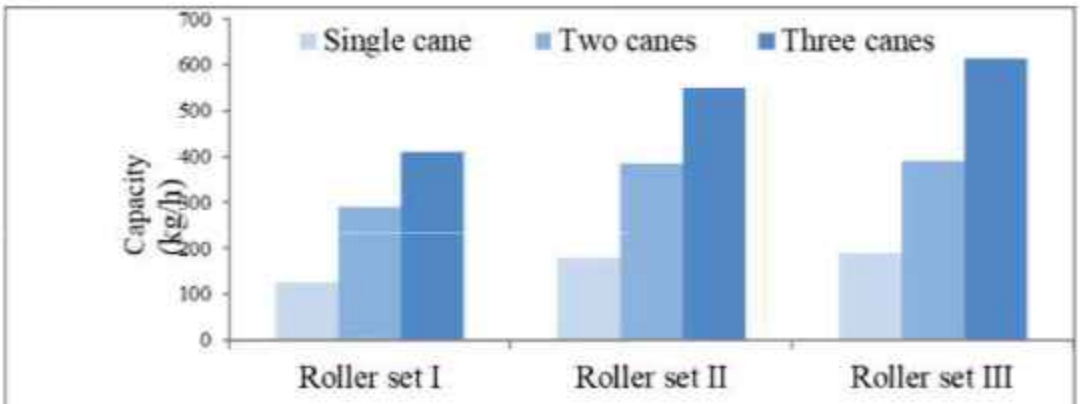


Fig 3: Effect of roller set on capacity of SC-c-W (Single pass)

Effect of number of passes on impurity removal

Effect of no. of passes on impurity removal for all the cases of roller sets for single cane feeding is shown in Fig. 4.

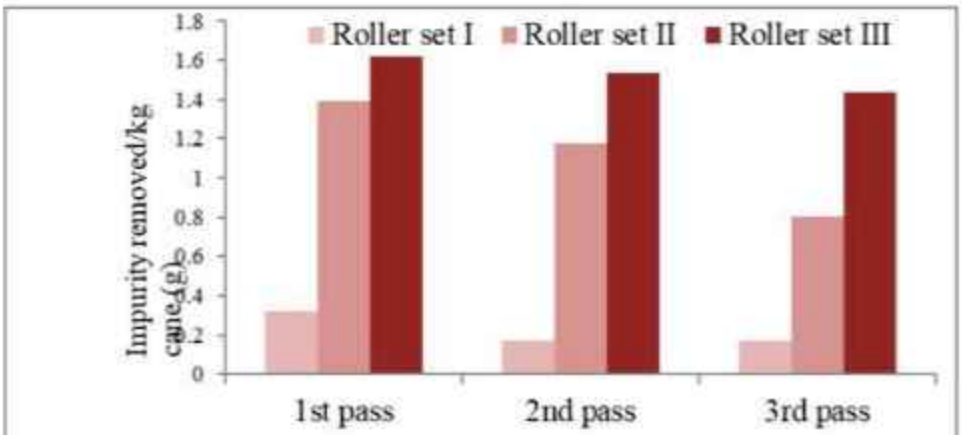


Fig 4: Effect of number of pass on impurity removal (Single cane)

It may be observed that impurities removal deceases with number of passes with all the roller sets. This is due to the fact that available impurities reduces with number of passes i.e. once impurities are removed in a pass less impurities are available for subsequent passes for further removal.

Visual observation of sugarcane juice and its L, a*, b* values

Sugarcane juice obtained from uncleaned, manually cleaned and cleaned with SC-c-W was filled in tumbler glass and kept at a place with good lighting for visual observation (Fig.5). Suspended impurities were seen in case of uncleaned juice. Also it was observed that colour of juice of manually cleaned sugarcane was almost yellow in colour. This is because of careful and effective cleaning of cane in manual cleaning where all the colouring material like black wax, chlorophyll etc. was carefully removed by the person doing cleaning job.

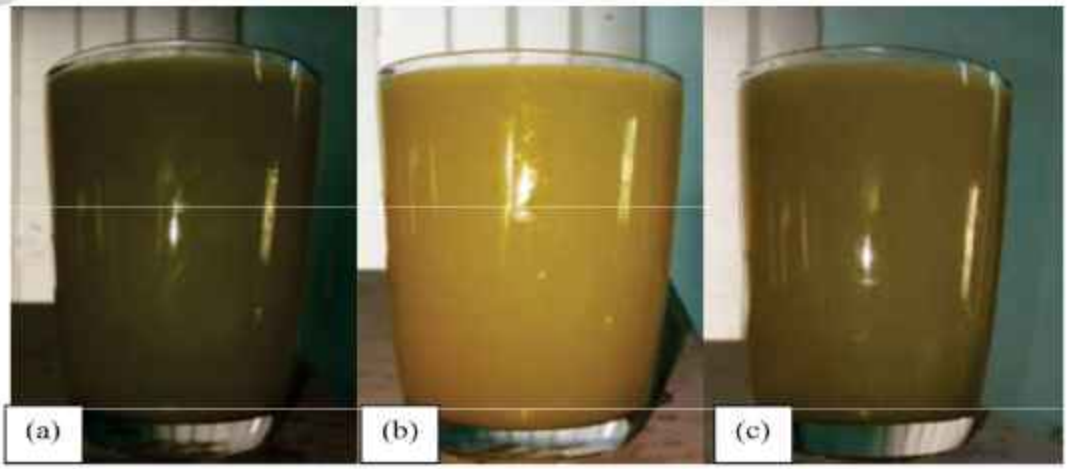


Fig 5: Visual observation of sugarcane juice (a) Uncleaned sugarcane, (b) Manually cleaned sugarcane and (c) Sugarcane cleaned with SC -c-W

Effect of Cleaning on Jaggery Qualit y
Colour (L*, a* and b*) values

Colour (L*, a* and b*) values of jaggery prepared from the juice of uncleaned, manually cleaned and sugarcane cleaned by SC-c-W have been presented in table 3.

Table 3: Colour values (L*, a* and b* values) of jaggery sample s

Sugarcane sample	L* values	a* values	b* values
Uncleaned cane	10.9	5.7	10.9
Manually cleaned sugarcane	32.1	7.6	18.3
Sugarcane cleaned by SC-c-W	15.8	7.1	12.7

It may be seen from above table that there are two extremes of L*, a*, and b* values for uncleaned and manually cleaned sugarcane juice respectively and these values for SC-c-W cleaned sugarcane juice lie between these two extremes. It means that SC-c-W has cleaning ability. The best values are obtained for manually cleaned canes where cleaning was done very effectively.

Density and hardness of jaggery

The data of density and hardness of jaggery samples are presented in table 4.

Table 4 : Density and hardness of jaggery samples

Sugarcane sample	Density (g/cc)	Hardness (N)
Uncleaned cane	1.26	6214
Manually cleaned sugarcane	1.41	6412
Sugarcane cleaned by SC-c-W	1.35	6367

It may be seen from above table that the density of jaggery sample prepared from uncleaned sugarcane is minimum (1.26 g/cc) and it is maximum (1.41 g/cc) in case of manually cleaned sugarcane. Low density in case of uncleaned canes is due to all impurities going into jaggery. Since most of the

Similar results was obtained with hardness; where jaggery of uncleaned canes showed minimum hardness (6214 N) and maximum hardness was observed in jaggery of machine-cleaned sugarcane. The value of SC-c-W cleaned jaggery was in between the two but more towards manual cleaned sugarcane. Since density also affects hardness due to more compactness, the results of hardness are in accordance with density.

Conclusion

Sugarcane cleaner-cum-washer developed at ICAR-Indian Sugarcane Research Institute, Lucknow performed well for impurity removal from cane stalks. It worked best with that combination speed of scrapping/scratching rollers where all rollers moved with different speed. Later on for accommodating more canes for capacity improvement, 1 h.p. motor was replaced by 2 h.p. Therefore, maximum capacity of 1000-1100 kg/h was achieved with three canes feeding in single pass. This capacity is matching with a sugarcane crusher of 1000 kg/h output. The juice obtained from SC-c-W-cleaned sugarcane was lighter in colour as compared to uncleaned cane and the jaggery thus prepared had good density and hardness. The machine may be useful for large scale juice extraction for juice sale purpose also.

Sugarcane Mechanization, Artificial Intelligence tools and Climate Smart Agricultural Techniques for Food-Energy Security in India

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Abstract

The climate-smart sugarcane production technologies with their integration advanced machine learning technologies and AI tools helps in enhancing productivity and farmer's ease of doing cost effective intercultural operations. These techniques empower precision sugarcane cultivation, improve resource use efficiency and crop management. It leadsto increase sugarcane production and reduce adverse environmental impact. The AI-powered cropping system followed by the farmers utilizes sensors based irrigation scheduling with mobile Apps, drones and satellite imagery for monitoring soil moisture, nutrient levels and detection of pests and diseases for crop management and minimises production losses.The prototypes and machine developed by the institute during past three decades, cutter planters, trenchers, ratoon management devices etc., has been transferred to agro-implements manufacturers by signing Memorandum of Agreement (MoA) for commercial manufacture, after sale service and supply to the farmers. The economic surplus model and simple tabular analysis was applied as tools to assess adoption level and impact of sugarcane mechanization on cost saving, productivity gains and farmers income. The results indicates that total surplus (TS) generated through adoption of mechanization technology accrued to ` 71464 crores in India. The maximum economic gains accrues in U.P. followed by Maharashtra, where more productivity and adoption. The economic surplus distribution amongst farmers, sugar mills and consumers reveals that farmers were key beneficiaries of ` 39924 crores(60.5 % surplus gain) in U.P. The internal rate of return (IRR) 41% reveals that investment on sugarcane machine R&D at ICAR-ISRI, Lucknow repay economic benefits to the farmers and sugar mills. The benefit-cost ratio indicates that each rupee invested on sugarcane implements R&D give dividend of ` 81. The NPV of net social gains was high which conclude that investment on mechanization is economical. Its adoption help in unit cost of cultivation reduction, labour drudgery and enhance productivity and sugar recovery.

Keywords: AI powered Tools, Sugarcane Mechanization, Impact assessment, Economic surplus model

Introduction

Sugarcane is cultivation as cash crop for food and energy security has concerns to conserve nature resources and enhance irrigation water productivity. It is known as a water guzzler crop as farmers apply 25-40 irrigation in Tropical India. India has becomes most populous nation of over 1.43 billion and harmful impact of agro-chemicals and inorganic fertilizers on human health,

environment are well documented. Sugarcane provides food, fuel energy and livelihood security to 7.5-8.0 million farmers and 1.4 million workers in sugar mills and ancillary industries. Its acreage is hovering 5.15 million ha, annual production 445.42 million tons with 84.3 tons productivity. The contribution of cane and sugar sector in Gross Value of Agriculture (GVA) was ? 1.26-1.37 lakh crores, out of which nearly ? 0.95 -1.08 lakh crores paid to farmers by the sugar mills and jaggery processors annually. It has influential role in socio-economic growth and resource mobilization for community welfare through diversified products such as jaggery, bio-ethanol, CNG and power co generation as excess sugar availability creates demand-supply disequilibrium. Farmer's income has not improved in inorganic farming of hi-tech input uses. Adoption of drip and sprinkler system ensure judicious use of irrigation water and use of liquid fertilizers with the help of the AI algorithms analyse data and suggest irrigation schedules at optimal soil moisture level, minimize water waste and optimizes fertilizer nutrient application on the basis of soil testing and health card, reduces nutrient costs and environmental impact due to fertilizers overdose. The AI-based tools may identify insects-pests and diseases early and support timely pesticide use targeted interventions that helps in minimizing crop damage. The AI techniques might also forecast sugarcane yield and determine optimal crop harvest time to improve sugar recovery andimprove raw material quality and crop productivity. The climate change adaptation tools and simulation techniques of AI analysetime series climate data for suggesting prediction future trends and help farmers for adapting crops and agronomical practices according to changing weather patterns.The application of drone based technologies equipped with high-resolution cameras and multispectral sensors provide real-time crop health monitoring and detect diseases and plant nutrient deficiencies. The soil sensors AI tools monitor moisture and nutrient level and provide useful information for precision irrigation scheduling and fertigation with application of plant nutrient in liquid fertilizers. The AI tools analyse data from numerous sources and suggest appropriate action plan to the sugarcane farmers for decision-making and its timely execution. The Variable Rate Technology (VRT) permits farmers to apply fertilizers and pesticides inputs at different rates across the field and optimize resource use and minimize adverse impact.

The precision in sugarcane cultivation and optimal resource use lead to better productivity and reduces cost of production, irrigation water saving with timely pest control which contribute to sustainable sugarcane farming practices and ecosystem management.The AI technology is being used to guide farmers in sugarcane farming on an experimental basis. The AI monitors soil pH levels and provides corrective measures for sugarcane farmers. The AI- tools are used to predict land acreage allocation amongst the crop and land cover strategies to manage natural farm resources and sustainable land use planning. The future R&D on AI and technology and its wider adoption in sugarcane farming could in play keyrole in developing advance sophisticated AI algorithms for data analysis, expand use of AI in selection of suitable clone in breeding programs, open data platforms for sharing weather, soil, and crop data. These may also help in providing the AI training to the farmers and developing regulatory frameworks for ethical AI use.It is not exaggerated that the ICAR-ISRI, Lucknow, is the birth place of all machinery engaged in sugarcane farming in India. It has played pivotal role in design and development of suitable machinery for climate

smart sugarcane farming agro-techniques. The machine has reduced human drudgery and also reduced labour requirement. It adoption has ensured timely operations which indirectly help in germination improvement and sugarcane yield. It has also increases water and nutrient use efficiencies in sugarcane cultivation. The sugarcane planting techniques such as ring- pit method, mechanized trench planting, wide row and paired row planting had evolved at ISRI and backed by machinery support have done wonders in transformation of sugarcane mechanized agriculture in India.

Rationale

Land and water are precious natural resources for sugarcane production. Besides these resources, scarcity of human and bullock labour has relevance in sugarcane production and value added processing to fulfil food and energy security. The freshwater utilization for crop production and livestock rearing in India is more than the world average and nearly 30-35% comes from groundwater resources (IAI and FICCI 2016). The over exploitation of groundwater has depleted water table at faster rate than natural groundwater recharge capacity in North-Western India (Rodell et al. 2009). During past decade (2007-2016) groundwater level have declined to an extent of 1-4 meter and key reason attributed to this is excess demand for agriculture, urbanization and industrialization have twisted over relianceon groundwater exploitation. The water pumped with submersible from deep tube well could not recharged by rainfall would no longer a renewable water source. Sugarcane is water guzzling crop and largest consumer of irrigation water in major sugarcane growing states Maharashtra and U.P. It isessential to develop sugarcane machine and production technologies to optimizeper unit irrigation water. Thesugarcane mechanization and water saving interventions; emphasizesadoption of efficient irrigation methods in sugarcane systems to save labour, water and reduce per unit production cost and improve profitability.

Sugarcane is a long durational labour and inputs intensive crop needs number of operations from field preparation, planting, chemicals and fertilizer application, intercultural operation, harvesting and transportation. In sugarcane cultivation, most of operations are performed manually by using human and bullock labour or mechanical power. It requires nearly 166-325 labour days per ha in major sugarcane growing states of India (Sharma and Prakash 2011). It need 128-235 man days to perform farm various operations in sugarcane cultivation and ratoon management (CACP 2015). These labour intensive operations contributes 39 to 60 per cent of Cost-A1, towards of labour wages. The non-availability of labour and high wages has aggravated the farmer's problems in sugarcane production in India. Therefore, it is require to adopt mechanize sugarcane cultivation to perform operations on time, and improve productivity per unit of resource utilize, cost reduction and better farmers income.

Sugarcane mechanization potential in India:

The sugarcane machine and farm implements developed by the ICAR- ISRI, Lucknow had played a vital role in improving sugarcane production and productivity. The research and development work of the institute was focused to sugarcane mechanization since, inception of Institute in 1952. The agricultural engineering division has developed number of prototypes for sugarcane cultivation operations. The prototypes and machine developed during past three decades, were various sugarcane cutter planters models, trenchers, sub-soilers, ratoon management devices (RMDs), Trash mulcher and shredder etc.,.

These machines are well adopted, extensively used by the sugarcane farmers and promoted by state cane development department, cane development societies and sugar mills in different states in India. There are nearly 2.78 lakh sugarcane growers who were using variants of sugarcane cutter planter, mechanised trenchers cum furrow openers. These machines were popular on large farms but also preferred by small and marginal farmers on custom hiring basis. To enhance adoption of sugarcane mechanization, governments offers25-50% subsidies on purchase of machines and machines repair and maintenance workshops establishment in villages. The AI tools and machines have been widely adopted in tropical and sub-tropical states. It have 3.6 lakh ha area which led supplementary economic return `750 crores annually (IISR Annual Report 2018-19). The adoption of mechanization in U. P. and Bihar has improved cane productivity by 25-28 and 8-15 tonne per ha respectively during 2013-14 to 2024-25. The sugarcane cutter planter could saving 25-30 Labour Day/ha, money saving of ` 6500-8000 per ha on prevailing labour wages. The moisture losses of sugarcane seed, improve germination, time and labour saving has improved its adoption on all categories of farms. Thesemachines have potential in context of labour shortage, water scarcity and climate resilience smart sugarcane agriculture to address future emerging scenario. An attempt has been made in this study to envisage potential of sugarcane mechanization in cost saving, productivity, profitability and to estimate economic benefits of mechanization to sugarcanefarmers, sugar mills and u consumers in an ex-ante framework.

Data and Methodology

Both secondary and primary data were used in the present study. The time series data on area, production and productivity pertains to states of U.P., Maharashtra, Bihar and India for the period 1990-91 to 2023-24 were compiled from various published sources. The data were also downloaded from websites of CACP, sugar directorate, kisan.net on raw material supply, sugar consumption and production. The selected cane states accounts for 85% crop area. These states were purposively selected and from each state, 2-3 districts have sizable area and sugar mills were selected. From each district, 25 cane farmers were randomly selected to make total sample of 240. The data on socio-economic parameters, cane production, supply to sugar mills, etc. were collected from 40 sugar mills with the help of survey schedule during crushing seasons, 2017-18 to 2023-24. The economic surplus of sugarcane mechanization implements developed by ICAR-ISRI, Lucknow during past three decades has been estimated by applying equilibrium displacement model. The partial equilibrium framework is the key approach for evaluation of crop specific technological innovations in agriculture (Alston et al., 1995; Norton and Davis, 1981). This approach has been used in ex-post and ex-ante impact assessments of crop and livestock technologies (Joshi and Bantilan 1998, Hareauet al., 2006; Pray et al., 2001; Qaim 2003, Kumar and Prasanna 2010). In present study, we applied a model with linear supply and demand curves and a parallel vertical shift in supply by machine adoption and to minimize probable errors of misspacification (Alston et al., 1995). It is assume a close economy framework where equilibrium price is determined by domestic sugar and co-products demand supply. The model was disaggregated for states, viz., Maharashtra, Uttar Pradesh, Bihar and India.

The economic surplus model suggested by Alston et al. (1995), annual change in consumer surplus (CS) and producer surplus (PS) from adoption of

machines like sugarcane cutter planters, trencher, rotavator and ratoon management devices (RMD's) commercialized and to the sugar mills, sugarcane farmers/end users by the ISRI was estimated as:

CS= P0 Q0 Z (1+0.5 Z ?)

PS = P0 Q0 (K-Z) (1+0.5Z ?)

Where, P0 and Q0 are the initial equilibrium price and quantity, respectively; and K is the vertical shift in supply, expressed as a proportion of the initial price. Z is the reduction in price as a result of the supply shift. It is computed as K? / (? + ?), where ? is the absolute value of the price elasticity of demand, ? is the price elasticity of supply.

The change in total economic surplus has been computed as the sum of changes in CS and PS. Since adoption of new agricultural technologies has been a gradual process over time, it was consider period of 20 years from 2006 to 2025, and articulated average annual socio-economic welfare in annuity. The assumptions to decide the rate at which future monetary flows have to be discounted was critical. We assumed a discount rate of 10% as financial institutions advances loans to farmers to calculate the present value of economic surplus.By using the total benefits from adoption of sugarcane mechanization, various measures of economic returns were worked out. The information derived through economic surplus model has been used for estimation of ought to be benefit-cost ratio (BCR), internal rate of return (IRR) and net present value (NPV) for sugarcane mechanization research output. The impact of technological intervention could be reflected by cost saving, timeliness of operations, productivity improvement through labour saving and less wages payments by the farmers and supply of quality raw material to sugar mills for processing efficiency and high sugar recovery.

Results and Discussion

Sugarcane is as commercial cash crop cultivated on 5.31 million ha area with nearly 50 % area under ratoon crop as farmers takes at least one ratoon after plant crop in all major cane growing states. Ithas long-duration of 10- 18 months and it's sowing done in autumn and spring season from September to November and February to May respectively. It requires about 121-225 man days per ha (Table1). Its planting, intercultural and harvesting is prime labour operations. Its cultivation needs 4-6 manual weeding in Sub tropical region. The field preparation, cane seed cutting, sowing and harvesting requires 80-110 man days/ha. However, labour for harvesting depends on productivity and harvest season. The labour requirement is more, if productivity is higher or crop harvesting in summer season which coincide with wheat and other Rabi crops harvesting when agricultural human labour demand is more.

Table 1: Utilization of human labour in sugarcane and competing crops in India

(Note: The figures pertain to the cost of cultivation of various crops for year 2014-15.) *(In Man days/ha)*

Particulars/ Major crop	Sub-tropical region		Tropical region			
	U.P.	Uttarakhand	Andhra Pradesh	Tamil Nadu	Maharashtra	Karnataka
Cotton	-	-	109.08	126.99	116.29	99.55
Groundnut	-	-	67.08	98.95	91.85	71.19
Wheat	49.18	40.87	-	-	-	-
Paddy	99.66	84.11	70.70	72.74	166.67	90.02
Sugarcane	143.04	121.02	202.07	216.42	225.01	148.96

As field operations in sugarcane were performed by human labour manually as sugarcane machine adoption was to limited operations. The labour requirement for wheat crop was 41 and 49 man days per ha in the Indo-Gangetic Plains as compared to 121 and 143man days for sugarcane in Uttarakhand and U. P respectively. In tropical states, labour-use was less in paddy, cotton and groundnut in comparison to sugarcane. The sugarcane mechanization adoption and expenditure on mechanical power was low as compared to other crops (Table 2). The share of machine power cost in total operational cost comprises of one-fifth in wheat and varies from 12 to 19 per cent for paddy in the major cane growing states. Hence, it is concluded that the sugarcane cultivation is least mechanized and its cultivation is labour-intensive in major growing states. The share of human labour wages in total sugarcane operational cost varies from 40 to 69 per cent in sugarcane growing states in India.

Table 2: Expenses on human labour and machine in sugarcane and competing crops in India
(Note:The figures pertain to the cost of cultivation of various crops for year 2016-17)

Particulars/ Major crop	Sub-tropical region		Tropical region			
	U.P.	Uttarakhand	Andhra Pradesh	Tamil Nadu	Maharashtra	Karnataka
Cotton	-	-	8.47	5.96	7.45	9.32
Groundnut	-	-	6.17	9.17	9.01	8.39
Wheat	20.31	17.34	-	-	-	-
Paddy	11.67	12.84	18.14	18.58	6.35	11.71
Sugarcane	2.61	4.01	3.22	2.28	13.79	4.56
Human labour wages						
Cotton	-	-	54.37	50.74	43.91	66.15
Groundnut	-	-	44.24	46.77	42.55	49.55
Wheat	36.01	34.25	-	-	-	-
Paddy	47.75	49.54	55.97	43.60	50.99	46.96
Sugarcane	58.66	50.62	39.78	69.04	61.23	59.56

The sugarcane need more human labour days in Tropical as compared to Sub-tropical states. Pawar et al., (2007) reported that labour requirement for Adsali and Suru sugarcane crop was 193, 263 and 149, 228 man days on small and large farms respectively. The labour requirement for sugarcane cultivation was highest in Andhra Pradesh (296 man days/ ha) followed by Tamil Nadu and Karnataka during first decades of 21st century (Table 3). In Haryana and U.P, human labour requirement ranges from 102 and 142 man days per ha (CACP 2023). It is reveals that during past four decades period, labour requirement for sugarcane has decrease in sub-tropical and tropical states, except A.P. and Karnataka. The less labour utilize in cane cultivation in these states could be endorsed to better adoption of sugarcane machines and technologies for sugarcane planting, intercultural operations, trash and ratoon management operations through tractor operated farm implements. In Maharashtra, decline in labour utilization was due to higher wage rates, adoption of sugarcane machines, labour and water scarcity problems. The better adoption of mechanization, human labour and water scarcity led to lessen sugarcane planting and intercultural operations manually as share of machine power was 13.79 per cent of total operational cost of production in Maharashtra. However, in Sub-tropical region,

use of human labour man days in sugarcane cultivation was less as compared to Tropical region. Table 3 reveals a decline trend in labour utilization in in U. P. and Haryana.

Table3: Aggregate human labour utilization in sugarcane cultivation in India (In Man days/ha)

Time decade	Sub-tropical region		Tropical region			
	U.P.	Haryana	Andhra Pradesh	Tamil Nadu	Maharashtra	Karnataka
1990s	155	130	281	327	237	206
2000s	156	143	288	289	266	276
2010s	142	102	296	278	211	264
2020s	139	98	294	271	204	268
Increase/ Decrease	-ve	-ve	+ ve	-ve	-ve	+ ve

Note: +ve means increase while -ve means decrease; these figures have been worked out as average values on the basis of cost of cultivation data for the decade.

Source: The Comprehensive Scheme for Studying Cost of Cultivation of Principal Crops, Govt. of India

Potential of sugarcane mechanization: ISRI developed machines

The tractor operated sugarcane cutter planter, trench opener, ratoon management device (RMD) have been developed, prototype evaluated, tested on farmers field and modified. The sugarcane lodging problem could be minimized through deep ploughing,mechanized planting and earthing up. Sugarcane cutter planter covered with light pressed soil with a free floating cover unit. The whole sugarcane has to feed in cutting unit. It cutscane into pieces and guided setts to furrow opened with tillage discs. The moisture losses in seed setts have conserved which helps in improving seed setts germination. A prior to transfer of technology to industrial agro-implements manufactures by signing memorandum of agreement (MoA), developed prototypes of machines have been extensively tested at institute farm and sugarcane farmer's fields. Sugarcane planting in deep trenches has become standard practice in U.P and Bihar. Trencher consists set of two furrow openers with long shank, and two wings mounted on standard cultivator frame. The prototypes has been fabricated in institute workshop and tested at different locations. The chronology and details of various sugarcane farm implements and machine suitable for mechanization has been presented in Table 4. The sugarcane farmers prefers for crop planting in paired rows (two rows parallel at 30 cm space) rather than seed setts sowing in furrow. The tractor operated trencher has been developed for sowing two rows of 25-30 cm deep furrows at desired space to facilitate cane trench planting at optimal depth. The spacing between the trench paired rows could be enhanced up to 45 cm by adjusting space between two mould boards plough shares. These mould board plough could penetrates furrows up to 30 cm depth. The developed prototype was well tested and performance was satisfactory.

Table 4: Sugarcane implements and machine developed by ICAR-IISR, Lucknow

Sugarcane machine/ implement	Time of development/ technology transfer
Sub-Soiler	1998-2002
Tractor drawn implements for deep trencher/furrow openers	1989-90 and 2012-13
Tractor drawn Implement for pit digging	1984-86 and 2005-06
Tractor operated sugarcane cutter planters/ RMD, sugarcane cutter planter variants	
Sugarcane cutter planter with discs	1992-95
Cutter planter with ridgers	1993-97
Three row multipurpose sugarcane planter	1999-2002 and 2009-10
Paired row sugarcane cutter planter	2008-12
Sugarcane-cum-potato planter	2006-08 and modified version in 2012
Raised bed seeders cum planter	2000-02, 2005-08 and 2009-10
Multipurpose equipment for sugarcane cultivation	2005-09, 2017-22
Inter-culturing equipment with sweep shovels	2009-11, 2018-21
Power operated de-trashing machine	1990, 2005-09 and 2012
Sugarcane trash handling and management	(1983-88, 2000-04, 2008-12)
Various variants of ratoon management devices (RMDs)	2005-09, 2012-16, 2017-22

Progress and adoption of sugarcane mechanization in Uttar Pradesh

In sugarcane, majority of planting and intercultural operations are performed by human labour. The non-availability of labour and high wage rate made sugarcane cultivation expensive, stagnant productivity and farmer's low profit. To sustain crop productivity, application of machine plays a key role in enhancing sugarcane productivity. The sugarcane mechanization aims at timeliness operation; reduce unit cost operations, human drudgery and increase productivity. The prototypes of sugarcane machine developed, commercialized by the institute and majority of them were well adopted by sugarcane growers during past three decades. The sugarcane cutter planter and prototypes of other machines developed earlier have lost practical utility on advent of improved/ modern technologies modified as per farmer's requirement. The status of sugarcane machine adoption is presented in Table 5.

Table5: Progress and status of sugarcane mechanization in U.P. during 2013- 2024

Figures within the parentheses are percentage of sugarcane acreage under plant and ratoon
(Area in lakh ha)

Particulars of machine/technology	2012-13	2013-14	2014-15	2015-16	2016-17	2018-19	2023-24
Sugarcane cutter planter	0.11 (1.01)	0.25 (2.29)	0.50 (4.69)	0.71 (6.87)	0.996 (9.68)	1.96 (12.99)	2.27 (13.41)
Mechanized Trencher /furrow	0.15 (1.31)	0.27 (2.48)	0.56 (5.27)	0.67 (6.58)	0.94 (9.49)	1.67 (11.03)	1.79(11.22)
Intercrops in autumn sugarcane	0.13 (1.22)	0.24 (2.21)	0.54 (5.08)	0.71 (6.96)	0.99 (9.64)	1.97 (13.05)	2.02 (12.01)
Ratoon management Devices	0.33 (2.96)	0.65 (5.86)	0.87 (8.17)	1.03 (10.08)	1.32 (12.85)	1.86 (14.54)	1.94 (14.04)
Sugarcane plant	11.66 (52.24)	11.84 (53.14)	11.16 (51.4)	10.76 (52.44)	11.07 (53.68)	15.12 (54.10)	14.54 (51.30)
Sugarcane ratoon	10.44 (47.76)	10.44 (46.86)	10.36 (48.6)	9.76 (47.56)	9.47 (46.11)	12.82 (45.90)	13.80 (48.70)
Total sugarcane	22.12	22.28	21.42	20.52	20.543	27.94	28.340

Source: Compiled from official record, Sugarcane Commissioner, Govt. of U. P.

It is evident that the cane area planted with sugarcane cutter planter have enhanced from 1 to 14 per cent of total plant crop area during last decade in U.P. The sugarcane planted by mechanized trencher had reached to 1.79 lakh ha during 2023-24. Similarly, the acreage under intercrops sugarcane and application of ratoon management device (RMD) for ratoon initiation has gone up to 2.02 and 1.94 lakh ha respectively in year 2023-24. It concludes that adoption of sugarcane machine would further improve yield and reach up to 30-35 per cent adoption level in next decades.

Impact of sugarcane machine on cost and net return in U.P.

The economics of sugarcane production in conventional and machine dominated Innovative sugarcane production techniques (ISPT) methods was worked out and presented in Table 6. The cost of sugarcane production was `161439 and `134267 per ha in traditional and ISPT method respectively. The high cost in conventional method was because of high seed cost as farmers use three bud setts and flood irrigation, without green manuring, fertilizer; labour wages for manual planting and intercultural operations. However, in ISPT method cost was less as they used two/ single bud setts, grow green manure, precision field level, FIRB/ trench planting, wider row spacing, saving irrigation water in trench/drip, RMD, mechanical power for performing inter cultural operations. The results reveal cost saving 25-45 % on seed, fertilizer, irrigation and labour in mechanized ISPT method. Farmers have adopted sugarcane mechanization for crop planting and intercultural operations to address labour scarcity and cost minimization.

Table 6: Comparative cost of sugarcane production in two techniques *(Rs / ha)*

Particulars/ cost components	Conventional	ISPT method	Cost saving (%)
Fixed cost components			
Depreciation	5207	5441	
Interest on fixed assets	4908	4612	
Rental value of owned land	28284	28663	
Total fixed cost	38399	38716	-0.83

Variable cost components			
Cane seed/setts	18543	10342	44.23
Fertilizer and manure	14572	11286	22.55
Plant Protection chemicals	3567	3538	0.81
Human labour	37676	27234	27.72
Mechanical power	33261	34733	-4.43
Irrigation	15421	8418	45.41
Total variable cost	123040	95551	22.34
Total cost (Cost C)	161439	134267	16.83

Table 7 reveals that the farmers realized higher sugarcane productivity and reap better returns in machined sugarcane production in ISPT as compare to conventional method, inter cropping with pulses, oilseeds and vegetables in autumn cane. Farmers used sugarcane cutter trencher for crop sowing, small tractor or multi-purpose power tillers for intercultural operations to minimize labour cost. Sugarcane harvesting by labour, loading and transport charges were also high in U.P. The high BC ratio of 2.369 reveals that the sugarcane cultivation was more profitable in ISPT as compare to traditional method. Incorporation of pulses, oilseeds and vegetables crops as intercrops in sugarcane based farming systems add to their net profitability and supplement nutritional security.

Table 7: Break up of cost and return from sugarcane production in U.P.

(In Rs/ ha)

Particulars/ cost components	**Traditional**	**ISPT method**
Cost A_1	123040	95551
Cost B_1	151324	124214
Cost C_1	156232	128826
Total Cost (Cost C_2)	**161439**	**134267**
Yield (tonnes/ha)	72	86
Price (Rs./tonne)	3585	3700
Cost of production (Rs./tonne)	2242	1561
Gross return	258120	318200
Net return on Cost A_1	135080	222649
Net return on Cost C	61888	189374
Benefit-Cost (BC)Ratio	**1.599**	**2.369**

Economicsurplus with adoption of sugarcane mechanization

Sugarcane mechanization is the need of hour to address the labour scarcity problem, cost saving and timely completion of various operations on time. The findings of simulation economic surplus model applied for sugarcane mechanization

implements used by the farmers in developed framework in major growing states is shown in Table 8. Total surplus (TS) generated with adoption of mechanization accrued amounts to ` 71419 Crores at country level. It could be immense economic benefit to the sugarcane farmers, sugar mills and sugar consumers in absolute terms for agro-industrial sugarcane with an aggregate 5.32 million ha area. The maximum share of aggregate economic gains accrues in U.P. followed by Maharashtra, where sugarcane area was more sugar recovery, productivity gains and machine adoption rate was high. The distribution of economic surplus amongst sugarcane farmers, sugar mills and consumers reveals that the farmers are key beneficiaries of ` 39898 Crores (i.e. 51.1 per cent total surplus in U.P.). Despite negative output price effect, sugarcane farmers were benefited, as machinery adoption minimizes per unit production cost and improve yield. The economic gain in producer surplus s to 941, 1681, 949 crores annually to sugar consumers, cane farmers and sugar mills respectively during past two decades. The sugarcane farmers of U.P. and Maharashtra have been benefitted most as these two states contributed nearly 72 % of sugarcane and sugar production during past five crushing seasons.

Table 8:Estimated economic surplus gains by sugarcane mechanization adoption (1990-2025)

Particulars/ State	Economic returns generated (InCrore)				Per cent share for Farmers/ Mills/ Stakeholders		
	CS	Farmers (PS-I)	Sugar mills (PS-II)	TS	CS	PS	Sugar mills
Uttar Pradesh	10509	20373	9014	39898	26.3	51.1	22.6
Bihar	1049	1969	967	3986	26.3	49.4	24.3
Maharashtra	4775	9749	3601	18124	26.3	53.8	19.9
INDIA	18814	33616	18989	71419	26.3	47.1	26.6

The economic benefits of ?20373, 1969, 9749 crores may be addedto sugarcane farmers of U.P., Bihar and Maharashtra respectively by the adoption of ICAR-ISRI sugarcane machine during past two and half decades. The added sugarcane yield and sugar recovery gain were due to crop quality and cost saving on labour wages and timeliness of cultivation operations through suitable farm implements which reduces drudgery.

Table 9: Parameters for impact assessment of sugarcane mechanization technology

Particulars/ State	NPV (In RsCrores)	BC ratio	IRR (in %)
Uttar Pradesh	183764	25.30	32.20
Bihar	18003	24.84	30.90
Maharashtra	90364	120.67	42.91
INDIA	300718	80.53	41.27

The estimated internal rate of return (IRR) of 41% (Table 9) reveals that the financial expenditure on R&D of sugarcane machine and implements developed by the ICAR-IISR, Lucknow could repay higher economic benefits especially to the sugarcane farmers and sugar mills and rural society. The benefit-cost ratio was 80.5, indicates that each rupee invested on the sugarcane farm implements research and development work may give the dividend of nearly ` 81. The expected NPV of net social gains was high enough to conclude that the R&D investments would be economically viable, productive and socially acceptable. It is expected that the sugarcane farmers, sugar mills and other clients would ensure better use of sugarcane mechanization techniques for further enhancing productivity, sugar recovery and minimize cost of sugarcane cultivation through optimal use of scare resources and farm input to meet the future demand of sweeteners and safe bio green energy.

Conclusions and policy options

Among the major sugarcane states, Uttar Pradesh is the leading state in adoption of sugarcane machines followed by Maharashtra. These states had promoted sugarcane machines and ISPT techniques in a big way cover nearly 14-18percent of total sugarcane area in these states. The study provides evidence of cultivating sugarcane with machine and climate smart technologies in large area; farmers save expenses on seed, irrigation and labour. They achieve better productivity on mechanized farms over non-mechanized farms. The factors responsible for adoption of sugarcane machines include family labour, education, and labour scarcity. The mechanized sugarcane production, cost and input saving techniques help in adding farmers' income and profitability. It is expected that utilization of sugarcane machine developed by the institute could further increase to address labour problem. Therefore, mechanized sugarcane productionwas win-win situation to farmers and sugar mills. The ex-ante evaluation of sugarcane mechanization reveals that B-C ratio 80.53, NPV `300718 crores and IRR 41 % in India. The results conclude that R&D investments on mechanization would be economical and socially acceptable.The sugarcane mechanization could be a viable option for minimizing cost of cultivation, enhanceresource use efficiency and helps in achieving objectives of enhancing farmers income.

Reference

Alston, J.M., Norton, G.W., Pardey, P.G. (1995) Science under Scarcity: Theory and Practice for Agricultural Research Evaluation and Priority Setting, Cornell University Press, Ithaca, USA

Bhalla, G. S. and Hazzel, Peter (1998) Food grains Demand in India to 2020: A Preliminary Exercise, Economic and Political Weekly, 32(52): A 150-A 154.

Comprehensive Scheme for Studying Cost of Cultivation of Principal Crops, Govt. of India, Various issues since 1990 to 2019

GoI (Government of India) (2024) Economic Survey, (2023-2024), Economic Division, Ministry of Finance, New Delhi.

Government of U. P., (2013) Sugar industry, cogeneration and distillery promotion policy, Sugar industries and Cane Development Departmentpp: 1-31

IAI and FICCI (2016) Accelerating growth of Indian agriculture: Micro irrigation an efficient solution. Strategy paper - Future prospects of micro irrigation in India, published jointly by Irrigation Association of India, New Delhi and Federation of Indian Chambers of Commerce and Industry, New Delhi

Indian Sugar Mills Association (2019), various press releases on sugar production, stock position and marketing. www.indiansugar.com/

Joshi, P.K. and Bantilan, M.C.S.,(1998) Impact assessment of crop and resource management Technology: A case of groundnut production technology. Impact Series no.2. International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, A. P., India pp: 60

Kisan.net. website for sugar mills information. www.kisaan.net /

Kumar, P. (1998), Food demand-supply projections, Indian Agricultural Research institute, New Delhi.

Kumar, P, Shinoj, P. S.S. Raju, Anjani Kumar, Karl M. Rich and SiwaMsangi (2010) Factor demand, output supply elasticity and supply projections for major crops of India. Agricultural Economics Research Review 23(1):1-14

Kumar, P, Anjani Kumar, Shinoj, P, and S.S Raju (2011) Estimation of demand Elasticity for Food Commodities in India. Agricultural Economics Research Review 24(1):1-14

Kumar S., and Prasanna, Lakshi, P.A.,(2010) Socio-economic analysis of production and marketing of Brinjal and Ex-ante assessment of economic benefits of BtBrinjal in India. Project Report, National Centre for Agricultural Economics and Policy Research, New Delhi-110 012, India

Murthy, S.R.S., (2010), Economics of sugarcane production and sugar processing, Occasional paper 54, NABARD, Mumbai. pp: 1-173

NITI Aayog, (2018) Composite water management index-a tool for water management. Research Report in association with Ministry of Water Resources, Ministry of Drinking Water and Sanitation, and Ministry of Rural Development, Govt. of India, New Delhi.

Norton and Davis (1981)Evaluating Returns to Agricultural Research: A Review. American Journal of Agricultural Economics 63(4): pp 683-99.

Rangarajan, C., (2012), Report of the committee on sugar sector regulation in India: The way forward. pp: 1-46

Rodell,M., Velicogna, I. and Famiglietti, J.S., (2009) Satellite-based estimates of groundwater depletion in India. Nature, August 20; 460(7258):999-1002. Doi: 10.1038/ nature08238.

Sharma A. K. and BrahmPrakash (2011) Causes and consequences of supply-demand gap for labour in sugarcane in India. Agricultural Economics Research Review 24 (Conf.): pp 401-407

Singh P.R., Singh A.K. and Gupta R., (2013) Six Decades of mechanization of sugarcane farming: An overview, In Souvenir: Diamond Jubilee Celebrations National Sugar Fest on 6 Decades of Research at IISR...towards Excellence, Lucknow. pp: 23-40

Thakur, D.S. and K.D. Sharma (2005), Organic Farming for Sustainable Agriculture and Meeting the Challenges of Food Security in 21st Century: An Economic Analysis, Indian Journal of Agricultural Economics. 60(2): 205-219

Post-Harvest and Food Processing Innovation in India: Trends, Challenges, and Future Prospects

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Abstract

India, one of the largest agricultural producers globally, faces significant post-harvest losses and value chain inefficiencies, despite its abundant output. Innovations in post-harvest technologies and food processing are crucial to enhancing food security, reducing wastage, and improving farmers' incomes. This review paper discusses the current state of post-harvest and food processing innovation in India across academic, research, and industrial domains. It highlights institutional contributions, emerging technologies, industry developments, challenges, and future directions. Strengthening R&D, promoting public-private partnerships, and integrating digital technologies are key to creating a sustainable and efficient food processing ecosystem in India.

Keywords: Post-harvest losses, Food processing, Innovation, India, Cold chain, Research institutions, Value addition

1. Introduction

India is one of the largest producers of agricultural commodities in the world, cultivating a diverse range of crops such as cereals, pulses, fruits, vegetables, and spices. However, a significant portion of this produce is lost or wasted due to inefficient post-harvest handling, inadequate infrastructure, and fragmented value chains. Estimates suggest that post-harvest losses in India range from 5-16% for cereals and 30-40% for fruits and vegetables, translating into substantial food and economic losses (ICAR, 2019; MoFPI, 2020). These losses represent not only diminished farmer income and wasted resources but also missed market opportunities and food security challenges.

Innovative approaches in post-harvest management and food processing are thus essential to reduce these losses, improve supply chain efficiency, and meet the growing consumer demand for processed and value-added products. Food processing plays a vital role in preserving agricultural produce, extending shelf life, improving food safety, and enhancing product diversity. It serves as a bridge between farm and market, enabling the transformation of perishable raw produce into storable, ready-to-consume goods. The Ministry of Food Processing Industries (MoFPI) recognizes this sector as a 'sunrise industry', given its potential to drive economic growth, generate employment, and support rural development (MoFPI Annual Report, 2022).

Despite these prospects, only around 10% of India's agricultural output is processed, highlighting a large gap and the need for both technological and institutional innovations (NITI Aayog, 2021). In the past two decades, India has seen concerted efforts from academic institutions, government research bodies, and the private sector to develop and deploy innovations aimed at reducing post-harvest losses and enhancing processing efficiency. Key public sector organizations such as the Indian Council of Agricultural Research (ICAR), the Central Institute of Post-Harvest Engineering and Technology (CIPHET), and the Indian Institute of

Food Processing Technology (IIFPT) have led R&D tailored to Indian conditions.

Simultaneously, the rise of agri-tech startups, supported by initiatives such as the Startup India program, PM Formalisation of Micro Food Processing Enterprises (PM-FME), and venture capital investments, has added momentum to this innovation landscape. These developments underscore the importance of integrated, sustainable solutions in building a more resilient post-harvest ecosystem.

This review paper explores recent innovations in post-harvest handling and food processing technologies in India. It synthesizes contributions from academia, research institutions, and industry, while also analysing prevailing challenges and policy gaps. The goal is to identify pathways to strengthen India's post-harvest infrastructure, promote value addition, and contribute to national food and nutritional security.

2. Current Status and Trends

India ranks among the top three global producers of cereals, fruits, and vegetables, yet only a fraction (around 10%) of agricultural produce undergoes processing. While traditional food preservation practices remain, the last decade has witnessed a surge in technology-driven interventions such as cold chain logistics, solar drying, vacuum packaging, and nutrient-retaining processing methods. Government initiatives like the Pradhan Mantri Kisan Sampada Yojana (PMKSY), One District One Product (ODOP), and Mega Food Parks aim to strengthen post-harvest infrastructure and promote value-added products.

3.Technological Innovations

Advancements in food processing have moved beyond traditional techniques like drying, milling, canning, and thermal pasteurization toward more sophisticated and precise methods aimed at improving product quality, nutrient retention, and functionality. Novel food processing technologies are being developed and adopted globally and are slowly gaining attention in India's research and industrial landscape. These technologies not only enhance processing efficiency but also enable the creation of new food formats, improve safety, and reduce energy consumption. Among the emerging tools, non-thermal processing, high-pressure treatment, and even 3D food printing are paving the way for a revolution in how food is processed, customized, and consumed.

One of the most promising areas is 3D food printing, which combines food science, additive manufacturing, and design to create customizable, layer-by-layer structured foods. Though still at a nascent stage in India, 3D food printers have potential applications in personalized nutrition, elderly care, high-end confectionery, and space food systems. Using edible inks made from purees, doughs, pastes, and hydrocolloids, these printers can produce intricate shapes, textures, and multi-ingredient combinations tailored to individual needs. Indian academic institutions such as IITs and IIFPT have begun exploratory projects on 3D-printed snacks and protein-enriched foods. The ability to modify food architecture at the micron level opens new possibilities for nutrition-sensitive food design and value-added product development.

Other innovative processing methods being explored include high-pressure processing (HPP), which uses intense pressure to inactivate microbes and enzymes without the need for high temperatures. This retains the sensory and nutritional properties of food, making it especially valuable for juices, ready-to-eat meals, and meat products. Similarly, pulsed electric field (PEF) and ultrasound-assisted processing are gaining research interest for their ability to enhance mass

transfer, extraction efficiency, and microbial inactivation.

Additionally, cold plasma treatment is being investigated for its role in surface decontamination of grains and fresh produce, providing a chemical-free alternative to traditional sanitation methods. Ohmic heating, which uses electrical resistance to generate internal heat uniformly in viscous foods, offers another route to energy-efficient and rapid processing.

Though the industrial-scale adoption of these novel technologies in India is limited due to high capital costs and regulatory challenges, their integration into the academic curriculum and pilot-scale facilities is a positive step. With continued research, public-private partnerships, and government support, these emerging technologies are expected to play a transformative role in the future of Indian food processing.



Fortification and Value Addition

Value addition and fortification are critical components of modern food processing that aim to enhance both the economic worth and nutritional quality of agricultural produce. In the Indian context, where a large section of the population still grapples with malnutrition, hidden hunger, and post-harvest losses, these two approaches play a transformative role. While value addition focuses on improving the market value, shelf life, and usability of raw produce, fortification ensures that foods meet essential dietary requirements through the inclusion of micronutrients.

Value Addition: Enhancing Utility and Marketability

Value addition refers to the process of converting raw agricultural commodities into products that have higher economic value and consumer appeal. This can be achieved through cleaning, grading, packaging, branding, and processing into intermediate or ready-to-eat products. In India, value addition is especially relevant for perishable commodities like fruits, vegetables, and dairy products, which face high post-harvest losses due to inadequate infrastructure.

Examples of value-added products include fruit juices, jams, pickles, dehydrated vegetables, flavoured dairy drinks, spice powders, millet-based snacks, and ready-to-cook grain mixes. Farmers, particularly those organized into Farmer Producer Organizations (FPOs) or Self-Help Groups (SHGs), are being trained to undertake primary processing steps such as sorting, pulping, or dehydration at the farm gate to access better markets. Agro-processing clusters and mini food processing units supported under government schemes like PM FME (Pradhan Mantri Formalisation of Micro food Enterprises) and One District One Product (ODOP) have further enabled small-scale entrepreneurs to generate income through value addition.

Emerging technologies such as vacuum frying, freeze drying, extrusion, and microwave-assisted dehydration are being explored for processing fruits, vegetables, millets, and pulses in a way that retains colour, texture, and nutrients. The incorporation of biodegradable packaging and improved labelling has also contributed to better

shelf appeal and environmental sustainability.

Fortification: Addressing Hidden Hunger

Food fortification is the deliberate addition of essential micronutrients-such as iron, iodine, zinc, vitamin A, and folic acid-to commonly consumed foods. This strategy is vital in combating micronutrient deficiencies that persist across many Indian states, particularly among children and women of reproductive age. Fortification offers a cost-effective and scalable solution to reach large segments of the population without changing dietary habits.

The Government of India has mandated fortification in several food products, including:

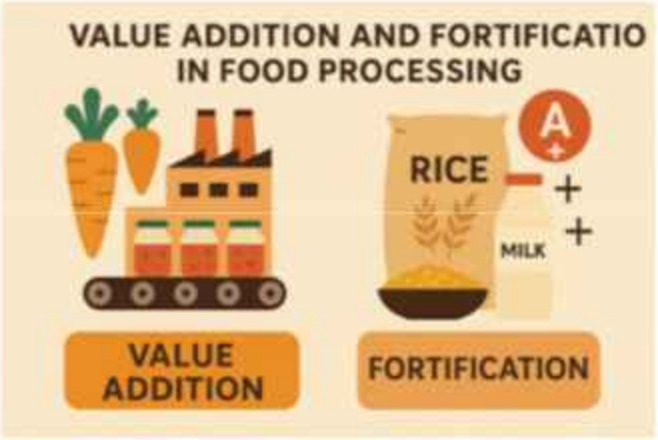
- Salt fortified with iodine and iron
- Wheat flour fortified with iron, folic acid, and vitamin B12
- Edible oil fortified with vitamins A and D
- Milk fortified with vitamins A and D
- Rice fortified with iron, folic acid, and B vitamins, especially in welfare programs like the Public Distribution System (PDS), Mid-Day Meal Scheme, and ICDS.

Research institutions such as the Indian Institute of Food Processing Technology (IIFPT), National Institute of Nutrition (NIN), and Food Safety and Standards Authority of India (FSSAI) are actively engaged in developing fortification protocols, testing kits, and guidelines for compliance. Efforts are also being made to ensure that fortification does not alter the taste, color, or texture of the food, thus maintaining consumer acceptance.

Furthermore, there is growing interest in biofortification, a complementary approach where crops are bred (either conventionally or through biotechnology) to naturally contain higher levels of essential nutrients. For instance, biofortified varieties of rice (high in zinc), pearl millet (rich in iron), and sweet potato (rich in vitamin A) are being promoted by ICAR institutes and NGOs.

Synergy and Way Forward

The combined approach of value addition and fortification offers a dual benefit-enhancing farm profitability and addressing public health concerns. As India moves towards ensuring food and nutritional security for its vast population, it is imperative to integrate these strategies across the agri-food value chain. Investment in R&D, capacity building for micro-entrepreneurs, consumer awareness campaigns, and robust regulatory frameworks will be essential for mainstreaming value-added and fortified products into the Indian food system.



Waste Valorization in Food Processing

Waste valorization in food processing refers to the strategic conversion of food and agricultural waste into value-added products such as bioenergy, biofertilizers, animal feed, nutraceuticals, and biodegradable packaging materials. This approach is particularly significant in the Indian context, where vast quantities of organic waste are generated across the agri-food value chain due to inefficiencies in harvesting, processing, storage, and distribution. Traditionally, much of this waste has been discarded in landfills, incinerated, or left to decay, resulting in severe environmental consequences

like greenhouse gas emissions, water pollution, and air contamination from open burning. With rising concerns about food security, sustainability, and climate change, waste valorization offers a pragmatic solution that promotes circular economy principles and supports India's national missions such as Swachh Bharat Abhiyan and the United Nations Sustainable Development Goals (SDGs).

In food processing industries, significant amounts of waste arise in the form of fruit and vegetable peels, pulp, pomace, seeds, dairy whey, cereal bran, and oilseed cakes. These residues, once considered burdensome, are now being recognized for their biochemical and nutritional potential. Technologies such as anaerobic digestion are increasingly being used to convert organic food waste into biogas and electricity, especially in food parks and municipal markets. Similarly, composting and vermicomposting are popular among small- and medium-scale processors for converting biodegradable waste into nutrient-rich soil amendments that benefit organic farming systems. High-value compounds like antioxidants, natural pigments, and dietary fibers are being extracted from by-products like citrus peels, pomegranate rinds, and grape pomace for use in functional foods, cosmetics, and pharmaceuticals.

Other innovative valorization pathways include the development of protein-rich animal feeds from cereal processing waste and dairy by-products, as well as biodegradable packaging materials from agro-residues like rice husk, bagasse, and starch-rich biomass. The fermentation of food waste is also being used to produce industrial enzymes and organic acids, further widening the scope of applications. Government schemes like PMKSY and the Food Processing Fund, along with research efforts from institutes such as ICAR-CIPHET, IIFPT, and CSIR-CFTRI, have supported pilot projects and start-ups working on scalable waste utilization technologies. However, challenges such as low awareness, lack of segregation at source, inconsistent raw material supply, and absence of product quality standards remain. Overcoming these barriers will require a coordinated effort involving policy support, industry participation, skill development, and investment in infrastructure. Ultimately, embedding waste valorization into the mainstream food processing ecosystem is essential for ensuring resource efficiency, environmental sustainability, and economic resilience in India's agri-food sector.



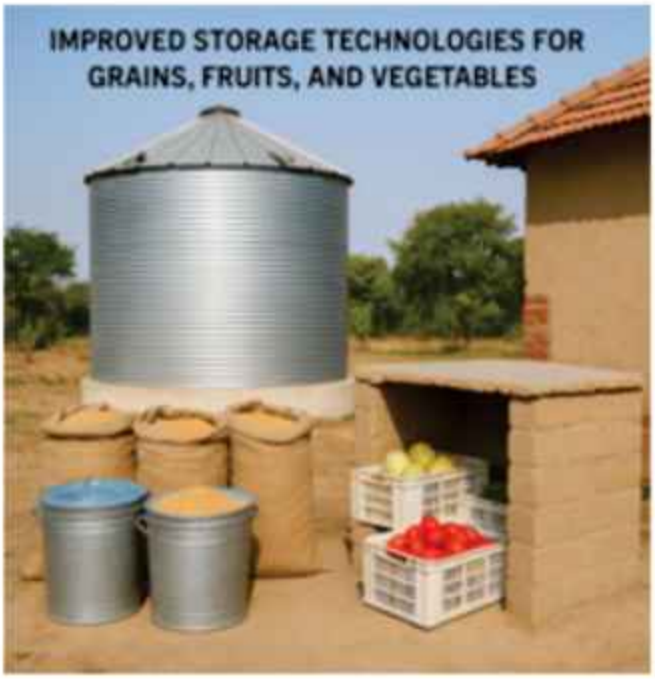
Storage Technology Advancements

Post-harvest storage plays a critical role in maintaining the quality, nutritional value, and marketability of agricultural produce. In India, where climatic variations and infrastructural gaps contribute to significant post-harvest losses, the development and deployment of improved storage technologies for grains, fruits, and vegetables is vital. Traditional storage methods such as mud bins, jute bags, and underground pits are still widely used, especially in rural areas. However, these systems often fail to protect produce from moisture, pests, fungal contamination, and temperature fluctuations, leading to both quantitative and qualitative losses.

For grains such as wheat, rice, pulses, and maize, several improved storage technologies have been developed and promoted. Hermetically sealed metal bins, galvanized iron (GI) containers, and high-density polyethylene (HDPE) structures help maintain low oxygen levels and prevent insect infestation. Community-level storage solutions like the Pusa bin and Hapur bin, developed by Indian research institutions, provide cost-effective options for smallholder farmers. On a larger scale, steel silos equipped with aeration systems and temperature monitoring allow for bulk storage with minimal deterioration over time. Modified atmosphere storage and fumigation systems are also being adopted in procurement and warehousing centers to enhance storage safety.

For fruits and vegetables, which are highly perishable and sensitive to environmental stress, improved storage is even more critical. Traditional ambient storage often results in high rates of spoilage due to microbial activity and enzymatic breakdown. In response, technologies like Zero Energy Cool Chambers (ZECC) have gained popularity in rural areas. These chambers use evaporative cooling to lower the storage temperature without requiring electricity. Cold storage units, particularly refrigerated chambers with precise humidity and temperature control, are now more commonly used for storing produce like mangoes, apples, bananas, and grapes. Controlled atmosphere (CA) and modified atmosphere (MA) storage technologies further enhance shelf life by adjusting oxygen, carbon dioxide, and nitrogen levels to slow ripening and microbial growth.

Digital innovations have also been integrated into storage systems in recent years. IoT-based sensors and mobile applications now allow real-time monitoring of storage parameters such as temperature, humidity, and gas composition. These technologies enable early detection of issues and remote management. Additionally, smart packaging with ethylene absorbers, antimicrobial linings, and freshness indicators is being explored to complement storage solutions. The integration of traditional knowledge with modern technology offers a pathway to sustainable, scalable, and farmer-friendly storage systems in India's agricultural ecosystem.



Industrial Development and Innovations

India's food processing sector stands as one of the most dynamic and rapidly growing industries globally, driven by increasing urbanization, rising incomes, changing dietary preferences, and growing export demand. With a projected compound annual growth rate (CAGR) exceeding 10%, the sector has become a key pillar in boosting agricultural income, generating employment, and reducing post-harvest losses. At the heart of this growth is industrial development marked by the adoption of automation, advanced traceability systems, and a strengthened cold supply chain network. Indian food processing firms are increasingly deploying technologies such as Internet of Things (IoT), blockchain, and Artificial Intelligence (AI) to monitor product quality, ensure supply chain transparency, and optimize logistics. One of the most promising trends has been the rise of agri-tech startups, which are innovating with solar-powered storage solutions, compact mobile processing units for decentralized operations, and on-farm primary processing facilities that reduce spoilage and add immediate value to produce. These innovations are democratizing access to modern technologies, especially for small and marginal farmers.

The startup ecosystem is also fostering solutions in packaging innovations, minimally processed foods, and e-commerce platforms that connect farmers directly to consumers or institutional buyers. Simultaneously, major private sector players such as ITC, Britannia, Amul, and BigBasket are actively establishing robust backward linkages with producers. These companies are investing in direct sourcing mechanisms, contract farming models, and farmer training programs to ensure consistency in quality, reduce procurement losses, and build long-term value chains. Cold chain infrastructure development by private players has also been instrumental in improving the shelf life and export potential of perishables. Government support, particularly through the Ministry of Food Processing Industries (MoFPI), has been a crucial enabler. Flagship schemes such as the Pradhan Mantri Kisan SAMPADA Yojana (PMKSY), Operation Greens, and Mega Food Parks provide capital subsidies, facilitate infrastructure development, and encourage cluster-based value addition. Moreover, the government has introduced Production Linked Incentive (PLI) schemes for the food processing industry to further attract private investments and scale up operations.

Another noteworthy aspect of industrial innovation is the growing emphasis on sustainable practices-such as waste-to-wealth models, water-efficient processing technologies, and biodegradable packaging materials-which align with global environmental standards and consumer expectations. Industry-academia collaboration has emerged as a powerful driver of innovation, as research institutions like IIFPT, ICAR institutes, and CSIR labs work closely with industries to develop, test, and commercialize new technologies. These partnerships are fostering rapid prototyping, product reformulation, and quality standardization that



enhance competitiveness in domestic and export markets. In summary, the convergence of technology, entrepreneurship, private investment, and policy support is creating a robust innovation ecosystem in India's food processing sector, paving the way for a sustainable, inclusive, and globally competitive agro-industrial economy.

4. Academic and Research Contributions

Academic and research institutions in India play a pivotal role in advancing post-harvest and food processing innovations tailored to the country's diverse agro-climatic and socio-economic conditions. The Indian Council of Agricultural Research (ICAR) and its affiliated institutes have made significant contributions toward developing cost-effective and scalable technologies. Notably, the Central Institute of Post-Harvest Engineering and Technology (CIPHET), Ludhiana, and the Indian Institute of Food Processing Technology (IIFPT), Thanjavur, have been instrumental in designing low-cost solar dryers, mechanical graders and sorters, and zero-energy storage structures. These innovations are particularly suited for small and marginal farmers, helping to extend shelf life and minimize losses without heavy energy dependence.

Academic institutions like the Indian Institutes of Technology (IITs), National Institutes of Technology (NITs), and state agricultural universities have expanded the frontiers of food technology by integrating engineering and data science. These institutions are engaged in the development of sensor-based tools for real-time quality assessment, intelligent packaging systems that respond to environmental changes, and AI-enabled models for predicting the shelf life and spoilage of fresh produce. Such technologies not only enhance food safety but also empower producers and processors to make data-driven decisions across the value chain.

There is also a growing emphasis on sustainable innovations, with a focus on reducing environmental impact. Researchers are actively working on biodegradable and bio-based packaging solutions derived from agricultural waste. Additionally, agri-waste valorization into high-value products like nutraceuticals, dietary fibers, and functional foods is gaining momentum, aligning with both circular economy principles and consumer demand for health-oriented products.

Importantly, these advancements are increasingly the result of interdisciplinary collaboration. Synergies between food science, mechanical engineering, biotechnology, and computer science are enabling comprehensive and context-specific solutions that are practical, affordable, and aligned with India's developmental goals in agriculture and food processing.

5. Challenges and Gaps

Despite the notable advancements in post-harvest and food processing innovations across India, the sector continues to grapple with several structural and operational challenges that hinder its full potential. A major roadblock is the infrastructure deficiency, particularly in rural and semi-urban areas. Many regions still lack access to modern storage systems, scientific warehousing, cold chain logistics, and basic processing units. The absence of these critical infrastructures leads to substantial post-harvest losses, especially in perishable commodities such as fruits, vegetables, milk, and fish. Grading, sorting, and mechanized packaging facilities are also scarce at the farm-gate level, limiting the ability of smallholder farmers to add value and fetch better prices for their produce. As a result, much of the agricultural output is sold in unprocessed form

with minimal value realization.

Another pressing issue is the fragmented and inefficient supply chain. Agricultural supply chains in India are often long and unorganized, involving multiple intermediaries, each adding costs and inefficiencies. The weak linkage between farmers and processors results in poor price discovery and low-quality raw material for food industries. Farmer Producer Organizations (FPOs), which were envisioned to strengthen aggregation and collective marketing, remain underdeveloped and underfunded in many areas. Additionally, the lack of adequate aggregation centers and logistics support leads to inconsistent supply and increased wastage, particularly in horticulture and livestock products.

The sector also faces regulatory bottlenecks, particularly concerning food safety standards, certification, and compliance mechanisms. While ensuring consumer safety is paramount, small and medium enterprises (SMEs) and startups in food processing often struggle with the cost and complexity of meeting FSSAI norms, obtaining licenses, and navigating multilayered approvals. The absence of a unified, simplified regulatory structure discourages innovation and delays commercialization of new products and technologies. Harmonization of standards with international norms is another challenge that restricts India's export potential in processed food.

Low technology adoption among smallholder farmers further compounds the problem. Awareness about modern post-harvest practices-such as moisture testing, scientific storage, solar drying, vacuum packing, and minimal processing-is limited in rural communities. Even when aware, financial constraints, risk aversion, and lack of training often prevent farmers from adopting these innovations. Access to affordable credit, especially for post-harvest infrastructure, remains limited, despite government efforts. Moreover, last-mile extension services are often inadequate or poorly staffed, making it difficult to disseminate technical knowledge and demonstrate the benefits of improved practices.

To overcome these challenges, there is a clear need for targeted policies that incentivize infrastructure development and reduce the cost of technology adoption. Inclusive financing mechanisms, such as low-interest loans, micro-credit, and public-private partnerships, can enable smallholders and agri-entrepreneurs to invest in storage and processing solutions. Strengthening extension networks, including digital platforms, mobile advisory services, and capacity-building programs, is vital to ensure that farmers receive timely information and handholding support. Addressing these gaps through coordinated action among government, industry, academia, and civil society is critical for building a resilient, inclusive, and future-ready post-harvest and food processing ecosystem in India.

6. Future Prospects and Recommendations

The future of post-harvest and food processing innovation in India holds immense promise, driven by advancements in science, technology, and policy reforms. However, to fully harness this potential and make the sector globally competitive, a multi-pronged strategy encompassing digital integration, sustainability, capacity building, regulatory support, and export orientation must be adopted. One of the foremost areas requiring attention is the digital integration of post-harvest and food processing systems. Leveraging technologies like artificial intelligence (AI), the Internet of Things (IoT), and blockchain can revolutionize how the supply chain is managed. These technologies enable real-time

quality monitoring, traceability, yield forecasting, demand prediction, and better logistics coordination, all of which reduce wastage and enhance transparency. For instance, smart sensors can monitor temperature and humidity in cold storage units, alerting stakeholders to deviations that could affect food quality.

Equally important is the adoption of sustainable technologies to align with India's climate goals and environmental responsibilities. Energy-efficient machinery, renewable energy-powered processing systems (like solar dryers), and biodegradable packaging materials need to become mainstream. Developing low-water, low-energy, and minimal-waste food processing models will ensure long-term viability, especially in water-scarce and energy-deficient regions. The design and promotion of climate-resilient infrastructure will also be key in tackling seasonal post-harvest losses caused by extreme weather events, which are increasingly frequent due to climate change.

Skill development is another cornerstone for the success of food processing innovations. Despite the abundance of raw materials, the shortage of skilled manpower-especially in rural areas-continues to hamper the efficient utilization of post-harvest resources. Therefore, structured training programs for farmers, rural youth, and women entrepreneurs in food processing, value addition, and machinery operation must be rolled out. Government institutions, agricultural universities, Krishi Vigyan Kendras (KVKs), and private sector partners should collaborate to deliver need-based, hands-on skill training modules that support employment generation and rural industrialization.

Furthermore, policy reforms are essential to remove bureaucratic hurdles and create an innovation-friendly ecosystem. A streamlined regulatory framework with single-window clearances for startups, access to finance, ease of doing business, and supportive taxation policies will attract more investment in the sector. Incentivizing innovation clusters and food processing hubs near production zones will enhance operational efficiency and reduce transportation losses.

Finally, a strong export orientation must be fostered. India has the potential to become a global food processing hub, but this requires adherence to international standards, quality certifications, improved branding, and enhanced global market linkages. Government support for international trade fairs, branding of Indian processed products, and subsidies for export-ready infrastructure can enable small and medium enterprises (SMEs) to enter foreign markets confidently.

Collectively, these future-oriented interventions will not only curb post-harvest losses and improve farmers' incomes but also contribute significantly to food and nutritional security. A robust, innovation-driven food processing ecosystem will pave the way for a sustainable, inclusive, and globally competitive agri-food sector in India.

7. Conclusion

Post-harvest and food processing innovation is central to transforming Indian agriculture into a value-driven sector. While substantial progress has been made through academic research, institutional support, and industrial growth, continued efforts are required to address systemic challenges. A multi-stakeholder approach-combining science, policy, and entrepreneurship-is essential to unlocking the potential of this critical sector. As India moves toward a more sustainable and tech-enabled agri-food system, post-harvest innovation will remain

a cornerstone of future growth.

References

CIPHET.(2020). Post-Harvest Loss Assessment of Major Crops in India. Ludhiana: Central Institute of Post-Harvest Engineering and Technology.

Indian Council of Agricultural Research (ICAR), (2019). Annual Report 2018-19. https:// icar.org.in

IIFPT.(2022). Research Highlights and Innovations. https://www.iifpt.edu.in

Startup India. (2023). Agri-tech Startups: Empowering Rural India. https:// www. startupindia.gov.in

Ministry of Food Processing Industries (MoFPI). (2020). Study on Post-Harvest Losses. Government of India. https://mofpi.nic.in

Ministry of Food Processing Industries (MoFPI). (2022). Annual Report 2021-22. https:// mofpi.gov.in/ sites/ default/files/ annual_report_english_2021-22.pdf

NITI Aayog. (2021). Reforming the Agriculture Sector for Doubling Farmers' Income. https://www.niti.gov.in

PM-FME Scheme.Ministry of Food Processing Industries. https://mofpi.nic.in/pmfme

Efficiency Enhancement in Sugarcane Processing for Jaggery Making

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Abstract

Sugarcane is a major cash crop of India. It is mostly produced for making three major products viz. sugar, jaggery and khandsari.Out of all these, jaggery is considered as a food material besides being a sweetener as well.due to the presence of nutrients of human diet. Sugarcane juice extraction, filtration, heating, boiling and concentration and juice clarification are some of the major unit operations besides jaggerymoulding and packaging. Juice heating/ boiling and concentration is one of the most energy intensive operation, which is done mostly over the open pan furnaces. These furnaces are not very energy efficient and consume lots of fuel (bagasse). Therefore, there has always been a scope for energy enhancement in these furnaces. At ICAR - Indian Sugarcane Research Institute, Lucknow, efficient 2-pan and 3-pan furnaces have been developed having some special features. Still efforts are going on to further enhance efficiency of the system. In one of the attempts for energy enhancement modified juice heating /boiling/ concentrating pans have been developed based on experimentation with fins provided to the pan bottom for increasing area of heat receiving surface. Another novel concept of efficiency boosting device (EBD) has also been developed for these furnaces for directing flames to the pan bottom with increase in heating ability of flames. A waste heat recovery system (WHRS) for recovering part of waste heat going through flue gases was optimized. This heat may be utilized for useful purposes like bagasse/jaggery drying and space conditioning. If these innovations are individually or collectively applied; it would enhance system efficiency.

Key words: Jaggery, Furnace, Sugarcane juice concentration, Juice boiling pans

Introduction

There are three major sweeteners, which are produced from sugarcane in India. These are sugar, jaggery and khandsari.Sugar and khandsariare at one hand aremerely sweeteners but jaggery is considered as a food material as well. It is due to the presence of important constituents of human diet. More than 70% of the total world jaggery production is done in India. It is popularly known as the "medicinal sugar" and is nutritionally comparable with honey. It has been used as a sweetener in Ayurvedic Medicine for 3000 years. Jaggery is produced nearly in 25 countries with a total production of about 13 million tonnes per year. India is the largest producer of jaggery under an unorganized agro-processing sector, sharing 55% of the total world production, followed by Colombia (11%).The major states involved in jaggery production are; Uttar Pradesh, Maharashtra, Madhya Pradesh & Chhattisgarh, Karnataka, Bihar, Andhra Pradesh and Tamil Nadu. Jaggery is not only consumed within India but it is exported to foreign countries for earning foreign exchange. Sugarcane juice extraction (crushing), filtration, heating,

clarification, boiling and concentration are some of the major unit operations besides cooling/puddling of concentrated mass, moulding and packaging.Juice heating, boiling and concentration, which is mostly done over open pan furnaces, require lots of heat energy. Bagasse obtained after juice extraction is used as fuel. Sometimes shortage of fuel is experienced. Therefore efficiency enhancement in jaggery furnaces will not only solve problem of fuel shortage but will improve system efficiency as well with more jaggery productivity per unit of energy consumed.

Sugarcane Juice Processing

Sugarcane juice processing involves filtration of juice followed by heating, boiling and concentration to a desired consistency. After juice heating to 80oC, it is clarified using vegetative clarificant and impurities from juice in the form of scum removed. For juice heating, boiling and concentration mostly open pan furnaces are used.In India, different types of jaggery making furnaces have been developed (Roy, 1951). Most of these furnaces are not so energy efficient consuming lots of fuel (bagasse). However, over time, many attempts have been made in design modifications leading to development of improved furnaces. Size and number of pans varies from design to design from single removable pan to multiple fixed pans. Size and number of pans depend on capacity of jaggery plant and system of jaggery making.A jaggery plant is said to be self reliant if bagasse produced from crushing of canes is sufficient enough to process the juice extracted from the same quantity of sugarcane. But it is not so in most of the cases.There is, therefore, always a need for energy-efficient furnace, which could not only process sugarcane juice in shorter period but at the same time would save bagasse.

Modified pans having fins

Juice heating/boiling/concentrating pans are integral part of any furnace.Efficient 2-pan and 3-pan furnaces have been developed at ICAR-Indian Sugarcane Research Institute, Lucknow. Flat and hemispherical bottom pans are used in 2-pan and 3-pan furnace respectively.A novel idea of providing fins to the bottom of pans have been conceptualized with the objective of increasing area of heat receiving surface.More the heat receiving area, more heat energy would be transferred to juice was the hypothesis.In this way more heat will be supplied to the juice and the furnace efficiency will be improved.

To test the hypothesis, three fin configurations viz.parallelfins (PF), flame spreader fins (FSF) and radial fins (RF) were considered (Anwar, 2017). Additional area provided by fins was kept same for all three configurations. All these configurations were compared with conventional plain bottom.



Fig 1: Fin configurations
(a) PF (b) FSF (c) Plain pan (d) RF

These fin configurations are shown in Fig.1.

For making finned pans, mild steel flats (25 x 3 mm) were welded to each of the three finned pans. The total length of flats, therefore the area, in all the cases was kept equal. These configurations were tested through water boiling test and the results are summarized in table 1:

Table 1: Performance of different fin configurations

Sl No.	Performance parameters	Fin configuration/geometry				
		Plain	PF	FSF	RF	Avg. (fins)
1	Water evaporated (kg)	1.720	2.273	2.180	2.143	2.199
2	Thermal efficiency (%)	9.93	12.47	12.06	11.90	12.14
3	Heat utilization efficiency (%)	7.52	9.94	9.53	9.37	9.62
4	% increase in thermal efficiency as compared to plain pan	---	25.58	21.45	19.84	22.29
5	% increase in heat utilization efficiency as compared to plain pan	---	32.18	26.73	24.60	27.93

It can be seen from above table that pans having fins performed better as compared to plain pan in terms of water evaporation and thermal/heat utilization efficiency. Parallel fins gave best results followed by plain spreader and radial fins.

Based on above results, pans (circular and rectangular) of 2-pan IISR furnace were modified and providedparallel fins (Anon. 2005-06).Modified pans are shown in Fig. 2.



Fig 2: Modified circular and rectangular pans of IISR 2-pan

Due to fins, per cent increase in area of heat receiving surface is given below:

Circular Main Pan

Plain pan : 12667.69 cm2

Modified pan : 27561.29 cm2

% Increase in area : 118%

Modified Gutter Pan

Plain pan : 7442 cm2

Modified pan : 17202 cm2

% Increase in area : 131%

Water boiling test and actual juice processing for jaggery making was performed.It was found that

water started boiling early in main pan in modified system. Modified system was found to be capable of evaporating about 15 kg more water that too with 75 kg bagasse in 90 minutes only as against with 100 kg bagasse in 120 minutes withplain pan. Therefore, 0.71 kg more water per kilogram of bagasse was evaporated with modified system. In another way, 0.21 kg less bagasse was consumed per kilogram of water evaporated with modified system. The heat utilization efficiency improved by 9.44%. Bagasse saving was also observed to the tune of more than 30% and 25% per unit weight of water evaporated and per unit of jaggery made respectively. Jaggery production was also increased by 20% with 17% time saving (Anwar, 2010a; Anwar and Singh, 2010).

Optimization of parallel fins

After getting best results with parallel fins, optimization of parallel fins was felt necessary. For this, smaller mild steel pans with increased area of heat receiving surface upto 311 per cent were fabricated. In second set of experiment, increase in area was kept constant but the size of fins varied. The performance of pans was evaluated performing water boiling test. It was found that the performance in terms of heat utilization efficiency increases with increase in number of finsi.e. area of heat receiving surface. It was also found that for a particular increase in area of heat receiving surface, more number of smaller fins work better than less number of larger fins (Anwar, 2010b).

Extracting Waste from Flue Gases for Useful Purposes

Despite many improvements, it was found that still lots of energy goes as waste through flue gases. This is shear wastage of valuable heat energy. Again a novel concept of Waste Heat Recovery System (WHRS) was conceptualized for recovery of part of this heat for other useful purposeslike bagasse/jaggery drying or space heating.

For recovering part of waste heat, a counter-current type of heat exchanger in the form of 100 mm mild steel pipe was fixed in flue gas channel. One end of pipe is exposed to open atmosphere for sucking fresh and clean air.A blower is attached to it via flow regulating valve for sucking air through the pipe.Heating of air is done through convective mode of heat transfer. Whole system is shown in Fig.3.

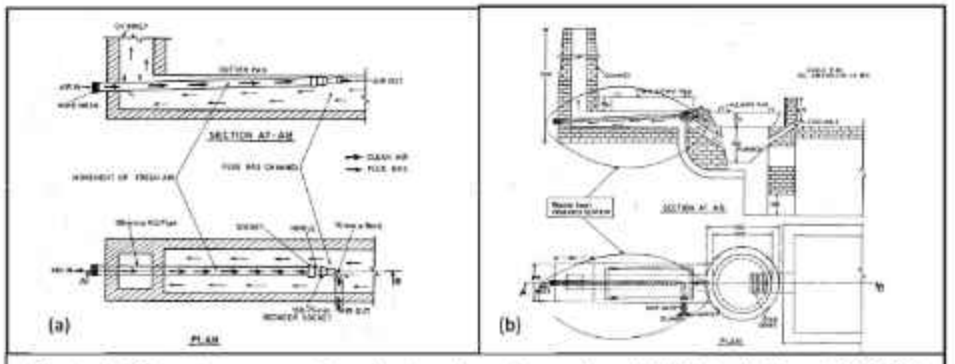


Fig 3: (a) Counter-current type heat exchanging unit and (b) installation of WHRS in IISR 2-pan furnace

Working of WHRS

During furnace operation, blower of WHRS is also operated which sucks fresh air through the pipe. Since the whole pipe is surrounded by hot flue gases, the air moving in it also gets heated. A bend was purposely kept at a position where flue gases come out of combustion chamber and becomes very hot. Air takes a sharp turn at bend where maximum heat transfer takes place. As a result, clean heated air is obtained.A temperature rise of 30oC was obtained at full blower speed at steady-

state conditions. This heated air can effectively be utilized for bagasse/jaggery drying and/or space conditioning (Anwar,2008a, Anwar, 2008b).

Efficiency Boosting Device (EBD)

Flames, which are formed during bagasse combustion in jaggery furnaces, drift towards flue gas opening and many of these flames do not even touch pan bottom. Therefore, heat energy is wasted. A device, which can direct flame towards pan bottom and also make turbulence for increased heat transfer will useful for more effective utilization of energy. Therefore, an Efficiency Boosting Device (EBD) has been conceptualized for forcing flames towards pan bottom. Also air supplied through EBD would help in has been conceptualized. The air supplied through this device would also help in complete combustion of unburnt gases, which would have otherwise gone as waste.

A miniature model of EBD was developed (Anwar, 2015). It consisted of components like G.I. nipples, sockets, tee, cross tee and bends (Fig.4&5). Holes (4 mm dia.) were drilled at specific locations for exit air. The size of efficiency booster was kept matching with a pan of 203 mm diameter. This was installed on a wood stove at such a height that it does not affect normal fuel feeding and was connected to a hand blower with suitable attachments. This was kept close to the pan bottom so that air coming out of holes would be able to strike pan bottom.

The unit was tested through water boiling test and it was observed that it required lesser time for water to reach boiling point. More turbulence in flames was also observed, which helped in more heat transfer. Lesser quantity of fuel was consumed with EBD and it had positive effect on all the performance parameters.

Further nipples were provided on 4 mm holes for directing flames and hot air towards pan bottom for more heat transfer. Nipples of 20 mm length and 4 mm diameter were provided. The unit was tested and compared against the unit with simple holes of 4 mm diameter and the results are summarized in table 2:

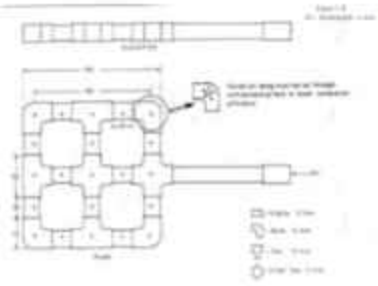


Fig 4:Line diagram of miniature model of EBD



Fig.5. Miniature model of EBD

Table 2: Comparison of EBD with 4 mm holes and nipples

Parameter	EBD with only 4 mm holes	EBD with nipples	Per cent increase/decrease
Water evaporated, kg	1.96	2.16	10.20 (increase)
Evaporation/kg fuel, kg	0.75	0.82	9.33 (increase)
Fuel consumed/kg water evaporated, kg	1.33	1.22	8.27 (decrease)
Time requirement/kg water evaporation, hours	0.36	0.34	5.56 (decrease)

The performance of EBD further improved with nipples of 4 mm diameter and 20 mm length. Hence based on above results, scale-up model of efficiency boosting device suitable for IISR 2-pan furnace has been developed.

Scale-up model of EBD

A scale-up model of the EBD has been developed and installed in IISR two-pan jaggery furnace. The performance of EBD was evaluated in combination with WHRS (Anon, 2020). Both systems were connectedthrough pipes and gate valves were provided for control of air flow. Performance of furnace was evaluated in terms of water evaporated per unit of bagasse consumed, bagasse consumed per unit ofwater evaporated, water evaporated per unit time, heat utilization efficiency (HUE) etc.With EBD fully open - WHRS half open, HUE and net energy gain (NEG) were 30.4%and 2.03 MJ/h respectively and with EBD fully open - WHRS fully open, HUE andNEG were found to be 28.2% and 4.82 MJ/h respectively. Overall system efficiency ofEBD fully open - WHRS half open and EBD fully open - WHRS fully open systemwere found to be 30.67% and 28.67% respectively. However, maximum heat utilization efficiency(33.32%) was achievedby using EBD alone. In this way all these efforts if used in combination are bound to improve system efficiency in terms of bagasse and time saving and improvement in jaggery productivity.

References

Roy SC. 1951. Monograph on the gur industry of India. ICSC, New Delhi

Anwar, S.I. 2017.Experimental identification of best fin configuration for pans of jaggerymaking furnace. In: E-Souvenir-cum-Proc. SOLARIS-2017, pp. 410-414.

Anonymous. 2005-06. Annual Report of Indian Institute of Sugarcane Research, Lucknow, pp.54.

Anwar, S.I. 2010a.Fuel and energy saving in open pan furnace used in jaggery making through

modified juice boiling/concentrating pans. Energy Conversion and Management 51, 360364.

Anwar, S.I., Singh, J. 2010. Modified pans for open pan jaggery furnace.Operation manual no.AE/10/01.

Anwar, S.I. 2010b. An experimental study for optimizing fins provided to jaggery pan for improved efficiency. In: Energy Conversion and Management. S.K. Shukla and J.V. Tirkey(Eds). Narosa Publishing House, New Delhi, 191-196.

Anwar, S.I. 2008a.Waste Heat Recovery from Open Pan Heating System. In: Processing, Handling and Storage of Sugarcane Jaggery. IISR, Lucknow, pp 76-78.

Anwar, S.I. 2008b. Waste heat recovery system for open pan jaggery furnaces. Agricultural Engineering Today. 32(4): 19-22.

Anwar, S.I. 2015.Improving thermal efficiency of open pan jaggery furnaces - A novel concept. Indian J of Sugarcane Technology, 29(1), 32-34.

Anonymous. 2020. Annual Report of Indian Institute of Sugarcane Research, Lucknow, pp.58.

An Empirical Study on Drip Irrigation System in Babina Block Jhansi Districts U.P.

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Abstract

Land and water are the basic needs for agriculture and economic development of the country. According to International Water Management Institute (IWMI), one-third of the world's population will face absolute water scarcity by the year 2025. Agriculture consumes more than 80% of the country's exploitable water resources. The overall development of the agriculture sector and the intended growth rate in GDP is mostly dependent on the judicious use of the available water resources. Hence, the Scheme based on Micro Irrigation (MI), which aims at increasing the area under efficient methods of irrigation viz. drip irrigation.Drip irrigation is an efficient method of providing irrigation water directly into soil at the root zone depth of the plants and thus, minimizes the conventional losses such as deep percolation, runoff and soil erosion etc. It also permits the utilization of fertilizers, pesticides and other water-soluble chemicals along with irrigation water resulting in higher yields and better-quality of produce. Drip irrigation system is regarded as solution for many of the problems in dry land agriculture and improving the efficiencyin irrigated agriculture also. Keeping all these in view, the present study was designed to study the extent of benefits derived from drip irrigation in horticultural crops and also to identify the constraints encountered by farmers in adopting the drip irrigation for horticultural crops. The results revealed that majority of drip irrigation farmers had expressed the advantages like saving of water, saving in labourcost for irrigation, increased yield, water saving, labour saving, increased quality of produce, reduced weed growth, extended self-life of produce and also uniform application of water. The constraints encountered by the farmers had, problem of non-availability of quality material, no follow up services provided by drip agencies, high initial investment cost, lack of capital to cover maximum holding under drip irrigation, delay in sanction of loan, leakage in the present drip system. Hence, it is clear from the study, drip irrigation agencies, financing institutions and also to supply adequate standard spare parts and other appropriate measures to ensure the satisfactory situation for proper adoption of drip irrigation method.

Keywords: -Water scarcity, Scheme on Micro Irrigation, Drip irrigation, Dry land agriculture, Irrigated agriculture

Introduction

Water and land are essential for farmers and the nation's prosperity(E.Sathyapriya et.al 2024). A third of the world's population will experience complete water scarcity by 2025, according to the International Water Management Institute (IWMI). The rapid expansion of agriculture, which uses more than 80% of the nation's usable water resources, has been attributed to irrigation. Effective utilization of the available water resources is essential to the overall expansion of the agriculture sector and the targeted GDP

growth rate. As a result, the federal government, the state governments, and various local and foreign nongovernmental organizations (NGOs), are actively encouraging micro irrigation technology across India by offering various forms of institutional, financial, and technical support systems.The main motivations behind the promotion of these technologies are to improve the food and nutritional security of rural communities and also to raise income and drop in poverty and to conserve water in irrigated agriculture. Increasing the area under effective irrigation techniques, such as drip irrigation, is the goal of this Micro Irrigation (MI) scheme. By effectively supplying irrigation water directly to the plants root zone.Drip irrigation reduces traditional losses such soil erosion, runoff, and deep percolation(Haimanote K. Bayabil et.al 2023).Products with higher yields and superior quality from soluble chemicals and irrigation water. Drip irrigation methods are therefore thought to be a solution to a lot of dry land farming issues and to increase the productivity of irrigated agriculture. Numerous programs are being put into place to encourage drip irrigation in the right direction. Therefore, it is essential for drip irrigation farmers to understand the advantages and limitations of the system in order to increase its efficiency. In light of these factors, the current study was conducted to determine the extent of the advantages to that of drip irrigation offers horticulture crops as well as the obstacles that farmers face when implementing drip irrigation.

Methodology

The present study was conducted Jhansi district of Uttar Pradeshthe expost -facto research design was used for the study. A sample consisting of 30 drip irrigation farmers were selected randomly from the purposely selected five villages of Babina block like Badanpur,Baghora, Dhikhauli, Dagariya and Budpurawhere in maximum area of horticultural crops is irrigated by drip method. The questionnaire was developed keeping the objectives of the study in the background, presented in non - sampling area and then employed for collecting the required data from the respondents. Which given the study area.

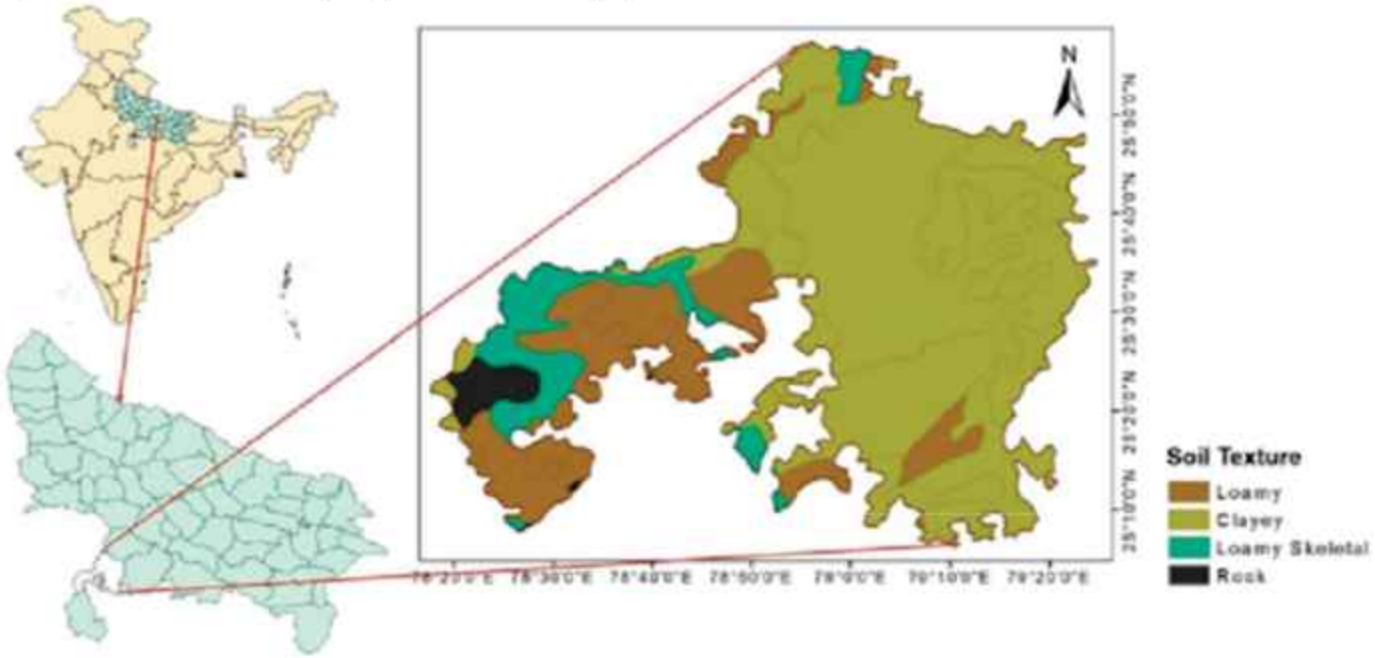


Fig 1: Location of the study area map of the soil type

Geographical and climates Conditions of Jhansi: -

Jhansi is located at 25.4333 N 78.5833 E. It has an average elevation of 284 meters (935 feet). Jhansi lies on the plateau of central India, an area dominated by rocky relief and minerals underneath the soil. The city has a natural slope in the north as it is on the south western border of the vast Tarai plains of Uttar Pradesh and the elevation rises on the south. The land is suitable for species of citrus fruit and crops include wheat, pulses, peas, and oilseeds. The region relies mostly on monsoon the rains for irrigation purposes. Under an ambitious canal project (the Rajghat canal), the government is constructing a network of canals for irrigation in Jhansi and Lalitpur and some part of Madhya Pradesh. The trade in agricultural produce based products (including grain and oilseeds) has of great economic importance. The city is also a center of manufacturing of brassware. Being on a rocky plateau, Jhansi experiences extreme temperatures. Winter begins in October with the retreat of the southwest monsoon (Jhansi does not experience any rainfall from the Northeast Monsoon) and peaks in mid-December. Temperatures are about 4 °C or 39.2 °F minimum and 21 °C or 69.8 °F maximum. Spring arrives by the end of February and is a short-lived phase of transition. Summer begins by April and summer temperatures can reach its peak at 47 °C or 116.6 °F in May. The rainy season starts by the third week of June (although this is variable year to year), while the monsoon rains gradually weaken in September and end before the last week of September. In the rainy season, the average daily high temperature hovers around 36 °C or 96.8 °F with high humidity.

Components of Micro Drip Irrigation System

Irrigation system applies water in low volumes uniformly along with the fertilizers onto or into the soil near the plant root zone. This involves several components. These are the network of pipes (main line, sub mains, laterals), emitting device called as drippers or emitters, control head consisting of pumps, filters and fertigation units; and other accessories such as valves, gages etc. The main line delivers water from water source with the help of pumping device or elevated water tank to the sub main and the sub mains to the laterals. The emitters which are attached to the laterals deliver water onto or into the soil for irrigation.Emitters arethe end device of the drip irrigation system.

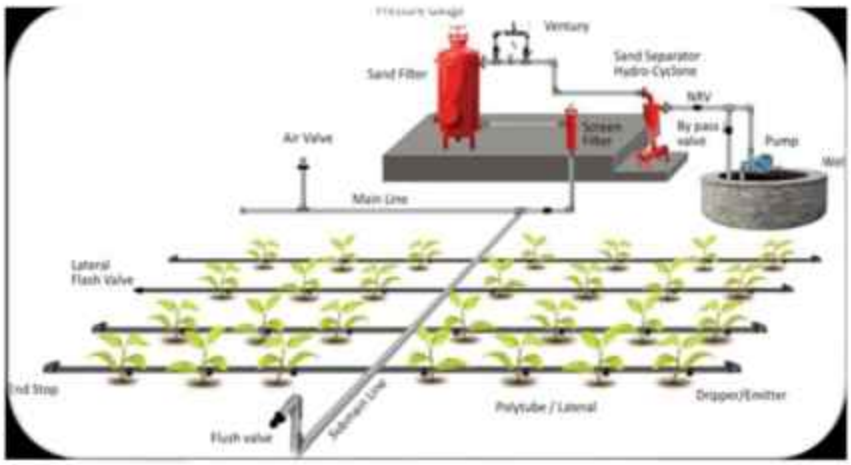


Fig 2:Components of Drip irrigation method

Pumping unit

The submersible pump was used to lift the water from ground water well to operate the micro-drip irrigation system to irrigate the garlic crop as per the irrigation schedule.

Water tank and pipes:

Water tanks are containers that store water for various uses, and pipes are used to move water into and out of the tanks. Water is fed into the tank through the inlet pipe, and distributed through the outlet pipe, with a silt stop on the outlet pipe to remove sediment to avoid choking of dripper

horticulture crop.

Lateral, submain and main:

Pipes of mainlines are usually made of poly vinyl chloride (PVC) or high-density polyethylene (HDPE). HDPE pipes can be installed inside or above ground, as they are impregnated with carbon black that provides protection against UV. The nominal working pressure of pipes has to be higher than that of the submain/drip laterals. The pipes of diameter 50 mm or above and the pressure rating of more than 4 kg/cm2 are used for mainline. Submains are installed underground (PVC or HDPE) or above ground (HDPE only.) The pipes of diameter 32 mm or above and the pressure rating of more than 2.5 kg/cm2 are used for sub mainline. Laterals are made of low-density polythene.Laterals usually haveinner diameters in the range of 12 to 20 mm with wall thickness varying from 1 to 3 mm. The wall thickness is made to withstand pressure more than 2 kg/cm2 depending on the requirement in horticulture crop.

Emitters

Emitters, the core of micro irrigation system or made of plastic material. The design of production of high-quality drippers is comprised of delicate and complicated process. Water passes through the emitters and need to be delivered at constant and low with the desired uniformity. The emitters are designed to dissipate pressure and yield low discharge which does not vary significantly because of minor differences in pressure head.



Fig 3:Types of on-line drippers

The Flow Characteristics of the Emitters: -

The flow characteristics of the emitters are presented by the following equation.

$$Q=KP^{x} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where,

Q = emitter discharge (Lh-1)

k = a constant of proportionality that characterize each emitter

P = working pressure head at the emitter (m)

x= the emitter discharge exponent that is characterized by the flow regime.

The lower the value of x, the less discharge will be affected by pressure variations. In fully turbulent flow x=0.5 and in laminar flow x=1.0. Non compensating orifice and nozzle emitters are

always fully turbulent with x = 0.5 and x =0.0 for fully compensating emitters. However, the exponents of long path emitters may range anywhere between 0.5 and 1.0.

Peak Crop Water Requirement

The design of drip irrigation system needs the information on the peak water requirement, however while the system is in operation, the water requirement during the specified irrigation interval is required. Water requirement of crops is a function of plants, surface area covered by plant, evapotranspiration rate. Crop water requirement is calculated for each plant and the water requirement of the whole area is estimated based on the water

requirement per plant and total number of plants. The daily water requirement for fully grown plants can be calculated as under:

$$V = ET_o \times K_c \times W_p \times A \quad \text{.....(2)}$$

Net volume of water to be applied (Vn)

$$V_n = V - R_e \times W_p \times A \quad \text{.....(3)}$$

Number of daily operating hours of the system (T)

$$T = \frac{V_n}{q \times N_e \times W_p} \quad \text{.....(4)}$$

Where

V =Volume of water required, L
ET_0= Reference crop evapotranspiration, mm $day-1$
Kc = Crop coefficient
A = Area occupied by a plant (row to row spacing x plant to plant spacing), $m2$
R_e = Effective rainfall, mm
W_p = Wetting fraction (varies from 0.2 for wide spaced crops and 1.0 for close spaced crops)
N_e = Number of emitters per plant
N_p= Number of plants q = Emitter discharge, L $h-1$
q = Emitter discharge, L $h-1$

Computation of Discharge of Lateral, Sub Main and Main : -

Flow carried by each lateral line ($Q1$)= Discharge of one emitter × No. of emitters per lateral Flow carried by each sub main line ($Q2$) = $Q1$ × No. of lateral lines per sub main

Flow carried by main (Q) = $Q2$ × No. of sub main line.

The diameter of the main, sub main and laterals are chosen based on the hydraulics of pipeflow.

Computation of Frictional Head loss of Lateral, Sub Main and Main lines

The pipes used in micro irrigation system are made of plastics (PVC) and considered as smooth pipe. The pressure drop due to friction or frictional head loss can be evaluated with the help of Hazen -William empirical equation as.

$$h_f = 10.67 \times \frac{L \times Q^{1.852}}{C^{1.852} \times D^{4.87}} \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Where:

hf = head loss due to friction (meters)

L = length of the pipe (m)

Q = flow rate (m^3/s)

D = internal diameter of pipe (m)

C = Hazen-William's roughness coefficient (dimensionless), Value of C for PVC pipes is considered as 140

Horsepower Requirement of Pump

The horsepower requirement of pump is computed by following equation

$$P = \frac{H \times Q_m}{75 \times n_m \times n_m} \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where,

P = power required in HP

H = total pumping head, m
Q_m = Discharge of main line
n_p = Efficiency of pump,
n_m = Efficiency of motor

Calibration of the micro -drip system

Calibrating a micro-drip irrigation system (commonly used for high-value crops like garlic) ensures each dripper delivers the correct amount of water. This is crucial for uniform growth, avoiding under- or over-watering. Calibration of dripper are done by catch cans method.

Average rate of discharge of dripper: -

Collecting water from emitters into containers (catch cans) over a measured period to determine the actual discharge rate.

$$\textbf{Flow rate } \left(\frac{L}{hr}\right) = \frac{\textbf{Volume collected (L)}}{\textbf{Time (hours)}} \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Emission Uniformity: -

Karmeli and Keller (1975) proposed the 'emission uniformity' as the measure for the performance evaluation of the drip irrigation system. Primary objective of the good drip irrigation system is to provide sufficient water or discharge to adequately irrigate the least watered plant or area (Dr. K N Tiwari Dr. N S Raghuwanshi). Therefore, the relation between the minimum and average emitter discharge within the subunit of the system is most important factor and is designated by the emission uniformity. EU is given by Equation.

$$\mathbf{EU = 100 \times \left[1 - \frac{1.27\, C_v}{\sqrt{n}}\right] \times \frac{q_m}{q_{avg}}} \quad \text{.....(8)}$$

Where,

EU =Emission Coefficient of micro-Drippers, per cent.

C_V= the manufacture's coefficient of variation

n = number of emitters per plan

q_m= the minimum emitter discharge at a minimum pressure in the section L/hr

q_{avg}= the average or design emitter discharge for the section, L/hr

Results and discussion

Collected information wereanalyses and results are presented in the following table.

Table 1: Benefits of drip irrigation

S. No.	Benefits of Drip irrigation farmers	No. expressing the advantages	
		Number (n= 30)	Per cent (%)
1	Saving of water	25	90.33
2	Saving of labour cost for irrigation	21	75.33
3	Uniform application	28	92.00
4	Improved quality of produce	19	68.67
5	Easy method of irrigation	22	80.70
6	Decreased weed growth	23	69.00
7	Increased crop yield	24	78.67

The above table revealed that majority of the respondents opined that saving of water (93.33 %) is major benefit of drip irrigation and followed by Uniform application (90.00 %), Easy method of irrigation (86.67 %), Increased crop yield (76.67 %), Saving of labour cost for irrigation (73.33 %), Decreased weed growth (70.00%) and Improved quality of produce (66.67 %).Constraints encountered by the drip irrigation growers

The constraints encountered by the farmers had possessed the problem of non-availability of quality material, no follow up services by drip agencies, high initial investment cost, lack of capital to cover maximum holding under drip irrigation and delay in sanction of loan, leakage in the present drip system.

Conclusions

1. The Benefits encountered by the farmers are saving of water,
2. Uniform application and easy method of irrigation and the constraints are problem of

non-availability of quality material and no follow up services by drip agencies.

3. It is clear from the study that the drip irrigation agencies, financing institutions and also to supply adequate standard spare parts and other appropriate measures to ensure the satisfactory situation for proper adoption of drip irrigation method.

Reference

1. Dr. K N Tiwari Dr. N S Raghuwanshi book,Irrigation Engineering
2. E.Sathyapriyaet.al (2024),An Empirical Study on drip Irrigation Dindigul district of Tamilnadu India
3. Haimanote K. Bayabilet.al (2023), IFAS extension university of Florida Basic Tips for Designing Efficient Irrigation Systems doi.org/10.32473/edis-ae539-2020
4. https://edis.ifas.ufl.edu
5. Jhansi, India page "Fallingrain.com retrieved 3 September 2012"
6. Kandaswamy. P., 1990. Drip irrigation need for more scientific research for large scale adoption. Kisan World, 17: 31-32.
7. Moore, W. G. (1971) The Penguin Encyclopedia of Places. Harmondsworth: Penguin; p. 371.
8. M. Patil, S. M., 1990. Drip irrigation very successful in Banana too. Kisan World, 17: 28-29.
9. Shivakumar, H. K., Ramachandrappa, B. K., Nanjappa, H. V .and Roopadevi, V. D., 2001. Micro irrigation macro future. Agro India, 5: 18-19.
10. The macMillan encyclopaedia: rev. ed . Landon: Macmillan, 1983 pp647.

Shifting of Traditional Agricultural Technology to AI-Driven Technology for Enhancing Agricultural Production and Sustainability

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Abstract

The agricultural sector is undergoing a profound transformation as traditional machinery is increasingly being replaced by advanced technologies driven by artificial intelligence (AI). This shift aims to enhance agricultural productivity by improving efficiency, precision, and sustainability. This paper delves into the integration of AI within agricultural machinery, focusing on its potential to optimize a variety of farming processes, including planting, irrigation, pest control, and harvesting. By harnessing the power of data analytics, machine learning, and automation, AI-enabled machinery can provide real-time insights and tailored solutions that address specific agricultural needs. The research presents case studies that highlight successful implementations of AI technologies in agriculture, showcasing significant improvements in crop yield, resource management, and labor productivity. However, the adoption of AI in agriculture is not without its challenges. Various obstacles, such as high initial costs, the necessity for specialized training, and the need for robust infrastructure, can deter farmers from integrating these technologies. Financial constraints particularly affect smallholder farmers who may lack access to capital, while the rapid pace of technological advancement necessitates ongoing education for agricultural workers to effectively utilize new tools. Moreover, the paper emphasizes the importance of collaboration among diverse stakeholders, including farmers, technology developers, and policymakers, to establish a supportive ecosystem for the successful integration of AI in agriculture. Policymakers can create incentives for technology adoption, invest in research and development, and ensure that farmers have access to necessary resources and training. The significance of adopting AI-driven machinery extends beyond productivity enhancements; it represents a strategic approach to addressing the growing global food demand amid climate change and resource scarcity. As the world's population continues to rise, the pressure on agricultural systems to produce more food with fewer resources intensifies. AI technologies can help optimize resource use, reduce waste, and improve overall sustainability in farming practices. In conclusion, embracing AI technologies in agriculture presents a promising pathway toward a more efficient, productive, and sustainable future, ultimately contributing to the broader goal of sustainable development while safeguarding the environment for future generations.

Keywords: AI technologies, agricultural productivity, sustainability, automation, precision farming.

Introduction

The agricultural sector is undergoing a profound transformation as traditional machinery is increasingly being replaced by advanced technologies powered by artificial intelligence

(AI). This shift is largely driven by the need to boost productivity, improve resource efficiency, and ensure environmental sustainability in response to mounting global challenges. According to the Food and Agriculture Organization (FAO, 2021), the world's agricultural systems must become significantly more efficient and sustainable to meet future food security goals. With the global population projected to reach nearly 10 billion by 2050, food production will need to increase by approximately 70% to meet rising demand (World Bank, 2023).

Conventional farming methods, while historically effective, are now struggling to keep pace with these demands. AI presents a promising solution by enabling farmers to make data-driven decisions, automate labor-intensive tasks, and adapt to changing environmental conditions. Technologies such as machine learning, predictive analytics, and autonomous equipment are being integrated into key agricultural operations including planting, irrigation, pest management, and harvesting (Zha et al., 2020). As of 2023, around 25% of large-scale farms in developed countries have adopted some form of AI or precision agriculture technology (Statista, 2023). These technologies enhance productivity by providing real-time insights and tailored solutions that improve input use and crop performance.

AI also plays a crucial role in promoting sustainable farming practices. Precision agriculture enables farmers to apply water, fertilizers, and pesticides more accurately, reducing environmental impact and conserving resources (Adewusi et al., 2024). Furthermore, with the agricultural workforce aging and labor shortages becoming more common, AI-powered automation (such as drones and autonomous tractors) helps maintain productivity while reducing dependence on manual labor (Khan et al., 2021).

By equipping farmers with advanced tools and analytics, AI fosters greater resilience in agricultural systems, allowing them to respond effectively to climate change, fluctuating markets, and limited natural resources. To ensure successful adoption, it is essential to foster collaboration among farmers, technology developers, and policymakers. Creating supportive policies, offering financial incentives, and investing in education and infrastructure will key to building a sustainable, AI-driven future in agriculture (Wolfert et al., 2017).



Fig 1: Automatically monitoring & controlling farm

Need

The shift towards AI-driven technology in agriculture is driven by several pressing factors. Firstly, the global population is expected to approach 10 billion by 2050, which will require a significant boost in food production to meet the rising demand. Traditional farming practices often fall short in efficiency and resource management, making it challenging to keep pace with this growth. Climate change presents substantial threats to agricultural productivity. Unpredictable weather patterns and extreme climatic conditions can severely impact crop yields, creating uncertainty for farmers. AI technologies have the capability to process and analyze large datasets, offering valuable insights that enable farmers to make informed decisions. By leveraging these insights, farmers can better navigate the challenges posed by climate variability, ultimately helping to safeguard their harvests.

The agricultural sector is facing labor shortages, a situation worsened by urban migration and an aging workforce. As fewer individuals enter the farming profession, there is an increasing need for automation and intelligent systems that can take over tasks traditionally performed by human laborers. AI-driven machinery can fill this gap, enhancing productivity and allowing farmers to maintain operations despite a dwindling labor pool. The transition to AI-driven agricultural machinery is essential for addressing the challenges of a growing population, climate change, and labor shortages. By adopting these advanced technologies, the agricultural sector can improve efficiency, enhance productivity, and ensure a more sustainable future for food production. Embracing AI not only helps meet current demands but also prepares the industry for the complexities of tomorrow's agricultural landscape.

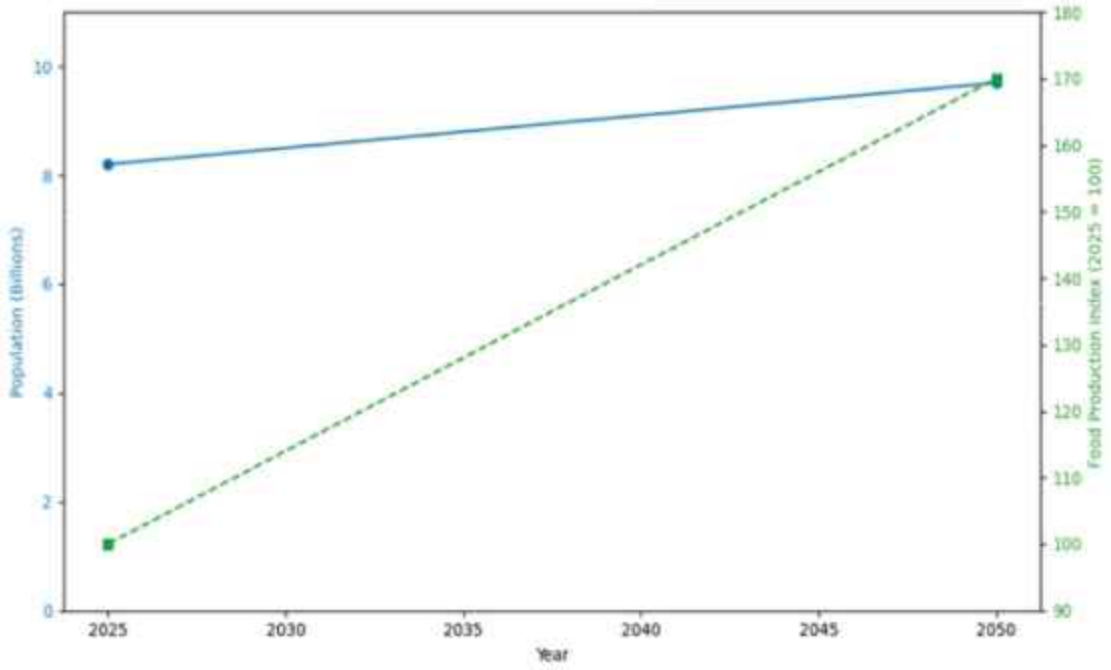


Fig 2: Projected World Population vs. Required Food Production Increase (2025-2050)

Benefits

The benefits of shifting to AI-driven technology are manifold. Firstly, these technologies enhance operational efficiency by automating repetitive tasks, allowing farmers to focus on strategic decision-making. AI systems can analyze data from various sources, such as soil sensors and weather forecasts, to optimize planting schedules, irrigation, and fertilization, leading to increased crop yields and reduced resource waste. Secondly, AI-driven machinery promotes sustainable farming practices by minimizing the use of chemicals and water, thereby reducing the environmental impact of agriculture. Additionally, the integration of AI can lead to improved pest and disease management, as predictive analytics can identify potential threats before they escalate. Ultimately, these advancements contribute to a more resilient agricultural system capable of meeting future food demands.

Some key benefits of AI-driven Technology

- Improved Efficiency: Streamlines operations, reduces the need for manual labor, and enhances the utilization of resources.
- Boosts Yield and Quality: Continuous monitoring facilitates better crop health and superior quality.
- Resource Preservation: Reduces the unnecessary use of water, fertilizers, and pesticides.
- Risk Management: Predictive analytics assist in addressing risks associated with weather fluctuations and pest infestations.
- Remote Management: Empowers farmers to oversee their operations from any location.
- Encouragement of Innovation and Collaboration: Promotes teamwork and drives ongoing advancements within the agricultural industry

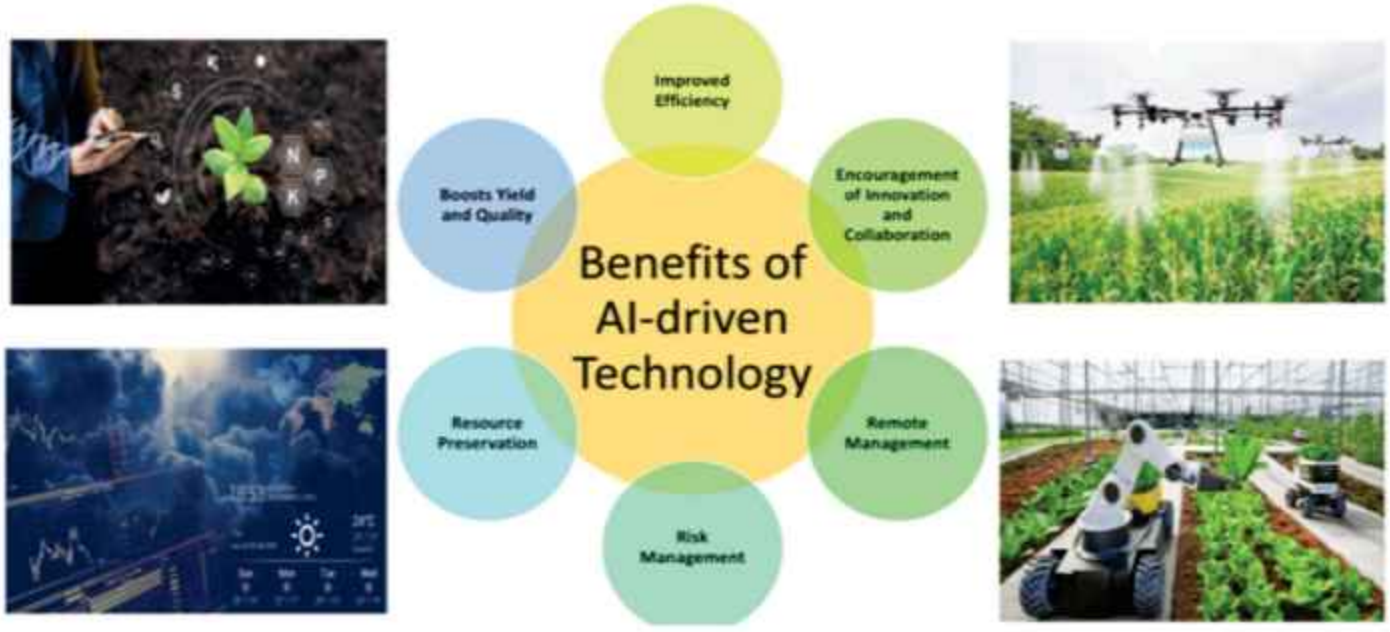


Fig 3: Benefits of AI-driven Technology

Table 1:Comparison of Traditional vs. AI-Driven Agricultural Operations		
Metric	**Traditional Farming**	**AI-Driven Farming**
Yield Increase	-	+20–30%
Water Use Efficiency	Low	+40% improvement
Fertilizer Use Reduction	-	-15 to 20%
Labor Requirement	High	-25 to 50%
Crop Monitoring Frequency	Monthly	Real-time

Challenges

Despite the significant promise of AI-driven technology in agriculture, several challenges impede its broader adoption. A primary hurdle is the high initial investment required for advanced technologies, which can be a financial burden for small and medium-sized farms. Additionally, many farmers may face a considerable knowledge gap, lacking the technical skills necessary to effectively operate and maintain AI systems.



Fig 3: Challenges for AI-driven Technology

Infrastructure challenges, especially in rural regions, can further complicate the implementation of these technologies. Moreover, concerns about data privacy and security, along with fears of job displacement, contribute to resistance among various stakeholders in the agricultural sector. Addressing these issues is crucial for facilitating the transition to AI-driven solutions and ensuring that all farmers can benefit from the advancements in agricultural technology.

Table 2: Barriers to AI Adoption among Farmers (Survey of 100 Farmers in India, (2025)	
Challenges	**% Farmers Reporting**
High Initial Investment	72%
Knowledge Gap	61%
Infrastructure Challenges	54%
Job Displacement Fear	38%
Data Privacy & Security Concerns	29%

Conclusion

The agricultural industry stands at a critical juncture where the adoption of AI-driven technologies can significantly enhance farming practices. By optimizing operations, improving crop yields, and promoting sustainable practices, this transition not only addresses the immediate challenges faced by the sector but also lays the groundwork for a more resilient and efficient future in food production. As we move forward, it is essential for stakeholders across the agricultural value chain to embrace these innovations and work collaboratively towards a sustainable and food-secure future.

The transition from traditional agricultural machinery to AI-driven technologies represents a pivotal moment in the evolution of farming practices. By addressing the pressing challenges of food production, climate change, and labor shortages, AI-driven machinery offers a pathway to enhanced agricultural efficiency and sustainability. While obstacles to adoption remain, the potential benefits far outweigh the challenges, making it imperative for stakeholders in the agricultural sector to embrace this technological shift. As we move forward, collaboration among farmers, technology developers, and policymakers will be essential to ensure that the transition is equitable and beneficial for all, ultimately leading to a more productive and sustainable agricultural landscape.

References

Adewusi, A., Zhang, Y., & Li, X. (2024).Enhancing sustainability in agriculture through AI-driven precision farming: A review of emerging trends and challenges. Journal of Smart Agriculture, 9(2), 101-115. https:// doi.org/ 10.1234/ jsa. 2024. 00902

Adib, B. R., &Kausik, M. A. K. (2024).AI revolutionizing industries worldwide: A comprehensive overview of its diverse applications. Hybrid Advances, 7, 100277. https://doi.org/10.1016/j.hybadv.2024.100277

Adinarayana, S., Raju, M.?G.,Srirangam, D.?P., Prasad, D.?S., Kumar, M.?R., &Veesam, S.?B. (2024). Enhancing resource management in precision farming through AI based irrigation optimization. In A.?Dey, S. Nayak, R.?Kumar, & S.?N. Mohanty (Eds.), How Machine Learning Is Innovating Today's World (pp.?221-251). Wiley.https:// doi.org/ 10.1002/ 97813942 14167.ch15

FAO. (2021). The state of the world's land and water resources for food and agriculture - Systems at breaking point. Food and Agriculture Organization of the United Nations.https:// doi.org/ 10.4060 /cb9910en

Hemathilake, D.?M.?K.?S.,&Gunathilake, D.?M.?C.?C. (2022). Agricultural productivity and food supply to meet increased demands. In R. Bhat (Ed.), Future Foods: Global trends, opportunities, and sustainability challenges (pp.?539-553). Academic Press.https://doi.org/10.1016/B978-0-323-91001-9.00016-5

Khan, R., Mehmood, T., & Ali, M. (2021).The role of artificial intelligence in transforming agriculture: A review of recent developments. Computers and Electronics in Agriculture, 188, 106321.https://doi.org/10.1016/j.compag.2021 .106321

Mahmud, M.?S.?A.,Abidin, M.?S.?Z., Emmanuel, A.?A., &Hasan, H.?S. (2020). Robotics and automation in agriculture: Present and future applications. Applications of Modelling and Simulation, 4, 130-140. Retrieved from https://arqiipubl.com/ojs/index.php/AMS_Jour nal/article/view/130

Statista.(2023). Adoption rate of artificial intelligence in agriculture among large-scale

farms in developed countries in 2023.https://www.statista.com/statistics/ai-adoption-in-agriculture/

Subeesh, A., & Mehta, C. R. (2021).Automation and digitization of agriculture using artificial intelligence and Internet of Things.Artificial Intelligence in Agriculture, 5, 278-291. https://doi.org/10.1016/j.aiia.2021.11.004

Talaviya, T., Shah, D., Patel, N., Yagnik, H., & Shah, M. (2020).Implementation of artificial intelligence in agriculture for optimisation of irrigation and application of pesticides and herbicides.Artificial Intelligence in Agriculture, 4, 58-73. https://doi.org/10.1016/j.aiia. 2020.04.002

World Bank. (2023). Agriculture and food: Overview. https:/ / www.worldbank.org /en/topic/agriculture/overview

Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M.-J.(2017). Big data in smart farming - A review.Agricultural Systems, 153, 69-80. https://doi.org/10.1016/j.agsy.2017.01.023

Zha, Y., Yang, Y., & Wu, H. (2020).Application of artificial intelligence in agriculture: A comprehensive review. AI in Agriculture, 4, 1-10. https://doi.org/10.1016/j.aiia.2020.12.001

inside a naturally ventilated polyhouse and to study the general suitability for growth of hydroponically grown crop during the summer season (Mid-march to Mid-June).

2.0 Methodology

The study was conducted in a naturally ventilated polyhouse located at Dr. NTR College of Agricultural Engineering, Bapatla, Andhra Pradesh, India at latitude 15°53'47" N and longitude 80°27'37" E. The polyhouse was constructed facing the east, which lets the wind movement from south to north. The dimensions of the polyhouse are 20m * 12m and 2.5m height. The walls of polyhouse were made of HDPE (High Density Poly Ethylene) Monofilament Yarn of 50 mesh size and the covering material was greenhouse film of 200-micronpolyethylene.

The NFT systems were placed inside the polyhouse in a pattern of 4*4 (rows*columns). The data of microclimate was collected at four corners of the polyhouse, at the center of the polyhouse and outside the polyhouse as presented in Fig. 1. The data of microclimate includes the data of temperature, relative humidity, light intensity and carbon dioxide concentration. The temperature-relative humidity data were collected using a temperature and humidity data logger (Extech Division 42280 Temperature and Humidity Datalogger). The data of light intensity was collected using a digital lux meter (Mextech Light Meter LX-102). The amount of carbon dioxide present in the air was determined using a gas analyzer (Felix Instruments, F-950 Three Gas Analyzer). The data was collected for 3 months April, May and June.The microclimatic data at various location at four different time intervals of 8.30 AM, 12.30 PM, 4.30 PM and 8.30 PM was collected on a daily basis, and imported to MS Excel. The weekly averages of each parameter at each point were calculated.

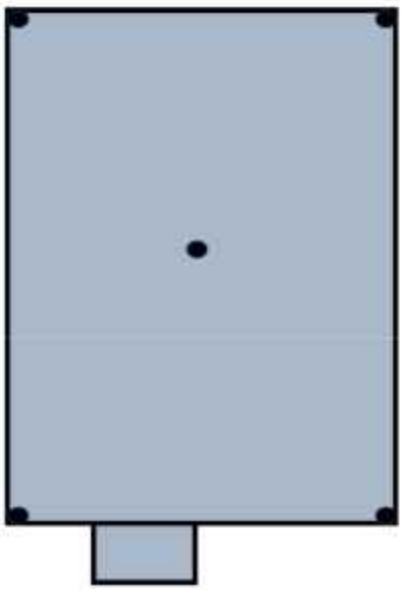


Fig 1: Data collection

3.0 Results and Discussion

The data was collected and analyzed for 3 months from Mid-march to Mid-June i.e. a total of 13 weeks and are used to understand how the microclimate varied from one corner to other in a naturally ventilated polyhouse.

3.1 Temperature

The weekly average values of temperature at the corners, center and outside the polyhouse at different time intervals were represented in Fig. 2. It was observed that during the crop season, the outside temperature was higher than inside temperatures of the polyhouse. The highest weekly mean morning temperature was recorded in week 7 (33.74 ^{0} C) outside the polyhouse. The lowest morning temperature was noted in week 9 (30.17 ^{0}C) at south east corner. The weekly average temperatures raisedup to week seven. In all the weeks, in the morning, north-east corner and north-west corner have lower temperatures. The deviation of temperatures was highest from north east corner to the center in week 3.

In the afternoon, highest temperature was observed in week 14 (38.67 ^{0}C) outside the polyhouse. The temperatures inside the polyhouse are low due to shade nets and operation of foggers. Inside the polyhouse, the temperatures were high at center parts. The north west corner experienced lower temperatures followed by north east corner. In the afternoon, lowest outside temperature (35.79 ^{0}C) was observed in week 3. It was noted that the evening temperatures reached their lowest point in week 2 (31.13 ^{0}C) and highest point in week 7 (35.07 ^{0}C) in the North-East corner. The highest deviation of temperature between the center of the polyhouse and outside the polyhouse (0.66 ^{0}C) was observed in week 8. It was also observed that, center of the polyhouse has the highest temperatures in week 11 (34.26 ^{0}C) and week 13 (34.28 ^{0}C).

In the night time the average temperaturefell down and lowest night temperature was recorded in week 2 (27.52 ^{0}C) in the center of polyhouse. It was observed that up to week 7, South-West corner exhibited higher temperatures. A maximum deviation of 0.46 ^{0}C was observed in week 2 between the outside temperature and temperature at the center of the polyhouse.From the above findings, it was concluded that during the crop season, the outside temperature was higher than inside temperatures of the polyhouse with shade nets and the operation of foggers. Singh et al., (2018) also reported that the foggers operated to reduce the high temperatures during the summer season were more effective in combination with shade nets.

3.2 Relative Humidity

The weekly average values of relative humidity at the corners (Fig. 3). From the plot, it was observed that the highest relative humidity (99.36%) was observed at the center of the polyhouse. The lowest value was observed in week 11 in the South-East corner (70.53%). The maximum deviation of relative humidity (7.25%) between the center and outside the polyhouse was noted in week 11. The maximum deviation between the center and south-west corner (17.67%) was observed in week 8. It was observed that highest relative humidity was observed at the center of the polyhouse throughout the season. The highest relative humidity of 67.36% was observed in week 12. The lowest value of relative humidity was observed outside the polyhouse in week 14 (46.32%). South-West corner was noted to have high values of relative humidity following the center of the polyhouse. The highest variation of humidity from the center of the polyhouse to outside was observed as 17.29% in week 1.

In the evening, highest relative humidity (80.03%) was observed in week 3 as presented. The lowest relative humidity was recorded in week 11 in the North-West corner (64.14%). The lowest values of relative humidity were measured in North-West corner up to week 11. The highest relative humidity during night was observed at the center of the polyhouse closely followed by the corners. Lowest values were observed outside the polyhouse followed by South-West corner. From the above observations, it was concluded that the variability of humidity can

be attributed to the variation in temperature across the polyhouse, operation of foggers, wind velocity and air flow distribution in the polyhouse. Roy and Boulard (2004) reported the same.

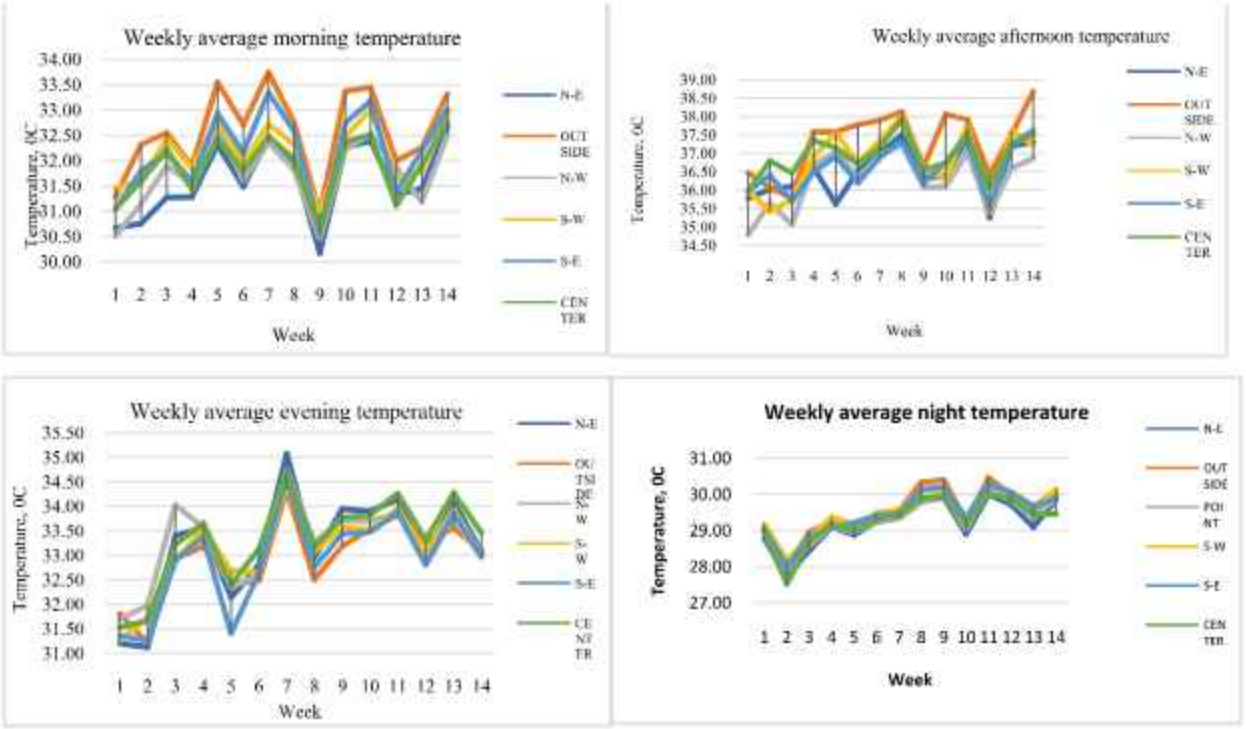


Fig2: Weekly average temperature s at different diurnal times

3.3 Light Intensity

The weekly average values of light intensity at the corners, center and outside the polyhouse at different time intervals were represented in Fig. 4. It was observed that, the lowest values of light intensity were observed in center of the polyhouse. The highest light intensity was observed in week 11 (4.31 Klx) outside the polyhouse. Inside the polyhouse, highest light intensity was observed in North-East corner (28.93Klx) in week 2. Inside the polyhouse, lowest light intensity (1.83 Klx) was recorded at the center of the polyhouse in week 7. After week 4, the corners of the polyhouse exhibited similar light intensity values due to the erection of shade nets. In the afternoon, lower values of light intensity were observed in the center and south-east corner of the polyhouse. Inside the polyhouse, North-East corner marked the highest light intensity (30.39 Klx) in week 3. The lowest values were marked as 56.30 Klx and 5.99 Klx outside and the South-East corner of the polyhouse respectively. It was observed that from week 4, south-west corner exhibited high light intensities inside the polyhouse.

The highest light intensity (38.0 Klx) outside the polyhouse was observed in week 2. Highest light intensity inside the polyhouse (12.86 Klx) was recorded in south-west corner in week 4. The lowest light intensity was observed in week 2 inside the polyhouse at south-east corner (2.62 Klx). The lowest deviation of light intensity between the south-west corner and center of the polyhouse was recorded as 1.99 Klx in week 1. In week 7, highest deviation was marked as 8.73 Klx between the center and south-west corner of the polyhouse. It was concluded that the variability of the light intensity was attributed to the orientation of polyhouse, the position of sun and the provision of shade nets. It was supported by Gupta et al., (2020).

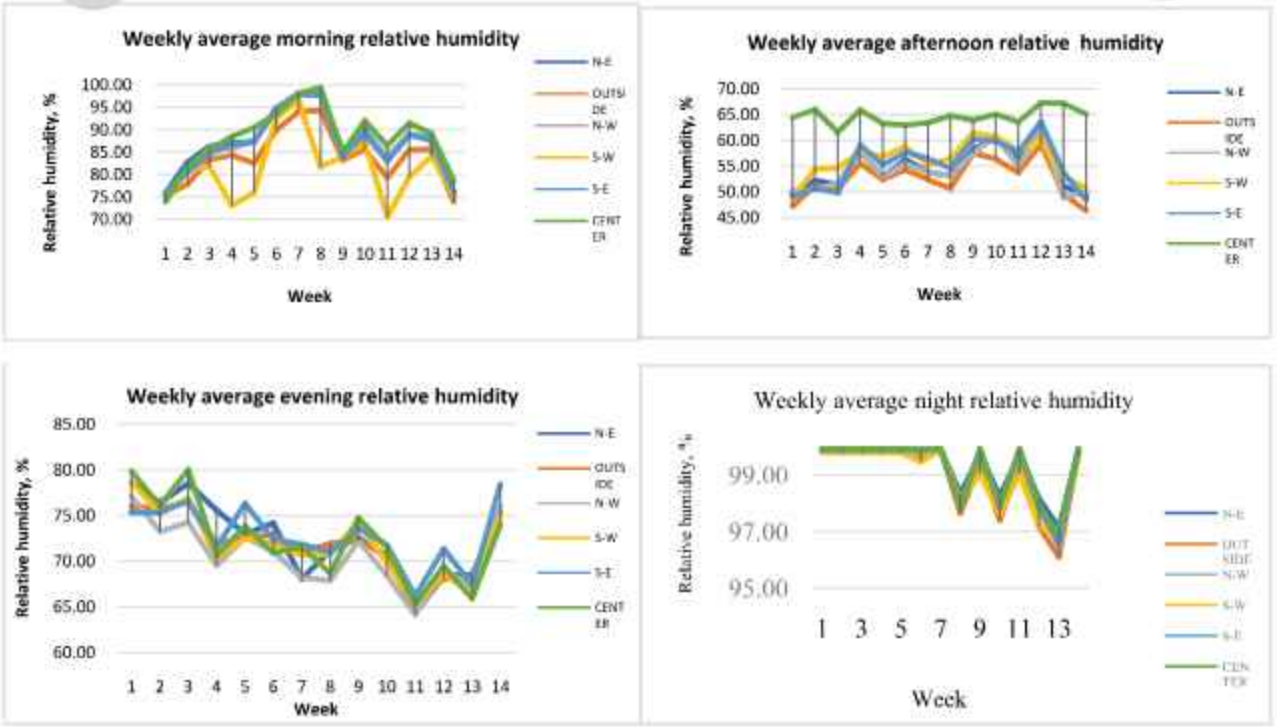


Fig3: Weekly average relative humidity at different diurnal times

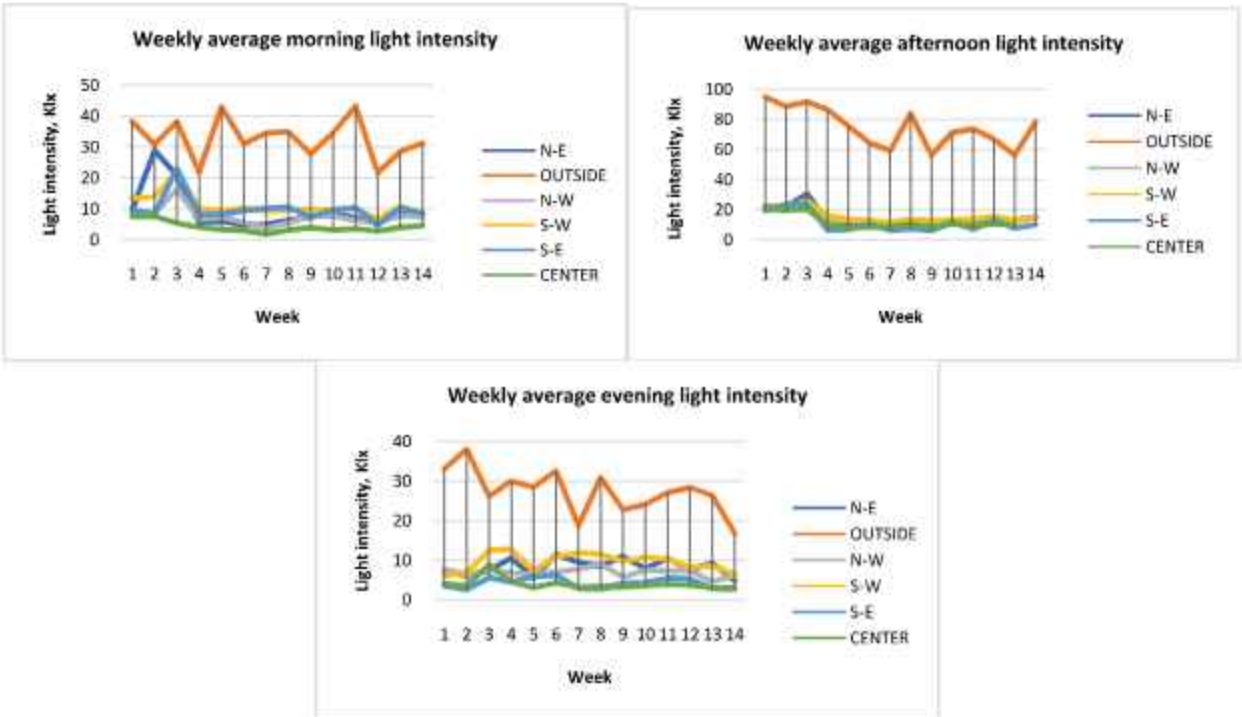


Fig4: Weekly average light intensity at different diurnal times

3.4 CO_2 Concentration

It was observed that the carbon dioxide concentration inside the polyhouse was higher than that of outside. This can be explained as the effect of crop presence inside the polyhouse. The weekly average values of CO_2 concentration at the corners, center and outside the polyhouse at different time intervals were represented in the following graphs from Fig. 5.

The carbon dioxide concentration had higher values in center except in week 13. The lowest values were observed outside the polyhouse. The highest CO_2 concentration (0.20%) was observed in week 8 at the center of the polyhouse and week 13 in south-west corner. the lowest concentration of CO_2 was observed as 0.17% recorded in south-west corner of the polyhouse in week 1. In the afternoon, the highest value of carbon dioxide concentration was recorded as 0.19% in week 14 at the center of the polyhouse. It was noted that the north-east, north-west and south-east corners of the polyhouse followed a similar trend of variation. The south-west corner varied heterogeneously exhibiting maximum and minimum values in some weeks. The variation of CO_2 followed the similar trend as in the afternoon. Higher values were recorded at the center of the polyhouse. The highest value was marked as 0.19% observed in week 12 and week 14 at the center of the polyhouse. In week 2, it was observed that all the corners of the polyhouse and the external environment recorded the lowest of 0.16% with center at 0.17% of carbon dioxide concentration. The carbon dioxide concentration in the night time varied across the polyhouse. The lowest value (0.17%) was recorded in week 14 in the south-east corner of the polyhouse. The highest value was recorded in week 9 at the center of the polyhouse as 0.21%. Highest variation was observed in week 14 as 0.04% with maximum and minimum values marked in the south-west and south-east corners of the polyhouse respectively.

The CO_2 concentration was high inside the polyhouse compared to that of outside represented the process of crop respiration in the absence of sunlight. It was concluded that the CO_2 concentration decreased from morning to evening. Parazoo et al., (2011) also reported that the observed variability, as seen from the spatial and temporal distribution of atmospheric CO_2, is highly correlated with the space and timescales of weather systems.

From the above results, it was concluded that there exists variation in the microclimate parameters inside a naturally ventilated polyhouse due to the action of wind and local conditions. The same was reported by Villagranet al. (2021) that inadequate final conditions are generated with a heterogeneous spatial distribution with the presence of factors that depend directly on wind direction and speed. The heterogeneous spatial distribution will affect the uniformity of growth and development of crops (Ma et al., 2019 a, b and Saberian and Sajadiye, 2019).

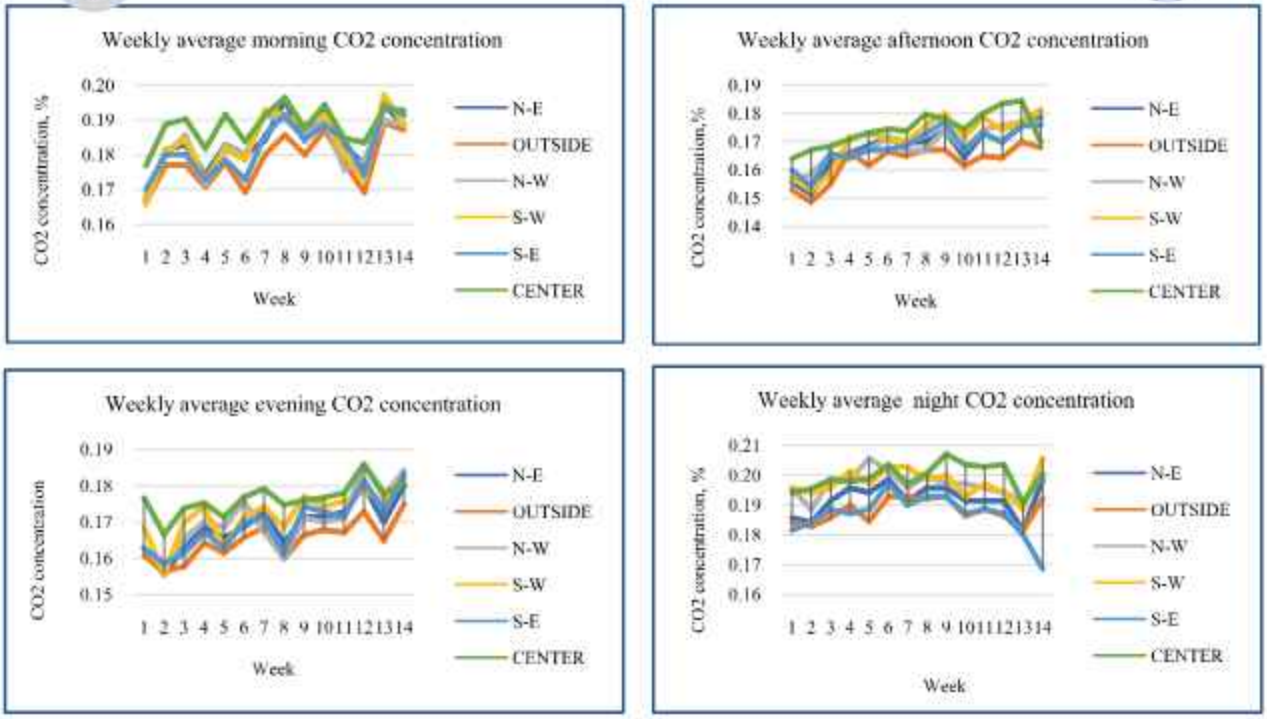


Fig 5: Weekly average CO_2 concentration at different diurnal times

Conclusion

The current study was carried out to analyze the spatial variability of the microclimate inside the greenhouse. In the present study, the data related to the microclimate was recorded during the summer season, from 15-03-2024 to 15-06-2024. The variation in microclimate parameters was then represented using line plots. From the plots, it was observed that the temperature and relative humidity varied inversely proportional to each other. It was observed that the microclimate inside a naturally ventilated polyhouse varied from one corner to other and from corners to the center which has a direct impact on crop growth. It can be concluded that, the spatial and temporal variation of microclimate inside a polyhouse effect the uniformity and quality of the crop production. This study looks at how the climate inside a polyhouse changes in different areas and its ability to affect the development of crop.

4.0 References

Challa, L.P., Singh, C.D., Rao, K.V. and Kumar, M., 2022. Micro-Climatic Variations in Naturally Ventilated PolyhouseUnder Cucumber Cultivation. Indian Journal of Ecology, 49(6), pp.2194-2201.

Ganesan, M., 2002.Effect of poly-greenhouse on plant micro climate and fruit yield of tomato.Karnataka Journal of Agricultural Sciences, 15(4), pp.750-752.

Gupta, D., Santosh, D.T and Debnath, S. 2020. Modeling and simulation application for greenhouse microclimatic studies and structural analysis.Maitra, S., Gaikwad, DJ, Shankar, T (eds.). Protected Cultivation and Smart Agriculture.300-312.

Lee, C.K.; Chung, M.; Shin, K.Y.; Im, Y.H.; Yoon, S.W.A study of the effects of enhanced uniformity control of greenhouse environment variables on crop growth. Energies 2019, 12, 1749

Ma, D., Carpenter, N., Amatya, S., Maki, H., Wang, L., Zhang, L., Neeno, S., Tuinstra, M.R and Jin, J. 2019a. Removal of greenhouse microclimate heterogeneity with conveyor system for indoor phenotyping. Computers and electronics in agriculture . 166, p.104979.

Ma, D., Carpenter, N., Maki, H., Rehman, T.U., Tuinstra, M.R and Jin, J. 2019b. Greenhouse environment modeling and simulation for microclimate control. Computers and electronics in agriculture . 162: 134-142.

Mashonjowa E, Ronsse F, Milford JR, et al. (2013).Modelling the thermal performance of a naturally ventilated greenhouse in Zimbabwe using a dynamic greenhouse climate model.Solar Energy. 91: 381–393.

Pattnaik RK and Mohanty 2021.Protected cultivation: importance, scope, and status. (3): 18-21.

Parazoo, N.C., Denning, A.S., Berry, J.A., Wolf, A., Randall, D.A., Kawa, S.R., Pauluis, O and Doney, S.C. 2011.Moist synoptic transport of CO_2 along the mid-latitude storm track. Geophysical Research Letters. 38(9).

Roy, J.C and Boulard, T. 2004. CFD prediction of the natural ventilation in a tunnel-type greenhouse: Influence of wind direction and sensibility to turbulence models. In International Conference on Sustainable Greenhouse Systems-Greensys2004 691: 457-464.

Saberian, A and Sajadiye, S.M. 2019. The effect of dynamic solar heat load on the greenhouse microclimate using CFD simulation. Renewable Energy. 138: 722-737.

Singh, M.C., Singh, J.P., Pandey, S.K., Cutting, N.G., Sharma, P., Shrivastav, V and Sharma, P. 2018. A review of three commonly used techniques of controlling greenhouse microclimate.International Journal of Current Microbiology and Applied Sciences . 7(1): 3491-3505.

Sojitra, M.A., Satasiya, R.M., Rank, H.D., Chauhan, P.M., Parmar, H.V. and Patel, D.V., 2023. Study the micro climatic parameter in protected structure. Environment and Ecology. 41 (2A): 953—960

Suay, R., López, S., Granell, R., Moltó, E., Fatnassi, H. and Boulard, T., 2008, October.Preliminary analysis of greenhouse microclimate heterogeneity for different weather conditions. In International Workshop on Greenhouse Environmental Control and Crop Production in Semi-Arid Regions 797 (pp. 103-109).

Umesha, B. 2011.Effect of weather parameters on growth and yield parameters of tomato under natural poly house.Indian Journal of Natural Sciences International .976: 0997.

Villagrán, E., Flores-Velazquez, J., Bojacá, C and Akrami, M. 2021.Evaluation of the microclimate in a traditional Colombian greenhouse used for cut flower production. Agronomy. 11(7): 1330.

Smart Solutions in Food Systems: The Role of Carbon Dots in Food Safety and Preservation

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Carbon dots, which are the products of natural and chemical origin having unique structural and functional properties, are becoming a new revolution in the field of nanotechnology in food safety and preservation. These quasi-spherical nanoparticles are suitable in the food industry because they are highly photostable, water soluble and are low toxic. Due to high sensitivity and specificity, they are able to detect chemical and biological contamination in food, thus, real-time monitoring of food adulteration and spoilage can be achieved by quick detection. Their strong fluorescent properties give greater ability to develop intelligent packaging that may sense a change in pH or the addition of spoiling agents to indicate the freshness and quality of food by a change of visible colour. Carbon dots are applied in conferring antioxidant and antimicrobial agents to coating agents and biodegradable packaging materials in food preservation. This enhances the shelf life of perishable products by reducing oxidative spoilage on top of inhibiting the growth of microorganisms. In conclusion, the incorporation of carbon dots into food systems is a new, eco-friendly technique to enhance food safety, shelf life and ensure food quality which can also potentially change the existing food preservation and monitoring approaches.

Key words: Carbon dots, food safety, real-time monitoring, food preservation

1. Introduction

Food safety is a non-negotiable aspect of public health: foodborne illnesses annually affect millions and cause significant mortality, economic loss and undermine consumer trust. In addition to the immediate risks of illness, ongoing low-level contamination and spoiling cause significant postharvest food loss and waste, which can amount to as much as one-third of the world's food production. Inefficient preservation reduces shelf life, makes cold chains more necessary, and significantly reduces food security, particularly in environments with limited resources.

Existing strategies: including refrigeration, canning, chemical preservatives and conventional packaging, offset spoilage and contamination but present new risks. Chemical additives can cause allergies, change flavour, leave residues, and exacerbate unfavourable customer perceptions. Physical techniques, such as heat and radiation, may degrade sensory qualities or nutritional value. Conventional pathogen detection uses laborious, centralised procedures. In contrast, packaging rarely offers real-time quality feedback and significantly adds to the environmental plastic waste problem. The rapidly changing landscape of food systems calls for more sensitive, sustainable and responsive solutions.

Data-driven packaging, intervention, and monitoring are used by smart food systems to dynamically maintain product quality. Through advancements in material science,

biofunctionalization, and sensor technology, nanotechnology creates opportunities for targeted antimicrobial activity, accurate contaminant detection, and intelligent packaging. Because of their remarkable fluorescence, surface chemistry, biocompatibility, and potential for green synthesis, carbon dots (or CDs), a recent addition to the toolbox of nanomaterials, have shown particular promise.

This review presents a thorough, in-depth viewpoint on the role of CDs in improving food safety and preservation by synthesising a large body of literature.It elaborates on fundamentals, recent developments, limitations, regulatory and safety aspects and future trends.

Carbon dots (CDs) are quasi?spherical particles comprising amorphous to crystalline lattice with a diameter of less than 10 nm. They have a sp2/sp3 conjugatedcore and contain appropriate oxygen content in the form of a variety of oxygen? containingsubstances such as aldehyde, carboxyl and hydroxyl groups(Ma et al., 2024).

2. Evolution of carbon dots

The evolution of carbon dot involves three distinct stages (I) the discovery stage ofCDs (2004-2006), (?) the initially developing stage of CDs (2007-2011) and (III) the explosively developing stage of CDs (2011-now).

Stage (?) refers to the initial time when CDs were named and defined. CDs was first reported and described as "fluorescent nanoparticles" by Xu et al. in 2004 during the purification of single walled carbon nanotubes through preparative electrophoresis. The term "carbon quantum dots" was defined formally by Sun et al. in 2006.

In stage (?), major existing fabrication strategies were explored using carboncontaining materials as precursors to generate CDs. Interestingly, it was found that the optical and electrochemical properties of CDs can occur by varying the experimental parameters. In addition, the potential application of CDs in various fields began to gain more attention.

In stage (III), there was an exponentially increasing number of publications about CDs since around 2011. Large-scale synthetic strategies of CDs were reported for reducing the cost of making the CDs (Li et al., 2021).

3. Classification of carbon dots

The carbon dots are classified as follows:

3.1 Graphene Quantum Dots (GQDs)

These are ultra-small fragments generally possessing a single or a few layers of graphene. Their distinctive electronic and optical properties are caused by quantum confinement and edge effects that are conferred by their structures' notable crystallinity and distinct edge sites.

3.2 Carbon Quantum Dots (CQDs)

This group is characterized by nearly spherical, highly crystalline carbon nanoparticles. Because of their quantum-sized core and surface effect interactions, CQDs usually show strong photoluminescence and well-resolved lattice fringes.

3.3 Carbon Nanodots (CNDs)

Generally amorphous or weakly crystalline on the inside, carbon nanodots are quasi-spherical particles. In contrast to CQDs or GQDs, their photoluminescence is primarily caused by functional groups or surface defects rather than an ordered sp2 carbon core.

3.4 Carbonized Polymer Dots (CPDs)

These are a more recently developed class of polymers in which polymer precursors undergo partial carbonisation and cross-linking to form hybrid structures. CPDs retain polymer chains or fragments on their surfaces, resulting in enhanced stability, uniform sizeand tunable emission. Both

the carbonised core and the surface polymer components influence their characteristics.

3.5 Carbon Oxide Dots (Oxidized Carbon Dots)

Carbon dots in this subgroup have a lot of oxygen-containing groups, which makes them more soluble in water and gives them more reactive sites for modification.

4. Sources for synthesis of carbon dots

CDs can be synthesized from a large number of precursor materials both from natural and chemical sources. Various sources are shown in table. The properties of CDs rely on source materials used for synthesis.They exhibit lower photoluminescence when prepared from chemical sources. Natural sources are more popular for synthesis of CDs because they are biodegradable, consists of biopolymers such as cellulose, hemicelluloseand proteins(Moradi et al., 2023).

Table 1: Sources of carbon dots and their methods of synthesis

Source Type	Examples	Typical Methods
Simple Chemicals	Citric acid, glucose, ascorbic acid	Hydrothermal, microwave, pyrolysis
Biomass/Waste	Orange peel, coffee grounds, rice husk	Hydrothermal, green synthesis
Polymers	Starch, cellulose, chitosan	Solvothermal, pyrolysis
Bulk Carbon	Graphite, carbon nanotubes, coal	Laser ablation, arc discharge
Microbial Sources	Yeast, bacteria, algae	Hydrothermal, green synthesis

5. Synthesis of carbon dots

The synthesis of CDs can be achieved by one of the two strategies, i.e., either by top-down or by bottom-up approaches. In the former case, carbonaceous materials are electrochemically, chemically or physically dissected into small nano-sized fragments; whereas the latter approach involves either carbonization of small organic molecules or stepwise integration of small aromatic compounds (Mansuriya and Altintas, 2021).

5.1 Top-Down approach

Currently, macroscopic carbonaceous materials including activated carbon, CNTs and graphite are being extensively employed for the production of CDs by carbon electrode are deposited on cathode. It poses the challenge of purifying CDs from mixture. First time CDs are observed when CNTs are synthesized by arc discharge method. Top-down approaches such as arc discharge method, laser ablation method, ultrasonic treatment and electrochemical methods. Nonetheless, these techniques are generally conducted under conditions such as high acidity, high potential, as well as high energy. Due to such harsh conditions, these top-down methods are relatively tedious, in comparison to the bottom-up approaches.

5.1.1 Arc discharge method

In arc discharge method, electric current is passed between graphitic electrodes with 1 mm or less spacing under inert argon atmosphere. CDs generated from vaporization of carbon electrode

are deposited on cathode. It poses the challenge of purifying CDs from mixture. First time CDs are observed when CNTs are synthesized by arc discharge method.

5.1.2 Laser ablation method

A high-energy laser pulse is used in the laser ablation process to irradiate the bulky carbonaceous material into a thermodynamic environment that generates high temperatures and pressures. This results in increased heat and the formation of plasma by evaporation. Subsequently, the generated vapor is converted into CDs by a crystallization process. Laser ablation itself produces CDs without photoluminescence. It gives CDs only when used carbonaceous suspension in different solvents.

5.1.3 Ultrasonic method

In this method, ultrasound waves with low and high pressures generate small vacuum bubbles and distribute them uniformly throughout the solution. As a consequence, it prevents aggregation and results in the strong hydro-dynamic shear force and rapidinfringement of the liquid jets. By employing the energy generated via ultrasonic technique, large-sized carbon-based nanomaterials like graphite, activated carbon and CNTs can be dissected into nanosized CDs.

5.1.4Electrochemical/chemical oxidation method

The most popular technique for creating CDs is electrochemical/chemical oxidation because of its benefits. Under normal pressure andtemperature, the CDs are electrochemically or chemically synthesized via oxidation/reduction reactionsStrong oxidising agents like nitric acid (HNO3), sulphuric acid (H2SO4) and hydrogen peroxide (H2O2) are used in it.The surface of CDs can be functionalized with hydrophilic groups such as -NH2, -COOH, -OH, etc., by regulating the redox reactions and the electrolyte components. The electrolytes and the electrode materials are crucial, because they have the ability to produce CDs with distinct features in terms of their fluorescence emission, cytotoxicity and surface states.

5.2. Bottom-Up approach

Bottom-up approaches are currently trending owing to their advantages such as promising practical applicability, involvement of non-toxic precursor molecules, cost effectiveness, easy instrumentation and their precise control and convenient methodology.

5.2.1 Thermal method

Thermal decomposition is one of the most preferable methods for the synthesis of CDs, which involves the carbonization or pyrolysis of the large-sized carbonaceous precursors under higher temperatures. Pyrolysis can be used to develop carbon nanomaterials from smaller carbon sources such as organic molecules and polymers because high energy generated leads to fusion of molecules during carbonization.

5.2.2 Microwave-Assisted method

Since microwaves contain a wide range of electromagnetic waves from 1 mm to 1 m, they offer accelerated energies for the decomposition of the chemical bonds that exist in precursor molecules. The microwave-assisted method is relatively easy, highly affordable and quite rapid with less reaction times and produces uniform heat for the homogeneous distribution of CDs.

5.2.3 Hydrothermal method

Synthesis of CDs by hydrothermal carbonization (HTC) technique is non-toxic, environment-friendly and inexpensive. It involves the reaction of organic solvents as the precursors and their sealing in a hydrothermal reactor under higher temperatures andpressures. The HTC technique can be used to create CDs from a variety of raw

materials, including proteins, glucose, citric acid, chitosan and others, as precursors.

5.2.4 Template method

Synthesis of CDs using the template method involves two steps, i.e.,

(i) calcination of the desired CDs in a suitable template or mesoporous silicon spheres and

(ii) etching step for the removal of supports.

6. Characterization of carbon dots

The goal of characterising carbon dots is to comprehend their optical, chemical, and physical characteristics. These include determining the kinds of functional groups that are present on the surface of the particle as well as assessing its size, shape, and internal structure. One important factor in determining their applicability is their optical behaviour, specifically their fluorescence emission and absorption properties. Other significant parameters examined during characterisation include surface charge and stability in various environments. The performance and biocompatibility of carbon dots in applications pertaining to food safety and preservation are determined by these attributes taken together. Different techniques used for characterization of CDs are mentioned in table 2.

7. Features of CDs and their applications in different fields

CDs offer a unique array of exceptional features such as tunable optical properties, good biocompatibility, low-to-negligible cytotoxicity, affordable cost, excellent water solubility, ease of preparation and large specific surface area which enable their applications in various engineering and biomedical fields. The attractive merits of CDs have sparked an immense interest across a wide range of applications, including the anti-counterfeiting, biomedicine, catalysis, sensing, photovoltaic devices, packaging, and light emitting diodes as shown in fig. (Oladzadabbasabadiet al., 2023).

Table 2: Techniques used for characterization of CDs

Type of technique	Specifications
Microscopic and Diffraction techniques	
Scanning Electron microscopy (SEM) and Transmission Electron Microscopy (TEM)	Size, size distribution, morphology
Atomic Force Microscopy (AFM)	2D, 3D images from surface morphology
X-ray Diffraction (XRD)	Crystalline properties
Particle Size Analyzer (PSA)	Size, size distribution
Dynamic Light Scattering (DLS)	Hydrodynamic particle size
Spectroscopic techniques	
Ultraviolet-visible (UV-vis) and Photoluminescence (PL) spectroscopy	Optical specifications

Fourier Transform Infrared spectroscopy (FTIR)	Surface functional groups
Raman Spectroscopy (RS)	Purity and size
Energy Dispersive Spectroscopy (EDS)	Elemental composition
Nuclear Magnetic Resonance (NMR)	Surface functionality
Mass spectrometric techniques	
Matrix-Assisted Laser Desorption / Ionization Time-Of-Flight Mass Spectrometry (MALDI-TOF MS)	Surface functionality

8. Applications of carbon dots in food preservation

CDs can be derived from natural resources like food by-products, animal and plant origins and microbial sources or from synthetic organic compounds. CDs based food applications include edible coatings, protective packaging, active and intelligent packaging and food additives as mentioned in fig. 7. These approaches help enhance food safety, shelf-life and quality and helps in sustainable food preservation (Moradi et al., 2023).

8.1 Coating Agent

Edible coatings on the surface of foods could control enzymatic browning, water loss and gas exchange and inhibit microbial spoilage through forming a semi-permeable barrier. Coating increases shelf-life and helps in long term storage of fresh foods. In general polysaccharides, proteins, lipids are used as lipid coatings. As efficient coating agents, carbon dots (or CDs) have drawn interest. The following points can be used to explain how they work as coating agents:

Antimicrobial activity: CDs generate Reactive Oxygen Species (ROS) and disrupts membrane and DNA of microorganisms.

Antioxidant properties: CDs act as antioxidants by scavenging free radicals, prevents oxidation reaction.

Barrier properties:

Oxygen and Moisture Barrier: CDs slow down permeability by creating a convoluted path for gas or moisture diffusion when they are integrated into polymer matrices (such as chitosan, starch, or polyethylene). This forces oxygen (O2) and water vapour (H2O) molecules to take a longer, indirect path. The hydroxyl (-OH) and carboxyl (-COOH) surface functional groups on CDs create hydrogen bonds with water molecules, which decreases the flow of free water and increases coatings resistance to moisture.

UV-Blocking Properties: Particularly when doped with elements such as sulphur (S-CDs) or nitrogen (N-CDs), CDs exhibit exceptional UV absorption capabilities. They prevent UV-induced deterioration of food packaging materials by absorbing harmful UV rays when applied as coatings.

Biocompatibility and safety: Functional groups (hydroxyl (-OH), carboxyl (-COOH) and amino (-NH?)) make CDs water-dispersible and minimise aggregation, which guarantees their compatibility with food and biological systems. CDs that have been functionalised exhibit improved stability and decreased cytotoxicity.

Eskalenet al. (2020) studied the effect of CDs as

coating agent which are fabricated from rosemary leaves as a carbon source by hydrothermal method. The banana storage experiment was conducted for the qualitative evaluation of the antioxidant ability. Three bananas were used as pure (no additive), PVA coated, and CDs + PVA coated. All the bananas were unripe and in greenish-yellow colour The difference between the CDs + PVA and PVA additive became apparent day after day. Although the PVAcoated banana surface became rough, the CDs + PVA-coated banana surface became negatively affected on the ninth day of the experiment. On the 19th day of the experiment, the untreated banana had turned black in colour, the PVA-coated banana was also mostly black in colour, while the CDs + PVA covered banana was in the best condition compared to the others.

8.2 Protective Food Packaging

Food packaging is crucial to preserving the product's quality and safety throughout the entire production, processing, shipping, and storage processes. Plastic materials like polystyrene, polypropylene, polyethylene terephthalate are using in food packaging to protect from contamination and convenient for transportation. This packaging cannot completely provide protection from environmental influences, so it cannot fully guarantee the safety and quality of food. These are non-biodegradable plastics causing serious ecological problems and environmental pollution by nano plastics fragments. It is necessary to shift to biodegradable and low toxic materials. Researchers are exploring the carbon dots in application of protective packaging and conducting the experiments to find the mechanical properties. The mechanical, water barrier effects of CDs had demonstrated in various kinds of packaging materials, including soy protein isolate (SPI), PVA, chitosan and carboxymethyl cellulose (CMC). SPI has the characteristics of satisfactory film-forming ability, natural degradability and easy availability. However, apart from the good filmforming capacity, excessive water sensitivity is a major hindrance, which limits the acceptance of SPI based plastics on a commodity basis. To minimize the water uptake and to increase the mechanical properties of SPI based materials, CDs are incorporated to make film.

Rani et al. (2020) synthesized amine and carboxyl functionalized CDs. Citric acid glycine (CCG) and citric acid polyethylenimine (CPI) have a diameter range of 2 to 4 nm.The tensile strength and tensile modulus of CPI and CCG incorporated SPI films increased and water uptake was decreased when compared with SPI films alone.

8.3 Active Food Packaging

Currently, the food packaging field has developed a class of active packaging, which is not only a passive container but extends the shelf-life of food. When CDs are incorporated in biopolymer, the CDs interact with the microbial membrane, triggering several antimicrobial mechanisms.

Physical Interaction with the Membrane: When the nanoparticle-biopolymer composite sticks to the microbial membrane, it damages the lipid bilayer and increases permeability.

ROS Generation and Oxidative Stress: Superoxide anion (O2-), hydrogen peroxide (H2O2), and hydroxyl radicals (HOo) are examples of reactive oxygen species (ROS) that are produced and lead to (i) Lipid peroxidation, which weakens the bacterial membrane.

(ii) Protein denaturation, affecting cellular functions (iii) DNA damage, inhibiting replication and transcription.

Disruption of Electron Transport Chain (ETC): When nanoparticles obstruct the ETC in bacterial

cells, oxidative stress and electron leakage result. Bacterial metabolism is weakened as a result of decreased ATP production.

Enzyme Inactivation: Important cellular functions can be disrupted by metal ions or reactive oxygen species (ROS) deactivating vital enzymes.

Inhibition of Biofilm Formation: By inhibiting the formation of biofilms, the composite lowers bacterial adhesion and colonisation.

Internalization into the cell: Certain nanoparticles have the ability to enter bacterial cells and harm them inside.

Leakage of cell content & cell death: Bacterial death and cell lysis are the results of severe membrane damage.The overall combined effect of these individual mechanisms results in loss of cell viability, inhibition of microbial growth and eventually cell death (Omerovic et al., 2021).

8.4 Intelligent Packaging

The intelligent feature of packaging is that it does not change the product's properties, but it can monitor the status of the product, packaging, or packaging environment. Food changes can be seen before consumption with the aid of intelligent packaging, which makes use of the communication capabilities of the packaging system to keep an eye on the food's surroundings or condition.Currently, the main indicators of intelligent packaging systems are biosensors, pathogen indicators, gas indicators, freshness indicators, and time-temperature indicators. Among them, freshness indicators can provide feedback on the freshness of food products in packaging systems. To the end, the indicator changes colour as food spoils and microbial metabolites grows during storage. The CQD has a pH response function through protonation and deprotonation of functional groups on the surface.

Using hydrothermally produced glucose-derived carbon dots, Khan et al. (2024) created a pH-responsive, ammonia-sensitive food packaging indicator to track the quality of prawns and fish.The key spoilage signals in proteinrich meat products and seafood are biogenic amines, which correlate closely with meatvalue measures, including pH and total volatile basic nitrogen (TVB-N) concentration. Additionally, the formation of nitrogenous chemicals by microbial activity can increase the pH value of meat samples during storage.

9. Cytotoxicity of carbon dots from various sources

The source, size, and surface chemistry of carbon dots (or CDs) all affect their cytotoxicity. At higher concentrations, synthetic or metal-doped CDs may cause oxidative stress and cell damage, whereas green-synthesized CDs made from plant or food waste typically exhibit low toxicity. The ease with which smaller CDs can enter cells raises questions regarding bioaccumulation. By employing benign functional groups for surface passivation, biocompatibility is enhanced. To determine their long-term safety in food systems, more in vivo research is necessary.

10. Regulatory environment for food applications of nanomaterials

Global regulations governing the use of nanomaterials, such as CDs, in food are still being developed. Although they do not have specific guidelines for carbon dots, agencies such as the FDA and EFSA mandate safety evaluations. The migration, exposure, and nanoscale behaviour of materials in contact with food are the main topics of current evaluations. Commercial use is uncertain due to the lack of standardised standards. For CDs to be used safely in food products and packaging, clear regulatory frameworks are required.

11. Risk-Benefit assessment

Benefits of using CDs in food include improved shelf life, antimicrobial activity, and spoilage detection. Chronic toxicity, environmental persistence, and migration into food are possible hazards, though. Exposure levels, toxic kinetics, and practical use should all be taken into account in a thorough risk-benefit analysis. Green-synthesized, food-grade carbon dots should be prioritised. Transparent risk communication and cooperative research are necessary to strike a balance between safety and innovation.

12. Challenges and future perspectives of carbon dots in food systems

In food systems, carbon dots (CDs) face a number of difficulties despite their promising uses. Variability in properties caused by non-standardized synthesis and characterisation techniques makes regulatory approval challenging. One challenge is increasing production while preserving cost-effectiveness and consistency, particularly for green synthesis. Furthermore, there are currently few long-term safety data on migration, environmental impacts, and chronic exposure. Underdeveloped regulatory frameworks apply to CDs in food applications. Standardisation, safety evaluation, scalable manufacturing, and Internet of Things integration for real-time food monitoring should be the main objectives of future initiatives.

13. Conclusion

As key players in improving food safety and preservation, carbon dots (or CDs) offer a variety of advantages, including contaminant detection, antimicrobial protection, and smart packaging innovation. Real-time quality monitoring across supply chains is made possible by their distinct fluorescence, biocompatibility, and tunable surface chemistry, which enable highly sensitive detection of pathogens, toxins, and spoilage markers. Strong antimicrobial and antioxidant properties provided by CDs as active packaging ingredients increase shelf life and decrease food waste, two benefits that are particularly beneficial for minimally processed and perishable foods. Their integration with digital systems and Internet of Things (IoT) technologies opens the door to automated safety alerts and intelligent packaging, while the ability to create CDs from environmentally friendly materials like food or agricultural waste further improves sustainability.

The full potential of CDs in food systems, despite their promise, depends on resolving three major issues: standardising synthesis and characterisation procedures, increasing environmentally friendly production, and carrying out thorough, long-term safety evaluations. Because of the intricacy of these problems, interdisciplinary research that brings together chemists, food technologists, toxicologists, regulators, and industry stakeholders is essential. It will be feasible to get past technical and legal obstacles by encouraging cooperation between these fields, guaranteeing the safe and efficient deployment of CDs. Carbon dots, in the end, are a revolutionary step towards safer, smarter, and more sustainable food systems that promote food security and global health via responsible technological integration, innovation, and transparency.

References

Eskalen, H., Çe?me, M., Kerli, S. and Ozgan, S., 2021, Green synthesis of water-soluble fluorescent carbon dots from rosemary leaves: Applications in food storage capacity, fingerprint detection, and antibacterial activity. Journal of Chemical Research, 45(5): 428-435.

Li, S., Li, L., Tu, H., Zhang, H., Silvester, D.S., Banks, C.E., Zou, G., Hou, H. and Ji, X., 2021, The development of carbon dots: From the perspective of materialschemistry. Materials Today, 51(2):

188-207.

Ma, J., Chen, Q., He, H., Jiang, H., Hu, J., Liu, Y., Yao, L., Mao, H., Li, J., Li, B. and Han, F., 2024, Carbon dots?based materials and their applications in regenerative medicine. MedComm-Biomaterials and Applications, 3(3): 1-19.

Mansuriya, B. D. and Altintas, Z., 2021, Carbon Dots: Classification, properties, synthesis, characterization and applications in health care-An updated review. Nanomaterials, 11(10): 2525-2580.

Moradi, M., Molaei, R., Kousheh, S. A., Guimaraes, J. and McClements, D. J., 2023, Carbondots synthesized from microorganisms and food by-products: active and smart food38 packaging applications. Critical Reviews in Food Science and Nutrition, 63(14): 1943-1959.

Oladzadabbasabadi, N., Dheyab, M. A., Nafchi, A. M., Ghasemlou, M., Ivanova, E. P. and Adhikari, B., 2023, Turning food waste into value-added carbon dots for sustainable food packaging application: a review. Advances in Colloid and Interface Science, 10(2): 1-25.

Omerovic, N., Djisalov, M., Zivojevic, K., Mladenovic, M., Vunduk, J., Milenkovic, I., Knezevic, N. Z., Gadjanski, I. and Vidic, J., 2021, Antimicrobial nanoparticles and biodegradable polymer composites for active food packaging applications. Comprehensive Reviews in Food Science and Food Safety, 20(3): 2428-2454.

Rani, S., Kumar, K. D., Mandal, S. and Kumar, R., 2020, Functionalized carbon dot nanoparticles reinforced soy protein isolate biopolymeric film. Journal of Polymer Research, 27(1):1-10.

Xu, X., Ray, R., Gu, Y., Ploehn, H.J., Gearheart, L., Raker, K. and Scrivens, W.A., 2004, Electrophoretic analysis and purification of fluorescent single-walled carbon nanotube fragments. Journal of the American Chemical Society, 126(40): 12736-12737.

Sensory Assessment of Jaggery-Coated Almond, Foxnut, and Peanut Products

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Abstract

Sensory evaluation plays a pivotal role in the development and quality assessment of food products. This study aimed to assess the sensory attributes of jaggery-coated nut-based products prepared using jaggery derived from sugarcane variety CoLk94184. Almond, foxnut, and peanut were selected as core ingredients and coated with molten jaggery using a standardized method involving controlled heating, coating, and drying processes. The finished products were evaluated for colour, appearance, taste, texture, and overall acceptability using a 9-point hedonic scale by a semi-trained panel. Results revealed that all jaggery-coated products were rated favorably, with scores ranging from 7.0 to 8.6 across different parameters. Among the three variants, jaggery-coated foxnut consistently achieved the highest scores in colour (8.2), appearance (7.9), taste (8.5), and overall acceptability (8.6), indicating its superior consumer appeal. These findings suggest that jaggery-coated foxnut holds significant potential as a healthy, value-added snack option.

Keywords Jaggery, foxnut, almond, peanut, sensory evaluation, hedonic scale

Introduction

Jaggery, commonly referred to as gur in the Indian subcontinent, is an unrefined natural sweetener produced through the concentration of sugarcane juice without the separation of molasses. The term 'gur' has its etymological roots in Sanskrit, reflecting its historical significance and long-standing production in India since ancient times. It remains a vital sweetening agent in many rural diets across several nations (Mandal et al., 2006). Unlike refined sugar, jaggery retains almost all minerals and vitamins naturally present in sugarcane juice, which underpins its classification as one of the healthiest forms of sugar available (Gopalan et al., 1991).

Nutritionally, jaggery comprises approximately 75.85% sucrose, 5-10% reducing sugars, and significant amounts of minerals such as calcium, iron, and magnesium, along with phenolic compounds and other bioactive components (Rao et al., 2009; Guerra &Mujica, 2009). Owing to these constituents, jaggery is often termed "medicinal sugar" or "healthiest sugar" and is known for its intrinsic flavour, distinctive aroma, and comparatively lower sucrose content than white sugar (90-95%). Traditional systems of medicine have historically acknowledged its therapeutic potential, particularly in alleviating respiratory disorders, supporting digestion, and providing quick energy (Kumar et al., 2022; Kouhestani&Honarvar, 2021).

The practice of coating food products with jaggery, especially nuts and seeds, is rooted in indigenous processing traditions, typically undertaken at cottage or household levels.

Historically, such coating was executed manually- a labour-intensive, time-consuming process often yielding inconsistencies in product quality, coating uniformity, appearance, and shelf life (Pandey, 2007). With growing consumer demand for value-added, health-oriented snack foods, there is a need for mechanized solutions that can ensure standardization, enhance production efficiency, and maintain product quality.

In this context, a jaggery coating machine was designed and developed at the ICAR-Indian Institute of Sugarcane Research (IISR), Lucknow. This mechanized system facilitates uniform coating of jaggery over various core ingredients such as almond (Prunusdulcis), foxnut (Euryale ferox), and peanut (Arachishypogaea), while optimizing operational parameters including coating vessel angle, rotational speed, and airflow for efficient drying. The development of such technology not only addresses the limitations of manual processing but also aligns with the broader objective of promoting jaggery-based functional snacks that combine traditional sweetness with nutritional enhancement.

The present study focuses on the preparation and sensory evaluation of jaggery-coated almond, foxnut, and peanut products using the developed coating machine. Sensory attributes including colour, appearance, taste, texture, and overall acceptability were assessed following a standardized hedonic evaluation protocol, thereby providing scientific insight into consumer preferences and the potential marketability of these products.

Materials and Methods

Experimental Site

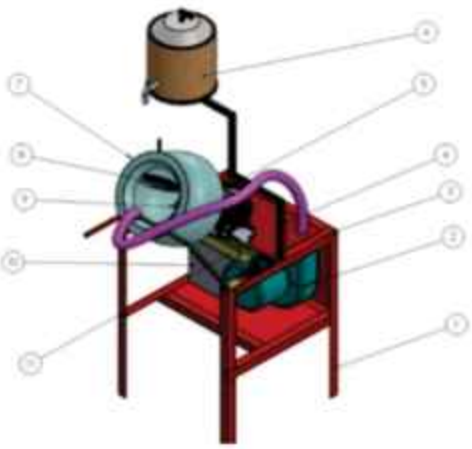
The present study was conducted at Jaggery Unit, Division of Agricultural Engineering, ICAR-Indian Institute of Sugarcane Research, Lucknow (U.P.) India.

Raw Materials

Jaggery (Sugarcane variety: CoLk94184) were used in the entire experimental tests. All other ingredients, viz., almond, foxnut, peanut etc. for preparation of jaggery coated products were procured from the local market of Lucknow.

Jaggerycoating Machine

In the present study, the jaggery coating machine was developed at ICAR-Indian Sugarcane Research Institute,Lucknow. As shown in Figure 1.



1. Main frame
2. Electric blower
3. Bearing
4. DC motor
5. Electric kettle and unit
6. Stainless steel coating vessel
7. Disperser 1st set
8. Disperser 2nd set
9. Machine cover plate
10. Sub main frame

Processing of Jaggery Coated Products

The fresh jaggery cubes with water was heated in an electric kettle at 103-106°C for 10 min or until the jaggery dissolved completely in the water and attained a consistency of one string. The amount of water to be added was calculated on the basis of experience from preliminary trials. It is important to maintain the temperature and consistency of jaggery properly for coating. The liquid jaggery solution was poured inside the rotating coating vessel over roasted nuts (batch of 50 g). The coating vessel was kept rotating for 4 to 5 min at different angle (31.5?, 42.5? and 52.5?) and speeds (13.5, 24.5 and 35.5 rpm)until the coating layer was distributed evenly on the nuts surface. The process was continued till the entourage (first) layer was completed. Disperser unit works as an agitator (mixing) or promotes the disaggregation between the nuts. After coating, to improve the quality of products, the jaggery coated products were sprinkled with powder/granular jaggery. Blowing of air inside the rotating coating vessel through the pipe was done for proper mixing and drying, and also to regulate the temperature of the coating vessel and nuts. Jaggery coated products (jaggery coated nuts) were withdrawn from the vessel and spread in the open air to further dry and finally allowed the coated products to cool completely at ambient temperature.

A detailed operating procedure for the development of jaggery coated products using developed jaggery coating machine is also shown with the help of a process flow chart (Fig.1).

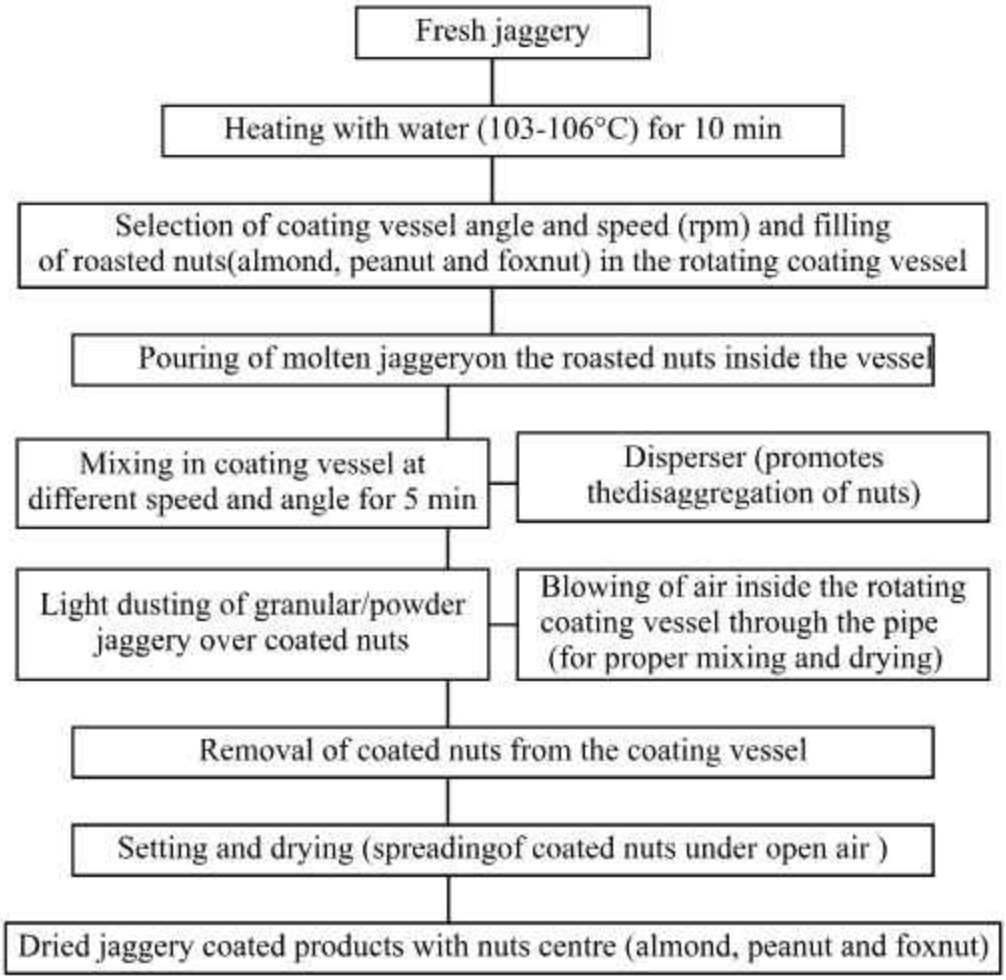


Fig 1: Process flow diagram for preparation of jaggery coated products

Sensory Evaluation

Sensory evaluation of jaggery coated product involves assessing the coated products by different sensory attributes such as; colour, appearance, taste, texture and overall acceptability through human senses by using 9-point hedonic scalefollowing the method described by Saadoudiet al. (2017). The sensory evaluation of samples was done by a panel of semi-trained judges consisted of 10 members from scientists, researchers, technical officers and students in the age group of 18-60 years belonging to ICAR-IISR, Lucknow at the onset of the sensory evaluation panellists were given an understanding of the test and explained the procedure in detail. Members were provided score card for assessment and scoring of the samples specially developed for the purpose. The samples placed before the judges/panellists were coded to avoid disclosure of the sample information and biasness. Judges were also requested to wash their mouth in between the samples during the process of evaluation. Table 1 shows the performa for sensory rating on 9-point hedonic scale.

Table 1: Performa for sensory rating on 9-point hedonic scale

Name:	Division:
Product name:	Date:
Code:	
9 = Like extremely	
8 = Like very much	
7 = Like moderately	
6 = Like slightly	
5 = Neither like nor dislike	
4 = Dislike slightly	
3 = Dislike moderately	
2 = Dislike very much	
1 = Dislike extremely	
Comments:	



Figure 2: Jaggery coated Products

Result and Discussion

The results of the jaggery coated products are depicted in Figure 3

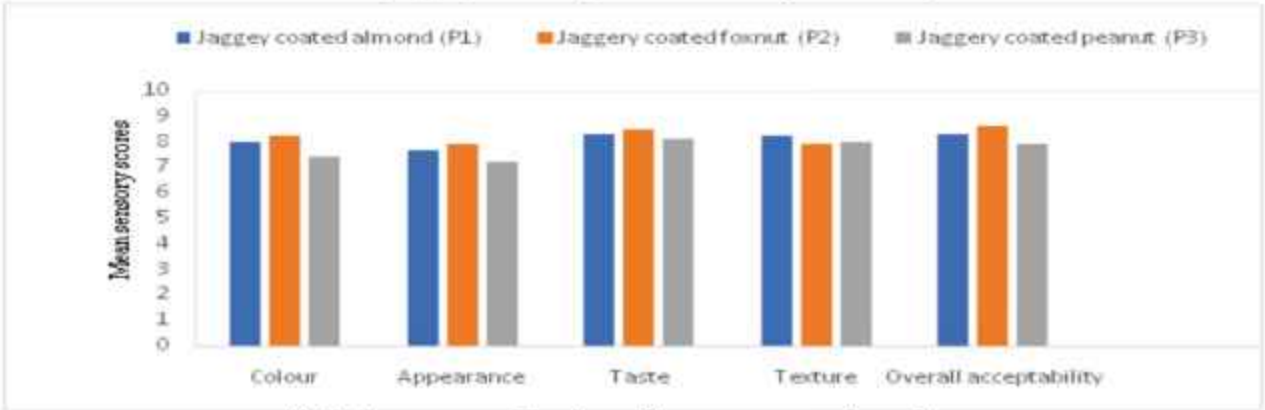


Fig3: Sensory evaluation of jaggery coated products

Colour

The sensory scores for the colour attribute of jaggery-coated almond, foxnut, and peanut were 8.0, 8.2, and 7.4, respectively. The colour of the coated products was generally perceived as dark, consistent with the natural hue of jaggery. The highest score for colour (8.2) was recorded for jaggery-coated foxnut, which may be attributed to the more uniform coating and better surface gloss achieved during processing. This observation is in agreement with previous findings where product appearance was strongly influenced by uniformity of coating and moisture content during the drying phase (Chand et al., 2011).

Appearance

Appearance scores ranged from 7.2 to 7.9, with jaggery-coated foxnut (7.9) receiving the highest rating, followed by almond (7.65) and peanut (7.2). The superior appearance of foxnut-coated products could be due to the spherical shape and lighter surface colour of the core material, which provided a visually appealing contrast with the jaggery layer. In contrast, peanuts showed comparatively lower scores, possibly due to irregular shapes and size variations leading to non-uniform coating.

Taste

Taste scores indicated strong consumer preference for all products, ranging between 8.1 and 8.5. Foxnut-based products achieved the highest taste score (8.5), suggesting optimal flavour balance between the mild, nutty core and the sweet jaggery coating. The higher rating may also be linked to the porous texture of foxnut, which potentially absorbed more jaggery syrup, enhancing sweetness perception. Similar findings have been reported for other coated snack products, where flavour absorption significantly contributed to consumer liking (Saadoudi et al., 2017).

Texture

Texture scores were highest for jaggery-coated almond (8.2), followed by peanut (8.0) and foxnut (7.9). Almond's inherent firmness and crispness likely contributed to the favourable texture rating, complementing the brittle jaggery coating. Foxnut, despite scoring slightly lower, still achieved acceptable ratings, though its lighter, airy structure may have been perceived as less crunchy compared to nuts with denser composition.

Overall Acceptability

The overall acceptability scores revealed a clear preference for jaggery-coated foxnut (8.6), followed by almond (8.3) and peanut (7.9). The high acceptability of foxnut products suggests a synergistic effect of desirable colour, appearance, and taste attributes, outweighing slightly lower textural ratings. These results demonstrate that foxnut is a promising core material for developing jaggery-based coated snacks targeted at health-conscious consumers.

Conclusion

The performance and sensory evaluation of the jaggery coating machine demonstrated its effectiveness across different product types. Foxnut, among the tested products, was found to yield the highest coating efficiency and coated product weight under optimal operational conditions. Sensory analysis further indicated that jaggery coated foxnut scored the highest in most attributes, particularly in taste and overall acceptability, making it the most preferred product. The developed coating machine, being economically viable can be considered suitable for small- to medium-scale jaggery-based snack production.

References

Chand, K., Singh, A., Verma, A.K. and Lohani, U.C.

2011. Quality evaluation of jaggery chocolate under various storage conditions. Sugar Tech, 13(2): 150-155.

Gopalan, C., B.V. Rama Shastri, and S.C. Balasubramanian. 1991. Nutritive value of Indian foods. Hyderabad: National Institute of Nutrition, ICMR.

Guerra, M.J. and Mujica, M.V. 2009.Physical and chemical properties of granulated cane sugar "panelas". Ciênc.Tecnol. Aliment, Campinas.

Kouhestani, S. and Honarvar, M. 2021.An overview on panela. Journal of Food Biosciences and Technology, 11(1): 35-42.

Kumar, D., Pathak, A.D., Mishra, C. and Mishra, S. K. 2022.Technical bulletin on jaggery.ICAR-IISR, Indian Institute of Sugarcane Research, Lucknow (Uttar Pradesh), ABI Lucknow/PUB. No. 2022/01

Mandal, D., Tudu, S., Mitra, S.R. and De, G.C. 2006. Effect of common packing materials on keeping quality of sugarcane jaggery during monsoon season. Sugar Technology, 8 (2 and 3): 137-142.

Pandey, Adya Prasad. 2007. Indian Sugar Industry a strong industrial base for rural India, BHU.

Rao, P.V.K.J., Das, M. and Das S.K. 2009. Changes in physicaland thermo-physical properties of sugarcane, palmyra-palmand date-palm juices at different concentration of sugar.Journal of Food Engineering, 90: 559-566.

Saadoudi, M., Hambaba, L., Abdeddaim, M., Lekbir, A., Bacha, A., Boudraa.S. and Zidani, S. 2017. Nutritional composition, physical properties and sensory evaluation of biscuit produced from jujubes (Fruits of Zizyphusotus L.). Food Science and Technology, 18(3).

Development of HAU Green DetoppingMachine for Carrot

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Abstract

According to the National Horticultural Board, India produces 14.56 lakh tons of carrots annually, with Haryana as the leading producer. Carrots are consumed raw and processed, and harvested between November and March. Presently, green detopping, a key post-harvest operation in carrot farming, is done manually using knives that make the process time-consuming, labour-intensive, and costly. This task especially burdens mainly women labourers. A half-hectare harvest typically requires 25 workers for a full day. Due to lack of mechanisation, input costs rise, reducing the farmer income. Low farmer income is a pressing national issue. Mechanizing operations like green detopping of carrots can reduce labour dependency, drudgery, time, and overall production cost, thereby enhancing profitability. To address these challenges, a portable, user-friendly carrot green detopping machine was developed at CCSHAU Hisar under AICRP on Post-Harvest Engineering and Technology. The research aimed to develop the machine and evaluate its performance and cost-effectiveness to support Indian farmers. The capacity of Green Detopping Machine for the carrots is about 150 kg/h, whereas, the machine damaged about 7% of the carrots during the detopping operation. The energy consumption of the developed machine is 2.38 units per ton of carrots. The operation cost of the machine was 90.87 Rs/h or 0.62 Rs/kg of carrots. The benefit-cost ratio, payback period, and breakeven point of the machine are 1.03, 0.96 year, and 676.46 h, respectively. While carrot diggers and washers are widely used in northern states, a detopping machine will complete the value chain, enabling quick, efficient, and high-quality carrot processing with minimal labour.

Key words: Detopping machine, Carrots, machine development, cost economics

1.0 Introduction

As per the National Horticultural Board, the annual production of carrot in India is 14.56 lakh tons whereas Haryana is the top-producing state with a production of 4.45 lakh tons followed by Punjab and Uttar Pradesh during 2017-18 (NHB, 2018). The carrot is consumed in raw and processed form. The harvesting of the carrots starts in November and continues till March. During harvesting, tractor-attached cultivator-typeimplements uproot the carrots from the soil with its green part. Labor collected the carrot with its green leaves to a common place where the green part used to be cut or detopped using a hand knife. Detopping is a post-harvest unit operation in which the green part of the carrot is cut from the carrot root. The manual cutting operation using a knife is time-consuming and labor-intensive (Shirwal et al., 2015). This operation needs mechanization to increase the income of farmers since it reduces the number of required labor and time for cutting. A farmer requires at least 25 workersfor the whole day to harvest the crop of a half hectare (Shirwal et al., 2015; Narender et al., 2018).

Presently, the low income of Indian farmers is a

national issue to overcome (Naresh et al., 2018). Many suggestions are coming from the scientific communities i.e. reducing the input of farmers, agro-processing, etc. Some of the post-harvest operations are not fully mechanized similar to wheat, paddy, and other commercial crops. Mechanization of labor-intensiveoperations therefore decreases the cost of operation (Srisompun et al., 2019). It decreases the time of operation as well. Carrot harvesting includes the green detopping before further cleaning operation. Currently, womenlabor cut the green part of carrots by using a knife and this method is responsible for the drudgery of the woman workers (Sucharita&Bishnoi, 2018). Lack of mechanization in farm operation increases the farm inputs in terms of money and time as well. Both inputs increase the cost of production for the farmers. Detoppingmachines will reduce time and laborcosts as well. It enhances the income of the farmers. In addition, the use of the machine reduces the drudgery of the woman agricultural workers (Potdar et al, 2020). This unit operation should be mechanized to reduce the cost and time of operation. There is a need to develop a machine for the green detopping of carrots.This research reduces the input cost of the farmers and therefore increases their income. This machine will also reduce the time of harvesting which allows the timely supply of carrots in the near markets. This machine will operate on the farms reducing the needfor extra transportation of agro produce. This machine will be portable and operated by unskilled labor like a chaff cutter. Keeping these points in view, a detopping machine was developed under AICRP on Post-harvest Engineering and Technology at CCSHAU Hisar. The objectives of the research project development were:

1. To develop a green detopping machine for the carrot.

2. To study performance evaluation and cost economics of developed machines.

2.0 Material and methods:

2.1 Concept of the detoppingmachine

The HAU green detopping machine for carrot has a loading rack that has to be loaded first before operation of machine. This loading rack is besides the feed conveyor of the machine. A labour feed the machine with carrots one by one on the feed conveyor. The feed conveyor kept the carrot in place with half circular slots. Later on, a belt pulley mechanism press the uncovered other side of the carrot. The feed conveyor feed the carrots with green in the cutting assembly where the cutting blade cut the top green part of the carrots. The detopped carrots and the green part of carrots were collected into different sides outside of the detopping machine (Fig 1). The word HAU stands for CCS Haryana Agricultural University, Hisar, Haryana.

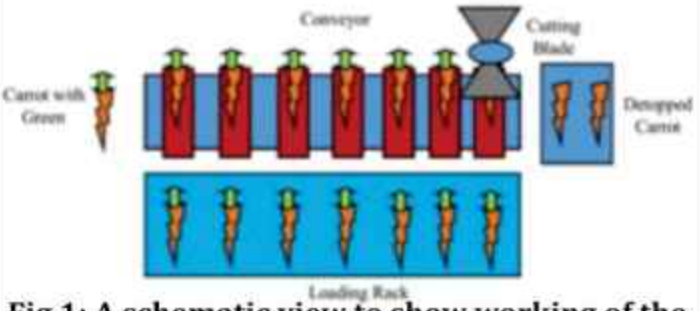


Fig 1: A schematic view to show working of the HAU Detoppping Machine for Carrots

2.2 Development of the machine

A continuous power operated HAU green detopping machine for carrot was developed with the help local manufacturer at Hisar, Haryana (Table 1). The machine consists of a main frame made of mild steel in which the motor (1HP) was installed with chain sprocket drive for feed conveyor. The chain sprocket drive is connected with a conveyor that feed the carrot to the cutting

blade assembly. The feed conveyor is also made of half circular shaped stainless steel pipes or slots fixed on chain and sprocket that holds and feeds the carrots to cutting blade assembly at 22 RPM. The RPM of the machine was optimised during development of machine. The basis of RPM selection was ease of feeding carrots in the machine anddetopping operation. Before cutting the green, the both sides of carrots was required to hold firmly on feed conveyor. Therefore, a belt and roller mechanism was installed near to the cutting blade assembly to fix carrots firmly on feed conveyor for proper cutting of green part of carrot. The cutting blade assembly is also made of stainless steel and have two cutting edges. It cut the green top part from the carrot and these detopped carrots are collected in the container outside of the machine. The carrots contact surfaces are made of food grade stainless steel SS304. The cutting blade assembly is kept covered for the safety of machine operator (Fig 2).

Table 1: Technical specification of the HAU green detopping machine for carrot

Parameter	Description
Length	74 cm
Height	106 cm
Width	88 cm
Motor	1 phase AC motor (1HP)
Material of construction	Mild steel and Stainless steel
Cost (Approx.)	40,000/-



Fig 2: HAU Green Detoppping Machine for Carrots

2.3 Testing and evaluation of the developed detopping machine

The developed detoppingmachine was tested for the capacity (kg/h), carrot damage (%) and power consumption (kWh) (Kenghe et al., 2015; Minh et al., 2020). The formulas for these dependent parameters are given below:

$$\text{Capacity of the detopping machine} = \frac{\text{Weight of the detopped carrots in kg}}{\text{Total time taken in hours}}$$

$$\text{Damaged carrots} = \frac{\text{Weight of the damaged carrots in kg}}{\text{Weight of the detopped and damaged carrots in kg}} * 100$$

$$\text{Power consumed by machine} = \frac{\text{Power consumed in kWh}}{\text{Weight of detopped carrots in quintal}} * 100$$

2.4 Cost economics of the developed machine

The results of developed machine werecompared with the manual detopping method. Also the cost economics was calculated on the basis of following formulas provided below (Hussain et al., 2019).

Depreciation = (C-S)/ (L*h)

Where,
C= Cost of machine in rupees
S= Salvage value, 10% of the cost of machine
L= life of the machine in years
H= Working hours of the machine

Interest= ((C+S)/2*h) x I

Where,
I= Interest rate in %

Benefit-cost ratio

$$BCR = \frac{\text{Benefit from the machine in one year}}{\text{Initial cost of the machine}}$$

Break -even point

BEP = Initial investment / Profit/ h

Payback Period

$$\text{Payback Period} = \frac{\text{Capital Invested}}{\text{Annual Profit}}$$

3.0 Results:

3.1 Manual Detopping of Carrots

The knife was used for the manual detopping operation of the uprooted carrots by cultivator by one unskilled labour. Under the manual detopping operation, the weight of detopped carrots, time taken and the weight of the green was recorded for the comparison purpose to the mechanical detopping of carrots. The results of the manual detopping operation is in Table 2.

Table 2: Manual detopping operation using the knife by one unskilled labour

Sr. No	Weight of Detopped carrots, kg	Weigh of Green, kg	Time taken, min
1	9.02	8.84	8.57
2	10.20	9.26	6.49
3	9.52	8.12	8.28
Mean	9.58	8.74	7.78

3.2 Mechanical Detopping of Carrots

The developed detopping machine for carrots was used for the mechanical detopping operation. Under this operation, the weight of detopped carrots, weight of green, time taken in detopping operation and damaged carrots was recorded. The machine was operated by one unskilled operator. The data of three replication is provided in the Table 3:

Table 3: Mechanical detopping operation of carrots using the developed machine

Sr. No	Weight of Detopped carrots, kg	Weigh of Green, kg	Time taken, min	Power Consumed, kWH	Damaged Carrots, kg
1	24.84	11.94	12.21	0.06	1.02
2	36.36	23.88	12.39	0.09	2.94
3	39.66	27.78	16.44	0.09	2.67
Mean	33.62	21.20	13.68	0.08	2.21

3.2 Mechanical Detopping of Carrots

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3	39.66	27.78	16.44	0.09	2.67
Mean	33.62	21.20	13.68	0.08	2.21

3.3 Calculation of the dependent parameters:

$$\text{Capacity of the detopping machine} = \frac{33.62 * 60}{13.68}$$

Capacity of the detopping machine=147.46 kg/h*

Capacity of the manual detopping=73.88 kg/h (as per Table 2)

*Capacity is twice to the manual method for detopping of carrots.

$$\text{Damaged carrots by machine} = \frac{2.21}{33.62} * 100$$

Damaged Carrots by machine=6.57%*

*Deformed carrots during its development phase increase damage percentage of carrots during detopping operation. Otherwise, damage percentage is between 1-2%.

$$\text{Power consumed} = \frac{0.08(\text{Total Power Consumed})}{0.33(\text{Weight of detoppped Carrot in quintal})} * 100$$

Power consumed by machine=0.24 kWh/quintal

3.4 Cost economics analysis of Detopping machine

Table 4: Assumptions for the cost economics of the detopping machine

S. No.	Particulars	Values
1	Average annual use (h)	700 h (3 months)
2	Life of machine (L)	10 years
3	Salvage value (S)	10% of initial cost
4	Labour charge	600 per day
5	Working hours in day	8 h

A) Fixed cost

i) Depreciation, (C-S)/ (L*h) = (40,000-4000)/(10*700) = 5.14 Rs/h
Cost of machine (C) = ₹ 40,000 (approx.)
ii) Interest= ((C+S)/2*h) x I = ((40,000+4000)/2*700) x 0.12 = 3.77 Rs/h
Interest for the machine (I) = 12%
iii) Insurance + tax + shelter (@3% of C) = (40,000 x 0.03)/700 = 1.71 Rs/h
Total Fixed cost (i+ii+iii) = 10.62 Rs/h

B) Variable cost

i) Total wage of 1 labor per hour (600/8) = 75Rs/h
ii) Electricity consumption per hour = 0.4kWh x 6 = 2.40 Rs/h
Electricity consumption = 0.4 kWh
Electricity rate = ₹ 6 per kWh
iii) Repair and maintenance = (40,000*0.05)/700 = 2.85 Rs/h
Cost of repair and maintenance = 5% of C per annum
Total variable cost (i+ii+iii) = 80.25 Rs/h
Operational cost of machine (FC+VC) = 90.87 Rs/h
Divide the operational cost to the capacity of machine = 0.62 Rs/kg

C) Profitability of detopping machine

Capacity of the machine is twice of the manual detopping operation. Manual detoppingrequire two labours for same quantity of detopped carrots as of machine. Therefore, cost of manual detopping is 150 Rs/h, whereas machine cost 90.87 Rs/h. The benefit from the machine will be 150-90.87 Rs/h or 59.13 Rs/h.

i) Benefit-cost ratio

$$BCR = \frac{\text{Benefit from the machine in one year}}{\text{Initial cost of the machine}}$$

BCR = (59.13*700h)/40,000 = 41391/40000=1.03

ii) Break -even point

BEP = Initial investment / Profit/ h

= 40,000 Rs / 59.13Rs/h = 676.47 h

iii) Payback Period

$$\text{Payback Period} = \frac{\text{Capital Invested}}{\text{Annual Profit}}$$

$$= \frac{40{,}000\ Rs}{41391\ Rs/year} = 0.96 \text{ year}$$

4.0 Discussion

Currently the woman labours are available free of cost in rural areas due to their requirement for the green part of the carrots. The green parts of carrots are being utilized as fodder for the milk cattle. Therefore, the cost economics of the machine is purely based on an assumption. On the other hand, the machine will be very useful in case of unavailability of the farm labour or to complete the work in small period the time.Presently urban areas are suffering from the shortage of labour. Also, the modern consumer demands for the fresh agricultural produce. Therefore, harvesting of carrots should be planned as per the market demand. It is hard to supply the fresh produce in a short period of time. This machine solve the purpose to harvest the carrots and perform detopping before the cleaning operation. Generally, the detopping operation performed at the field under the sun for longer period. The sun affects the quality of the carrots and responsible for physiological weight losses. Longer duration on the filed under the sun also reduce the shelf life and quality of the carrots. Mechanisation of carrot detopping is the demand of time to decrease the harvesting time of carrots. Carrot digger and carrot washer is the great success in harvesting operation and being utilized at large scale in Haryana, Punjab, Delhi, Rajasthan, Uttar Pradesh etc. Detopping machine for carrots will fill the gap and complete the value chain for the carrots. The harvested, cleaned and detopped carrot may be stored or sold in market at earliest without human drudgery and carrots will be of good quality.

5.0 Conclusion:

The power operated detopping machine for carrots was tested for its performance. The machine capacity and percentage of damaged carrots were 147.46 kg/h and 6.57% respectively. Operation cost of machine was 90.87Rs/h or 0.62 Rs/kg of carrots. The benefit cost ratio, payback period and breakeven point of the machine are 1.03, about 1 year and 676.47 h, respectively. This machine test results were found satisfactory and it is suitable for farmers and small entrepreneurs.

Conflict of interest

Authors have no conflict of interest.

References

Hussain, S. Z., Naseer, S., Farooq, M., & Mir, U. M. (2019). Design, Development and Evaluation of Portable Washer for Lotus Rhizomes.Journal of Scientific & Industrial Research. 78: 629-633.

Kenghe, R. N., Magar, A. P., &Kenghe, K. R. (2015).Design, development and testing of small scale mechanical fruit washer. International Journal of Trend in Research and Development, 2(4), 168-171.

Minh, D. H., Van Phuong, B., Van Binh, P., &Duc, N. V. (2020). Design, development and performance evaluation of a new-type fruit vegetable washer. Journal of Mechanical Engineering Research and Developments 43(4):265-274.

Narender, Mukesh, S, Rani, V, Kumar A, Verma, K., &Karwasra, N. (2018).Performance evaluation of vegetable washer for carrot crop. Int. J. Curr. Microbiol. App. Sci, 7(1), 454-458.

Naresh, Jain, M., Rani, V. Kumar, A. &Narender (2018). Design and Development of Tractor Operated Carrot Digger. Agricultural mechanization in Asia, Africa and Latin America N, 3, 79-85.

NHB (2018).National Horticulture Board.https://agriexchange.apeda.gov.in/India%20Production/India_Productions.aspx?hscode=1073.

Potdar, R. R., Tiwari, P. S., Shukla, P., Patel, A., &Jyoti, B. (2020). Drudgery reduction in operation of cleaner-cum-grader: An ergonomic intervention. Quarterly Research Journal of Plant & Animal Sciences/ Bhartiya Krishi AnusandhanPatrika, 35(4).

Shirwal, S., Mani, I., Sirohi, N. P. S., & Kumar, A. (2015).Development and evaluation of carrot harvester. AMA-Agricultural Mechanization in Asia Africa Latin America, 46(1), 28-34.

Srisompun, O., Athipanyakul, T., &Isvilanonda, S. (2019). The adoption of mechanization, labour productivity and household income: Evidence from rice production in Thailand (No. WP-016).TVSEP Working Paper.

Sucharita, S., &Bishnoi, I. (2018).Drudgery reducing equipments for farm women; Availability and options.Internat. J. Appl. Home Sci, 5(1), 246-251.

Enhancing Viability of Agriculture as Profession in Amrit Kal - A Road Map

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Abstract

Indian agriculture will go for a significant change in next two decades. By 2050, it is expected that food and feed demand will increase to 251 Mt and 111 Mt respectively. The water demand will increase to 900 BCM. The scenario of micro nutrients deficiency will further deteriorate significantly with different micro nutrient deficiency reaching these levels: Zn(49%), B(32%), Mb (13%),Fe(12%), Cu(3%), Mn(4%), S(41%). Although good sign is that percent of people dependent upon agriculture for their livelihood has declined to 42% from more than 50% about 15 years ago, but NSSO survey reveals that 40% farmers ready to leave agriculture if proper alternative is available. About 60% farmers are above 50 years age and it is only profession where old outnumber young. These data are about 15 years old and upcoming census will show whether reduction in dependent upon agriculture is from younger group or natural elimination of older group. A major reason for this imbalance is agrarian distress. While42% of population derive their livelihood from agriculture but contribute only 15-16% of GDP ,there is a huge in built disparity with other sectors. This distress has led to loss of pride in agricultural community. Those communities who felt proud of being farmer are on roads to demand reservation in shrinking government job market.This distress can be attributed to (i) decline in per capita availability of natural resources land and water; (ii) Shrinking land holding sizes with small and marginal holding nearing 90% ; (iii) Over-exploitation and quality deterioration of groundwater resource - > 15% blocks over-exploited; (iv) Poor water use efficiency/irrigation efficiency (v) Impact of climate change on Irrigation & Drainage Infrastructure and water use ; and (vi) Post harvest management and waste utilization.

Thus, for reducing this agricultural distress in next 25 years, comprehensive strategies will have to be developed. Few of them will be (i) Reduce pressure on land. Ensure quantum jump in productivity of foodgrains on suitable lands and divert rest to horticulture, fodder, industry and infrastructure; (ii) Increase water use efficiency and water productivity. Present share of agriculture is 84% . It has to be reduced significantly; (iii) Make a quantum jump in irrigated area especially in eastern India using out of box technologies; (iv) More investment to develop climate smart agricultural technologies; and (v) Better post-harvest management, waste utilization , protected cultivation. Our target for this Amrit Kal should be: (i) Reduce population deriving livelihood from agriculture to 20% with GDP contribution rising to 20%. This will reduce disparity of agriculture in comparison to other sectors. (ii) Reduce land under food crop from present 105 M ha to 80 M ha, divert 12.5 M ha to horticulture, 6.25 M ha to feed and fodder production and rest for infrastructure and industry to absorb 25% population from agriculture; (iii) Increase efficiency of surface irrigation by investing in conveyance system. Since land is getting costly go for underground pipelines. In next 10 years no unlined channels; (iv) Prepare ground water recharge plan to

replenish maximum percentage of ground water used and recycle waste water. Target should be to make our aquifers WATER POSITIVE; (v) Enhance use of gray water. Use about 50-60% water to green our wastelands and plantation along highways; (vi) Identify agricultural waste who are going to be menace with changing socio economic scenario and develop technologies for their monetization; (vii) Reduce cost of agricultural inputs by (a) taxation and subsidy; (b) search for less costly alternatives (c) alternatives which can be subsidized in a transparent manner and (d) the target beneficiaries; (viii) Policy intervention for making leasing legally enforceable and making leasee eligible for loans and subsidy.

This article discusses a roadmap for achieving these targets and few technologies which can be adopted to give tangible results.

Precision fertigation management for cluster bean under semi-arid tropics of Maharashtra

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Abstract

A field experiment was conducted on cluster bean at the research farm of the All India Coordinated Research Project on Irrigation Water Management, VNMKV, Parbhani.A split-plot design with three replications was used in study. Drip irrigation method with every alternate day was adopted for all the plots with five different irrigation levels as main plot viz., 0.4 ETc (I1), 0.6 ETc (I2), 0.8 ETc (I3), 1.0 ETc (I4) and Farmer practice (I5). Fertigation levels were Control (F1), 50% (F2), 75% (F3) and 100% (F4) of recommended dose of fertilizers (40:60:60 NPK kg ha-1) with six splits during crop growth period.Among the various irrigation levels considered, irrigation treatment I4 (drip irrigation with a 1.0 ETc), showed significantly superior cluster bean growth attributes. It is also observed that I4 (drip irrigation with 1.0 ETc) was comparable with irrigation schedule I3 (drip irrigation with 0.8 ETc).

In case of fertigation, the application of fertilizers at 100% recommended dose of fertilizer (F4) showed significantly superior growth characteristics of cluster beans, which were comparable with the fertilizers which applied at 75% RDF (F3).The drip irrigation scheduled at 0.8 ETc on alternate day and application of drip fertigation @ 30:45:45 NPK kg ha-1 was found to be both productive and profitable with saving of 20 % water and 25% fertilizers, respectively.

Key words: Cluster bean, fertigation

Puffing Machine and Process Development for increasing Entrepreneurship a t Cottage Level.

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Abstract

Food process mechanization can significantly contribute to entrepreneurship development in rural areas through machine and process development by increasing efficiency and productivity, improving product quality and consistency, reducing labor costs and manual handling, enhancing scalability and competitiveness. The roasting and puffing machines are used for the preparation of various products such as puffed rice soynuts, peanuts and popped sorghum, popcorn, popped amaranth and other roasted and puffed/popped ready-to-eat (RTE) snacks. Mechanization can help entrepreneurs to increase production capacity, improve product texture and flavor, meet growing demand, and compete in larger markets. LPG-operated puffing-cum-popping machine using table salt as heating media with a capacity of 10 kg soynuts per hour; was designed and developed for the production of puffed products from different types of grains. The performance of the developed machine was evaluated by preparing soynuts with optimum level of process parameters such as puffing temperature of heating media as 150 ?C; stirrer speed 40 RPM and puffing time 5 min. The cost analysis was performed by considering the production capacity as 80 kg/day of soynuts by operating the machine for 8 hours/day. As per the market rates, the selling price of puffed soynuts was 200 Rs./kg and the total cost of production was 129 Rs./kg. The benefit cost ratio and breakeven point for the production of puffed soynuts were observed as 1.47 and 30.43%, respectively. The machine and soynut, peanuts, bengal gram, popcorn, popped sorghum, etc. production processes, were demonstrated to the farmers and new entrepreneurs of Parbhani district (M.S.).

Keywords: Food process mechanization, soynuts, optimization, puffing cum popping machine.

Smart Water Allocation: Optimizing Use Based on Availability and ROI

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Background/Introduction

India's growing population, changing climate, and agricultural dependency place tremendous pressure on its finite water resources. Agriculture remains the largest consumer of fresh water, using over 80% of national reserves, yet inefficiencies in allocation persist due to outdated policies, lack of dynamic planning tools, and poor integration of data sources. While programs like CADWM focus on infrastructure, the question of where and how much water should be allocated remains inadequately addressed.

Recent studies show that regions with similar rainfall and soil profiles experience widely varying returns on irrigation investments due to crop choice, market access, and marginal utility of water. Therefore, precision in water allocation itself must become the focus of smart irrigation strategies, guided by data science and regional return-on-investment (ROI) metrics. This study proposes a model to rationalize irrigation decisions not only for maximizing yield, but also economic and ecological outcomes.

Objective/Goal

To design a predictive, ROI-optimized water allocation framework that dynamically suggests where and how much water should be used across agricultural zones, based on real-time and forecasted data. The framework aims to maximize the impact of each unit of water ("per drop return") by balancing economic yield, ecological sensitivity, and resource sustainability.

Methodology/Proposal

The proposed solution is a Decision Support System (DSS) that integrates multi-source data and triggers data-driven irrigation actions. Rather than merely guiding planners and farmers, it acts autonomously to optimize irrigation allocation through the following components:

- Forecasting Models/Water Availability Assessment: Predictive hydrological models combined with real-time and seasonal water availability projections from reservoir monitoring systems.
- IoT-based Soil Health Sensors: Collect and assess soil health parameters, land productivity indices, and nutrient content.
- IoT-based Environmental Sensors: Monitor humidity, soil moisture, and temperature to support microclimate-responsive irrigation.
- Soil and Crop Suitability Mapping: Integration of soil data with regional agronomic recommendations to determine crop compatibility.
- AI-driven Water Stress Prediction & Risk Indexing: Utilizes geospatial overlays, drought projections, and climate risk assessments to forecast water-stressed zones and trigger precision irrigation

protocols.

- Economic Optimization Engine: Simulates ROI across crops using MSP data, market trends, input costs, and yield expectations.
- Marginal Utility Modeling: Calculates diminishing returns of water use across zones and prioritizes allocations for maximum system-level efficiency.

Water Credits & Incentives To reinforce sustainable water usage, the framework introduces targeted incentives that reward conservation and efficiency. These mechanisms are designed to align farmer behavior with broader ecological and economic goals.

- Incentives for Optimal Utilization of Water: Farmers who consume less than their optima allocation earn Water Credits, redeemable as fertilizer subsidies, higher MSP, or other financial incentives.
- Sustainable Farming Incentives: Export Incentives will be offered for crops that use less virtual water, aligning trade policies with sustainable farming practices.

The DSS will be deployed in selected pilot districts and refined through stakeholder feedback loops involving FPOs, irrigation authorities, and local governments.

Findings/Expected Outcomes

- Improved ROI per Drop: Strategic targeting of irrigation where it has the highest financial and yield impact.
- Ecological Safeguards: Prioritization of climate-sensitive and groundwater-depleted areas to reduce ecological degradation.
- Data-Driven Governance: Empowered decision-makers with real-time dashboards and predictive insights for policy and distribution.
- Scalability Across States: A modular framework adaptable to varying agro-climatic zones and crop calendars.
- Farmer-Centric Benefits: Enhanced planning capacity for small holders through mobile-based recommendations and participatory planning models.

Conclusion/Significance

Water is no longer a static entitlement but a dynamic asset that must be optimized for national food and livelihood security. This research introduces a paradigm shift in irrigation thinking: from supply-based delivery to intelligent, ROI-oriented allocation. By leveraging digital technologies, economic logic, and climate foresight, India can institutionalize a predictive water governance model. This proposal complements ongoing CADWM and PMKSY efforts, offering a layer of precision and intelligence that can transform India from water-stressed to water-smart agriculture.

Keywords: Water allocation, Decision Support Systems, ROI-based irrigation, Precision agriculture, Smart water use

Scaling CADWM through Global Insights and Data-Driven Strategy

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Background/Introduction

India's agricultural sector is at a pivotal juncture, grappling with mounting pressure on its water resources due to a combination of climate variability, inefficient irrigation practices, and increasing demand from a growing population. Agriculture consumes nearly 80% of India's freshwater resources, yet irrigation efficiency remains low, often under 40% in many regions. Traditional flood irrigation methods dominate, leading to excessive water loss, soil degradation, and declining groundwater levels.

Climate change further exacerbates this vulnerability, intensifying monsoon unpredictability and increasing the frequency of droughts and floods. These environmental stressors, combined with fragmented land holdings, outdated canal infrastructure, and limited access to real-time data, hinder India's ability to implement sustainable water management strategies.

Despite the establishment of programs like the Command Area Development and Water Management (CADWM) scheme, designed to enhance water use efficiency through better canal infrastructure and field-level application, implementation has been inconsistent. Challenges include a lack of coordination between central and state agencies, poor maintenance of distribution systems, and insufficient farmer training.

Given that over 60% of India's rural population depends on agriculture for their livelihoods, the urgency to shift from reactive to proactive, technology-enabled irrigation planning is paramount. A modernized, data-driven approach, integrating geospatial intelligence, remote sensing, and IoT-based decision support systems, can help transform India's irrigation landscape and ensure long-term water and food security.

Objective/Goal

The primary objective of this study is to develop a scalable, data-backed strategic roadmap to promote the widespread adoption of smart irrigation practices across India. This initiative is centered on modernizing the Command Area Development and Water Management (CADWM) framework by integrating advanced technologies, predictive analytics, and global best practices into its core design and execution.

Smart irrigation, defined by the use of real-time data, automation, and optimization algorithms, can significantly reduce water wastage, improve crop yields, and enhance decision making at both farm and policy levels. By aligning CADWM with contemporary innovations such as IoT-based soil moisture sensing, AI-driven irrigations scheduling, GIS-enabled command area mapping, and cloud-based water demand forecasting tools, India can transition from legacy irrigation practices to a more efficient, equitable, and an adaptive system making her a "Global Leader in Agriculture."

This road map aims not only to guide the technical modernization of irrigation infrastructure but also to serve as a policy blue print for central and state governments to implement context-sensitive, data-informed, and outcome-oriented irrigation strategies. Its ultimate goal is to improve water productivity, enhance farmer

incomes, and contribute to India's broader agenda of climate-resilient and sustainable agriculture under the Viksit Bharat vision for 2047. This will become a "Lucrative &Profit-making model for farmers as well as Agri-Entrepreneurs."

Methodology/Proposal

This research adopts a multi-pronged strategy to design a robust, scalable roadmap for modernizing India's irrigation framework under CADWM. The methodology emphasizes evidence-based policy design, incorporating both international best practices and domestic pilot project learning to create a tailored and actionable plan for India's diverse agro-ecological landscape.

Key components of the methodology include:

❖ Comparative Case Study Analysis: A review of successful precision irrigation programs in countries such as Israel, Australia, and the Netherlands, nations that have demonstrated exceptional efficiency in water use through smart irrigation technologies and governance reforms (World Bank, 2020). This comparative analysis will extract key operational, technological, and policy insights applicable to India.

❖ Agro-Climatic and Socio-economic Profiling: Mapping of India-specific agro-climatic zones (ICAR- CRIDA, 2022), cropping patterns, and farmer resource profiles to ensure region-sensitive strategy design. This includes identifying areas with the highest irrigation inefficiencies and water stress for targeted intervention.

❖ Technology Stack Integration: Deployment of advanced tools including:

IoT-based soil and moisture sensors for real-time field data;

GISandsatellite-based remote sensing for area mapping and commandtracking;

AI and machine learning models to predict water demand, crop suitability, and irrigation cycles (FAO, 2021).

❖ Stakeholder and Institutional Mapping: Identification and engagement of key factors-Farmer-Producer Organizations (FPOs), state irrigation departments, agricultural cooperatives, and technology partners. A participatory planning approach will be followed to ensure on-ground alignment and implementation viability.

❖ Pilot Testing and Feedback Loop: Select districts will be chosen for pilot implementation based on irrigation potential, policy readiness, and infrastructure. Results will be used to calibrate the national strategy, creating a robust feedback mechanism for policy learning and refinement.

This methodology ensures that the proposed roadmap is technically sound, socially inclusive, and administratively implementable, setting the foundation for nationwide scale-up.

Findings/Expected Outcomes

The preliminary framework and review of global and domestic practices strongly indicate that the proposed CADWM-aligned smart irrigation roadmap will deliver multi-dimensional impact at both micro(field-level) and macro (policy-level) scales. Key anticipated outcomes include:

❖ Substantial Gains in Water Use Efficiency: By integrating real-time monitoring via IoT devices and predictive analytics, the roadmap is expected to increase irrigation efficiency by15-25%, particularly in command areas with historically low water productivity (NITI Aayog, 2019). Automation and demand-based scheduling will significantly reduce conveyance and application losses.

❖ Greater Transparency and Governance Accountability: The use of GIS mapping, digital dashboards, and public water audits will improve institutional transparency, allow for decentralized decision- making, and enable timely interventions by state water management authorities (FAO, 2021).

❖ Data-Driven Decision Support Systems: The roadmap will embed AI-enabled decision models that synthesize weather, crop, and soil data to guide water allocation strategies. These systems will al- low for targeted interventions and adaptive resource management, improving resilience to climate variability (ICRISAT, 2020).

❖ Scalability and Replicability Across States: The modular design of the framework ensures it can be customized and deployed across diverse agro-ecological zones in India. It can serve as a replicable model for other irrigation schemes beyond CADWM, thereby mainstreaming smart irrigation into state and national policy instruments.

❖ Socio-Economic Benefits: Indirect benefits such as reduced farmer distress, increased crop yields, and improved rural livelihoods are expected as a result of more predictable irrigation and enhanced resource security (World Bank, 2023).

These outcomes, once validated through pilot implementations and policy feedback loops, will help institutionalize precision irrigation as a national strategy for sustainable agriculture, aligning with India's climate commitments and development goals.

Conclusion/Significance

This research contributes meaningfully to India's broader mission of sustainable agriculture, rural resilience, and water security by reimagining the Command Area Development and Water Management (CADWM) framework through a technology-firstlens. By operationalizing CADWM using modern digital tools, IoT, GIS, AI, and data analytics, the proposed strategy not only modernizes legacy infrastructure but also builds institutional and farmer-level capacities for adaptive and responsive irrigation management.

The roadmap directly supports India's national priorities under the Viksit Bharat 2047 vision, which emphasizes inclusive development, technology-enabled governance, and climate-resilient systems (NITI Aayog, 2023). Furthermore, it aligns with India's Sustainable Development Goals(SDGs), particularly SDG2 (Zero Hunger), SDG6 (Clean Water and Sanitation), and SDG13 (ClimateAction), by promoting water-efficient food systems that leave no community behind.

Democratizing access to precision irrigation through open-source platforms, cooperative models, and decentralized planning ensures that smallholder farmers-, who constitute over 80% of India's farming population, are not left out of the digital agriculture revolution (FAO, 2020).

Ultimately, this work offers a scalable and inclusive policy blueprint that integrates technology, local capacity, and institutional alignment, positioning India as a global leader in climate-smart irrigation and sustainable water governance.

Keywords: Smart irrigation, CADWM, Precision agriculture, Data-driven planning, FPOs

Decoding Irrigation Patterns Amid Water Stress Trends

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Background/Introduction

Water stress is a persistent and growing threat to India's agricultural sector, which already consumes over 80% of available freshwater resources. With increasing climate volatility, monsoon dependency, and regional drought patterns, India's irrigation strategies must evolve to be both adaptive and predictive. Historical practices such as flood irrigation are increasingly untenable in water-scarce regions, leading to inefficiencies and ecological degradation.

Amid these challenges, understanding how irrigation behaviors shift during water stress periods is critical to planning sustainable futures. New patterns are emerging as farmers adapt cropping choices, irrigation techniques, and timing in response to water availability. However, these patterns remain under-studied and poorly quantified at scale. This study uses satellite data, open datasets, and AI tools to decode irrigation dynamics in stressed geographies and proposes a roadmap for context-sensitive technology transitions.

Objective/Goal

To develop a data-driven policy and planning frame work that decodes irrigation shifts under water stress and guides future irrigation strategies for India. The goal is to support adaptive planning through evidence-based insights on behavioral trends, spatial irrigation reconfiguration, and economic-environmental trade-offs.

Methodology/Proposal

The research methodology combines geospatial analytics, climate trend modeling, and machine learning over open and historical datasets. Key components include:

- Historical Stress Mapping: Analyzing past 20 years of water stress indices using IMD and global drought datasets.
- Satellite-based Irrigation Detection: Using remote sensing to identify changes in irrigated area, crop types, and method adoption.
- Behavioral Pattern Analysis: Training ML models to correlate stress events with cropping patterns, irrigation technology transitions, and yield shifts.
- Quantified Benefit Modeling: Comparative simulations to measure the net benefit of switching from flood to drip or sprinkler irrigation.
- Decision Tools for Drought Zones: Creating a toolkit for planners to model future scenarios in semi-arid and drought-prone regions with AI-backed recommendations.

Findings/Expected Outcomes

- Irrigation Trend Insights: Spatial-temporal visualization of irrigation shifts linked to water stress conditions.
- Technology Recommendations: Region-specific advisories on optimal irrigation methods based on water availability and cost-benefit outcomes.
- Improved Planning Models: Inputs for national irrigation and cropping strategy models that account for stress-responsive behaviors.
- Targeted Interventions: Tools to help

policy makers and FPOs prioritize investments in drip/sprinkler systems in the most at-risk areas.

Conclusion/Significance

Future-proofing India's irrigation strategy requires more than infrastructure-it demands intelligence. This research highlights the untapped value of decoding irrigation trends under stress using historical data, satellite imagery, and AI/ML. The proposed framework empowers government agencies, cooperatives, and agri-tech providers with tools to anticipate and act-not just react-to emerging irrigation needs. It paves the way for adaptive, efficient, and climate-resilient irrigation policy that ensures both water sustainability and farmer well-beings.

Keywords: Water stress, Irrigation planning, Drought mapping, Precision agriculture, AI/ML

Design and Development of an Automated Organic Fertilizer Application Machine

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Abstract

The increasing demand for sustainable agriculture has led to a renewed focus on organic farming practices. A critical aspect of this approach is the efficient utilization of organic fertilizers, which not only improve soil health but also reduce dependence on chemical inputs. This study presents the development and evaluation of an organic fertilizer machine designed to process, handle, and apply organic manure with precision and minimal human effort. The machine is equipped with a hopper, metering mechanism, and a sensor-based discharge system that ensures uniform application of compost, vermicompost, or biogas slurry-based solidmanure,By automating the application process, the machine enhances operational efficiency, reduces labour requirements, and minimizes environmental impact. Preliminary trials indicate improved nutrient distribution and time-saving benefits for small and medium-scale farmers. The machine aligns with the goals of sustainable farming and offers a viable solution for organic waste management and productivity enhancement in agriculture.

Empowering Marginal Farmers and Rural Women through Circular Economy Based Organic Moringa Farming with Waste Utilization and Carbon Credit Integration

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Abstract

This manuscript proposes an inclusive and scalable model under the theme; Circular Economy: Organic and natural farming for providing better quality food; waste utilization to monetiseagri waste for increasing farmers' income as well as protecting environment; carbon credits to support farmers in earning credits for sustainable practices.Designed specifically for small and marginal farmers, the project focuses on Moringa cultivation using organic and natural farming practices such as Jeevamrut, Beejamrut, mulching, and intercropping. Moringa, being drought-resistant and nutrient-rich, offers high-value output with minimal input costsmaking it ideal for farmers with less than 2 acres of land.A key innovation is on-farm waste utilization. Moringa stems andleaves, intercrop residues, and cow dung will be converted into vermicompost and biochar using low-cost rural techniques. Biochar improves soil health while sequestering carbon. This not only reduces dependency on chemical inputs but also creates micro-enterprises for income generation from agri-waste.The model integrates rural women's empowerment by engaging them in composting, drying, grading, value-added production of Moringa powder, tea, and herbal capsules providing livelihood opportunities, financial independence, and skill development within the village ecosystem.To future-proof the initiative, the project introduces a carbon credit readiness system using simple digital tools to track organic input use and biochar application. This will prepare the farming group to earn carbon credits in upcoming voluntary carbon markets.This holistic model delivers nutritional food, climate action, livelihood generation, and gender equity; all from a small piece of land. It is ready for implementation and suitable for scaling through Farmer Producer Companies (FPCs), SHGs, and CSR-supported village clusters across India.

Yield and Water Use Efficiency of Linseed Influenced under Tillage and Mulching Practices

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Abstract

This study aimed to identify the most suitable conservation agricultural management practices for enhancing both crop yield and water use efficiency in linseed cultivation. The research was carried out over three consecutive Rabi seasons (2019-2022) in the Navsari district of Gujarat, located within Agro-climatic Zone-3 (South Gujarat Heavy Rainfall Zone-I). A total of eight treatments, comprising various combinations of conservation tillage practices, were evaluated using a randomized block design (RBD) with three replications. The results revealed that the highest yield attributes were obtained under the conventional tillage combined with rice straw mulching and sunnhemp (Crotalaria juncea) green manuring during the preceding Kharif season treatment. Except for the first year, this treatment consistently outperformed both reduced tillage and conventional tillage without additional practices, showing statistically significant superiority. Conventional tillage combined with rice straw mulching and sunnhemp (Crotalaria juncea) green manuring during the preceding Kharif season treatment also recorded the highest grain and stalk yields, followed by conventional tillage + sunn hemp green manuring and reduced tillage + rice straw mulching + sunn hemp green manuring. Additionally, conventional tillage combined with rice straw mulching and sunnhemp (Crotalaria juncea) green manuring during the preceding Kharif season treatment significantly enhanced water use efficiency. Based on these findings, it is recommended that linseed growers adopt a combination of conventional tillage, rice straw mulching, and sunn hemp green manuring during the preceding Kharif season as an effective strategy to improve crop yield and water use efficiency.

Keywords: Tillage; Green manuring, Mulch, Yield and water use efficiency

The Future of Weed Control in Ornamentals: A Review of Autonomous Robotic Solutions

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Abstract

Weed management remains a critical challenge in modern agriculture, particularly in high-value floriculture crops where manual weeding is labour-intensive, time-consuming, and economically unsustainable. Mechanical weeding, when combined with automation, presents a promising alternative that enhances precision, reduces labour dependency, and promotes environmentally sustainable practices. This review aims to provide a comprehensive overview of autonomous weeding robots with a specific focus on their mechanical weed removal approaches. The paper explores various mechanical mechanismsincluding blades, rotary tools, harrows, and tine-based systemsemployed by robotic platforms to physically disrupt and remove weeds. Key components such as navigation systems, actuation technologies, crop-row detection methods, and control strategies are discussed, with emphasis on their integration for effective operation in structured and semi-structured floriculture fields. The review also highlights advancements in sensor technologies, artificial intelligence, and machine vision that support real-time decision-making in autonomous systems. Challenges related to miniaturization, crop-weed discrimination, energy efficiency, and field variability are examined. Finally, the paper presents future prospects and research directions to improve the adaptability and cost-effectiveness of robotic mechanical weeders, particularly in the context of small and medium-scale ornamental crop production systems. This review serves as a valuable resource for researchers, engineers, and policymakers aiming to advance the development and deployment of autonomous weeding robots in floriculture and other specialized crop sectors.

Keywords: Agricultural robotics,Mechanical weeding, Floriculture crops, Weed management.

Energy-Efficient Powertrain Architecture for Carbon-Neutral Electric Agricultural Machinery

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Abstract

The transition to sustainable agriculture necessitates the development of clean, efficient, and robust powertrains for modern farming machinery. This paper presents the design, multi-domain optimization, and experimental validation of a high-performance Switched Reluctance Motor (SRM) powertrain specifically tailored for electric tractors, with the goal of reducing dependency on internal combustion engines and minimizing the carbon footprint of agricultural operations. The SRM was selected due to its magnet-free construction, high reliability, and excellent torque characteristics at low speeds, which are essential for direct-drive agricultural traction systems that demand high pulling force and precise speed control under variable loads.

To improve performance and compactness, the motor design incorporates Soft Magnetic Composites (SMCs), such as Somaloy, enabling three-dimensional magnetic flux paths, isotropic thermal conductivity, and significantly reduced core losses, especially under high-frequency excitation typical of variable-speed field operations. The proposed SRM operates efficiently across a wide torque-speed envelope, supporting both low-speed high-torque tillage and higher-speed transport operations, eliminating the need for traditional multi-speed gearboxes.

The system architecture integrates a high-voltage battery pack, bidirectional DC-DC converters, and asymmetric H-bridge inverters for independent phase control, allowing real-time torque optimization and adaptive flux regulation based on task-specific load cycles. Advanced control algorithms, including torque ripple minimization and optimal current profiling, were implemented to improve drivability, reduce vibration, and extend battery life. Comprehensive Finite Element Analysis (FEA) and thermal-electromagnetic co-simulation were used to validate the design under worst-case agricultural load conditions.

Experimental results from a lab-scale prototype confirm improvements in static torque density, thermal stability, and overall drivetrain efficiency. The proposed SRM-based electric powertrain provides a scalable and fault-tolerant solution for next-generation electric tractors, enabling precision farming with lower emissions, reduced maintenance, and enhanced energy utilization, thus supporting global initiatives for carbon-neutral agriculture.

Design, Development and Field Evaluation of a Tractor-Operated Ginger Planter

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Abstract

Ginger rhizome planting in India faces significant challenges due to the lack of suitable mechanized solutions and acute labour shortages during the sowing season in major cultivation regions. Manual ginger planting is a tedious, drudgery-prone, labour-intensive, and time-consuming operation because it requires constant bendingposture during planting. To address this issue, a tractor-operated ginger rhizome planter was designed, developed, and evaluated at ICAR-Central Institute of Agricultural Engineering, Bhopal, with the aim of improving planting efficiency, reducing labour dependency, and achieving precise seed placement. Laboratory evaluation of the metering system was conducted using a sticky belt setup to study seed distribution under different forward speeds (0.42, 0.56, 0.69, and 0.83 m/s), rhizome sizes (small <35 mm, medium 35-50 mm, large >50 mm), and pickup finger types (P1 and P2). A factorial Completely Randomized Design (CRD) with three replications was used to analyse key performance parameters, including average spacing, miss index, multiple index, quality of feed index (QFI), and visible damage. Results indicated that speed, seed size, and finger type significantly influenced these parameters. Field evaluations were conducted under varying forward speeds, metering cup sizes, and seed grades. Cup size, speed, and seed grade significantly affected planting accuracy. Optimal field performance was observed at 2 km h-1 with cup size A2 and graded seeds, achieved highest QFI (75%). The planter demonstrated a field capacity of 0.25 ha h-1, reducing labour requirements by 76% and operational costs by 40% compared to manual planting. It performed better with properly graded seeds, however, its efficiency reduced when using non-graded seeds, which are more commonly used by farmers. Therefore, further refinements are necessary to enhance its adaptability to seed size variability.The developed planter offers a practical, efficient, and cost-effective mechanized solution for ginger cultivation.

Keywords: Ginger planter, mechanization, seed spacing, quality of feed index, labour saving, field efficiency

Comparative Impacts of Tillage and No-Till Systems on Soil Health: A Review

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Abstract

Soil tillage is a core agricultural practice used to prepare land for planting, manage crop residues, suppress weeds, and improve soil structure by incorporating organic matter and nutrients. It also plays a crucial role in regulating soil conditions such as moisture levels, temperature, and aeration. This article examines the effects of conventional tillage techniques and explores alternative methods to lower production expenses, mitigate environmental harm, and promote sustainable farming. The analysis is based on secondary sources, including published research, official reports, and institutional studies. Conventional tillage relies on mechanical soil disturbance, which influences moisture retention, heat distribution, and air circulation. Although this method can boost short-term yields, prolonged use often leads to soil compaction, erosion, and reduced organic content, ultimately degrading land quality. On the other hand, no-till and reduced tillage systems present a viable alternative, addressing pressing issues like climate change, water scarcity, and soil degradation. These practices allow diverse crops to be cultivated efficiently while cutting fuel and labor costs. Today, no-till and minimal tillage methods are gaining global adoption across farms of all sizes, demonstrating significant potential for long-term agricultural sustainability.

Keywords: Soil tillage, conventional tillage, agricultural, soil health, soil.

Engineering the Future of Indian Agriculture: A Roadmap to Viksit Bharat 2047

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Abstract:

Agriculture plays a vital role in India's socio-economic fabric, employing a significant portion of the population and contributing to food security. As the nation envisions becoming a developed country by 2047 under the Viksit Bharat mission, transforming the agricultural sector through innovation and engineering is essential. The traditional farming practices, while effective in the past, are now facing challenges due to climate change, resource scarcity, urbanization, and increasing population pressure. To overcome these challenges, agricultural engineering must adopt modern, sustainable, and technology-driven solutions. This abstract presents a comprehensive overview of innovative approaches that can shape the future of Indian agriculture. These include precision agriculture using GPS and sensors for real-time monitoring, automation and robotics for efficient field operations, and smart irrigation systems to optimize water usage. The integration of AI and machine learning into decision-making processes enables predictive analytics for crop planning and disease detection. Additionally, the use of renewable energy such as solar-powered pumps and dryers, ensures sustainability in operations. Post-harvest engineering innovations, such as cold storage chains, mechanized sorting, grading, and packaging systems, can significantly reduce losses and enhance value addition. Further, custom-designed machinery suited for small and marginal farmers helps bridge the gap in mechanization. The roadmap also emphasizes the need for skill development, farmer training programs, and policy frameworks to support the adoption of these technologies. Creating digital platforms for market access, weather forecasting, and agricultural advisories can further empower farmers. By integrating these engineering innovations and fostering collaboration among researchers, industry, and policymakers, India can build a resilient and futuristic agricultural ecosystem. This roadmap will not only ensure food and nutritional security but also elevate the status of Indian agriculture on the global stage by 2047.

Keywords: Agricultural Engineering, Smart Farming, Precision Agriculture, Sustainable Agriculture, Automation and Robotics, Artificial Intelligence (AI)

Design and Development of Maize Sheller for Hilly Regions

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Abstract

Crops are grown in hilly regions, similar to plain part of India. But, machinery available for agricultural operations are very less resulting, lower mechanization in hilly regions. Hill Farmers somehow do land preparation and sowing using indigenous plough and power weeders. Post-harvest operations in hills are still a challenging practice for any crop. The prevailing maize sellers (mostly tractor or power operated) are of very high capacity, costly, heavy in weight and unfit for hill topography. Keeping in view the above-mentioned points, low cost, light weight, small capacity, HalfHp electric motor operated maize Sheller suitable for hilly topography was developed at ICAR-VPKAS, Almora during the year 2017-20, namely "VL Maize Sheller". VL Maize Sheller comprises of frame, hopper, lugged rotor, supporting roller, concave, sieve and belt guard. Weight of machine was 54 kg. Shelling capacity of the VL Maize Sheller was 115 kg/h, almost 5 to 6 time more than manual shelling of maize cob. Maximum shelling efficiency was observed more than 95 % with less than 1 % grain damage and minimal cob wood breakage (<2%), at 13 to 14 % moisture content. VL Maize Sheller gave its best performance at 10 to 12 degrees of slope of rotor to the horizontal. Optimum lugged roller speed was 960 rpm. Overall dimension of machine was 1030 mm length, 300 mm width and 950 mm height. The unbroken cob woods were also desirable characteristics of VL Maize sheller. Cob wood has calorific value of 17 MJ/kg, hilly region farmer uses these as fire wood to generate heat during winter season.

Keywords: Maize sheller, post-harvest, light weight machine, hilly regions.

Farm pond: A Climate Resilient Farming Technique for Rainfed Eco-System of Marathwada region, Maharashta

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Abstract

Runoff is one of the important hydrologic variables used in most of the water resource applications. Watershed characteristics such as slope, shape and size of land, cover of soil, duration, intensity and distribution of rainfall have a direct effect on the peak flow and volume of runoff from any area (Chandler and Walker, 1998). Estimation of runoff is very important to manage the water resources efficiently. Marathwada region of Maharashtra receives mean annual rainfall of 880 mm. Rainfall in uncertain and erratic in this region and sometimes suffers from severe droughts that affect the productivity in rainfes eco-system. The rainfall data mainly from rain scarcity zone, assured rainfall zone and moderate to high rainfall zone of the Marathwada region were collected from the Agro-meteorological station under VNMKV, Parbhani. Runoff was estimated using SCS curve number method considering the all parameters like soil type, vegetation etc. The rainfall runoff relationship was worked out for further planning of small water harvesting structures like farm ponds. The runoff potential for rain scarcity zone, assured rainfall zone and moderate to high rainfall zone is found to be 20.07 %, 28.31 % and 31.69 % respectively, indicating a good scope for rainwater harvesting. Standardization of farm ponds is important for rainfed farmers of the region which proved as a most effective climate resilient technique. Farm pond provide a source of supplemental / protective irrigation particularly during dryspell condition to sustain the crop productivity in rainfed eco-system. A relation between rainfall and runoff for rain scarcity zone, assured rainfall zone and moderate to high rainfall zone were worked out as Y = 0.301X - 55.711 (R2value - 0.75), Y = 0.4043X - 88.882 (R2 value - 0.8687) and Y = 0.6018X - 209.2 (R2 value -0.9575) respectively. The linear rainfall-runoff relation obtained can be used for finding out runoff corresponding to any rainfall occurring in the area. The rainfall runoff relationship was found useful for determination of rainwater harvesting potential and its reuse for enhancing production potential of various rainfed crops. Based on runoff potential, the standard sizes of farm ponds were designed for 1 ha, 2 ha and 3 ha catchment area respectively for rain scarcity zone, assured rainfall zone and moderate to high rainfall zone of Marathwada region.

Key words: Farm pond, Micro-catchment, Rainfall, Runoff,

Planning, Designing and Cost Estimation of Soil and Water Conservation measures for Sarastal Micro Watershed

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Abstract

In order to select suitable sites for proposing soil and water conservation measures survey of India (SOI) topographical map was used to create the basic maps, such as the watershed boundary and drainage network. The different thematic maps were prepared and morphometric analysis done for the Sarastal micro watershed with the help of GIS techniques. By overlay of land use / land cover map and soil map, curve number map has been generated and curve number with antecedent moisture content was obtained. Finally runoff depth map was generated and found that maximum runoff depth was 24 mm. On the basis of geographical situation, present land use condition, soil type and runoff depth suitable site were selected for the conservation measures of soil and water. Some of the Engineering and agronomical conservation measures were designed for the study area such as loose stone check dam, gabion structure, farm pond, contour trench, contour bunding, grassed waterway, stubble mulch, strip cropping, mix cropping system and pasture development. Based on the result it was concluded that the drainage pattern was not affected by structural disturbance as evidenced by the low bifurcation ratio. The high elongation ratio compared to the circulatory ratio suggests that the watershed is elongated. The use of remote sensing and GIS, helped for identification of soil and water conservation measures for the study area by considering the factors like physiography, soils, slope, drainage pattern etc. Cost estimation for these proposed structure has been done. The cost of the one loose boulder check dam is estimated as Rs. 8000.00, cost for the one gabion structure is estimated as Rs. 26000.00, cost of one farm pond is estimates as Rs. 500000.00, cost of contour bund is estimated as Rs. 181200.00, cost of one grassed waterway is estimated as Rs. 5400.00 and cost estimated for agronomical measure is Rs 25000.00.

Key Words: Morphometric analysis; Runoff; Thematic Map; Land use/cover; GIS.

Development of machinery package to facilitate the adoption of controlled traffic farming in sugarcane cultivation

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Abstract

In India, sugarcane plays a pivotal role in the industrial sector and significantly contributes to the socio-economic development of rural communities. This contribution is closely linked to the mechanisation of sugarcane cultivation, which enhances productivity, reduces labour dependency, and ensures timely operations. Recognising the limitations of conventional planting systemsparticularly soil compaction due to uncontrolled traffic and inefficiencies in mechanised operationsa need was felt to develop a suitable machinery package to support controlled traffic farming (CTF) in sugarcane cultivation. A machinery package was developed to enable the adoption of CTF in sugarcane cultivation by modifying the conventional planting geometry and associated field equipment. The primary objective was to segregate plant and traffic zones to minimize soil compaction in the root zone and enhance crop productivity. Traditionally, sugarcane is planted in symmetrical patterns with 750 to 900 mm row spacing in tropical regions and up to 1500 mm in subtropical areas using paired-row trench planting (300 mm apart within a trench and 900 mm between trenches). This layout often results in intermixing of traffic and plant zones. To address this, two modified planting geometries were developed including double-row planting with 600 mm spacing forming a compact plant zone (1350 mm total width) followed by a 400 mm dedicated traffic lane, and paired-row planting within a trench (300 mm apart) maintaining the same spatial configuration. To support these geometries, farm machinery was adapted. The tractor's track width was increased from 1.0 m to 1.2 m, and the sugarcane planter was modified to accommodate 600 mm row spacing. A rotary weeder was redesigned by reducing flange numbers to narrow the operational width to 300 mm. An integrated weed manager with three 600 mm-spaced tynes was developed for targeted weed control. Earthing-up implements were adjusted to manage soil ridging for both outer and middle rows. Trash management equipment was also introduced to handle post-harvest residues efficiently. This machinery suite, designed for systematic traffic patterns, significantly enhanced field efficiency and crop growth. Yield improvements were notable, conventional sugarcane planting yielded approximately 80 t/ha, while modified configurations recorded 101 t/ha and 125 t/ha, respectively. These results underscore the potential of machinery-supported CTF in optimizing sugarcane production systems.

Sensor based Precision Water Management in Fruit Orchard

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Abstract

In the face of increasing water scarcity and climatic variability, it becomes a real and practical challenge to go for efficient watering schedule based on soil and crop moisture status. Precision water management encompasses soil moisture sensors, remote sensing, weather forecasting and automated irrigation systems to optimize water application rate. Traditionally, through gravimetric method soil moisture status has been observed, which is very tedious and time-consuming. Hence, modern techniques like soil resistivity sensor, tensiometers, infrared moisture balance and dielectric techniques like Time Domain Reflectometry (TDR) and Frequency Domain Reflectometry (FDR) etc. can be practical aids while going for need based application of irrigation to plants. The modern fruit orchards tend to monitor various soil, weather and plant parameters in order to have a better control over wastage of water resources. Therefore, by integrating site specific data and predictive models, the fruit growers will be able to achieve maximal productivity even under marginal conditions.

Key words: Precision, Sensor, Orchard, TDR, FDR

Farm mechanization for cost-effective cultivation of sugarcane

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Abstract

In India,sugarcane plays a pivotal role industrial sector.It significantly contributes to the socio-economic development of rural communities. While factors like variety, natural inputs, and general production aspects are essential, the advent of mechanization has become a crucial component in sugarcane cultivation. Mechanization has brought about substantial changes in recent years, enhancing input efficiency and overall productivity in sugarcane farming.Currently, the mechanization level in sugarcane cultivation stands at 35%, with seedbed preparation leading at 65%, followed by intercultural activities and plant protection at 30%. Even in labor-intensive processes like sugarcane planting and harvesting, there is potential for mechanization, reaching 20-25%.

The ICAR-Indian Sugarcane Research Institute, Lucknow has been consistently working towards developing agricultural machinery for sugarcane mechanization.Various machinery and equipment have been developed to streamline operations from seedbed preparation to ratoon management. The institute has introduced a range of equipment, including ridger type and paired row sugarcane cutter planters, raised bed seeders, sugarcane-cum-potato planter, and ratoon management devices. Recent developments include deep furrow sugarcane cutter planters, trench planters, and disc-type sugarcane ratoon management devices.Extensive field testing and demonstrations have confirmed the utility of these machines, showcasing their cost-effectiveness, reduced labour requirements, timely operations, and diminished human drudgery.

Collaborative efforts among stakeholders are crucial for widespread mechanization in sugarcane cultivation to achieve overall system efficiency. Initiatives are underway to promote lateral expansion of sugarcane planters and cultivation practices, aiming for the adoption of sugarcane combine harvesters.The emphasis on using cost-effective machinery for various cultural operations in sugarcane-based cropping systems is essential for enhancing farmer profitability by minimizing operational costs, increasing input efficiency, and improving overall productivity of sugarcane.

Trisul Technology: A way to enhance the Pigeon pea production potential for climate resilient agriculture

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Abstract

Pigeon pea is one of the major pulse crop in tropics and subtropics due to its ability to bring forth economic yields under scarce rainfall conditions. It is contributing a substituent crop of dry land agriculture where rainfall is one of the key meteorological parameter that influences on crop production. The crop yield -weather relations, is requisite to account for the influence of improved technology on the crop yields. Among these, rainfall distribution has profound effect on crop performance in rain fed agriculture in present climate change scenario. In this context, VNMKV Trisul technology is an independent model of pigeon pea production where rainwater harvested in lined farm pond and used by solar water lifting system to operate the micro irrigation system. The Trisul model is installed at Irrigation Water management Experimental farm, VNMKV, Parbhani to evaluate the production potential of Pigeon pea (Cajanuscajan L.) under different row spacing with standardize fertigation schedule using micro irrigation system. The experiment was conducted with randomized block design (RBD) with seven replications during monsoon season 2024-25 in a medium black soil. The treatment was consisted of five planting geometries viz. 240 cm x 30 cm, 180 cm x 30 cm, 150 cm x 30 cm and 120 cm x 30 cm with BDN 2013-41 (Godavari) genotypes. Amongst the planting geometries, planting geometry (treatment Spacing -S2) of 150 cm x 30 cm recorded significantly higher yield (29.01q ha-1) as compared to other treatments followed by treatment spacing -S1 (180 x 30 cm). The spacing treatment S2 recorded the highest cost benefit ratio 3.06. The highest irrigation water use efficiency was recorded under the spacing treatment S1 followed by S2. By application harvested rainwater through micro irrigation system, with spacing of 180 x 30 cm farmers can irrigate the 2.61 times more area as compare to conventional furrow irrigation with same quantity of irrigation water with additional gross monitoring. Solar water lifting system using micro irrigation system recorded the addition benefits of carbon credits.

Wireless soil moisture sensors-based irrigation scheduling in wheat

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Abstract

An experiment was conducted during the 2023-24 wheat growing season to evaluate the performance of a wireless soil moisture sensor-based automatic irrigation system. The main objective was to develop an efficient, real-time-based irrigation system for the surface irrigation method. Resistance-based multipoint wireless soil moisture sensors were strategically installed at 50% and 75% of the field length. The sensors continuously monitor the soil moisture at different depths and send it to the cloud server through LoRa and GSM wireless protocol. The irrigation event started as the soil moisture depletion reached 50% of the available water capacity, a threshold considered critical for optimal crop growth. The wireless sensors utilized LoRa (Long Range) communication technology to transmit real-time soil moisture data to a gateway at 15-minute intervals. This gateway, equipped with GSM (Global System for Mobile Communication) connectivity, relayed the data to a cloud server for centralized monitoring and data analysis. The system was integrated with an automated check gate installed at the field channel, which controlled the irrigation flow based on sensor feedback. When soil moisture dipped below the predefined threshold, the system automatically triggered the check gate to initiate irrigation. Conversely, as the soil moisture content approached field capacity, the system triggered the motor to close the gate, thus preventing over-irrigation. This smart irrigation system demonstrated significant improvements in water use efficiency. Results show that the sensor-based irrigation method led to water saving of approximately 25-30% compared to conventional irrigation practices in wheat cultivation. These findings highlight the potential of wireless sensor-based automation in improving on-farm water management, enhancing crop productivity, and supporting sustainable agriculture under limited water availability conditions.

Groundwater Potential Zoning in Meerut District Using Remote Sensing and GIS Technique

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Abstract

The over-exploitation of our reserved and safe ground-water resources is an extremely thinkable issue. It hinders the ultimate objective of sustainable management of water-resources worldwide. In the last decades many progresseshave been made in the mapping of Potential Zones of Groundwater (GWPZ). But due to limited availability of datasets, it has been very difficult and time consuming for analysing the geological parameters and ground truthing the same at large scale.

In the current scenario, the vast availability of satellite datasets for rainfall, temperature, morphological parameters (slope, drainage density, aspect, curvature etc.), geological parameters (lithology, lineament density etc.), have explored the ground water situation. The applications of remote sensing and geographic information system (GIS) are imparting significant role in the identification and delineation of ground water potential zones, particularly in arid and semi-arid regions.

This study delineates groundwater potential zones (GWPZ) in Meerut region by integrating Remote Sensing (RS), Geographic Information System (GIS), and Analytical Hierarchy Process (AHP) techniques. Ten thematic layers-geomorphology, land use/land cover, lithology, soil, slope, rainfall, drainage density, curvature, Topographic Wetness Index (TWI), and Topographic Position Index (TPI)-are analysed. Weighted overlay using AHP produced a groundwater potential zonation map categorizing the district into five zones: Very High, High, Moderate, Low, and Very Low. Moderate and Low zones dominated the area, while Very High and High zones are primarily located along riverbanks and alluvial plains. The findings offer a scientific foundation for sustainable groundwater management in the region.

Keywords: Groundwater Potential Zone (GWPZ); Geographical Information System (GIS); Analytical Hierarchy Process (AHP).

Spatial distribution of reference evapotranspiration for Aurangabad district of Maharashtra

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Abstract

Evapotranspiration estimation is required for effective water management and crop planning. So that reference evapotranspiration was calculated using Hargreaves Samani and Penman Monteith method for Aurangabad district. The primary objective of this study is to investigate the possibility for application of the Hargreaves-Samani equation in Aurangabad district for computing daily reference evapotranspiration. An evaluation of the Hargreaves-Samani equation and its modifications proposed in literature is made by comparing daily estimates with Penman-Monteith results DSS_ET software was used to calculate reference evapotranspiration. Annual Average reference evapotranspiration for Aurangabad district was found to be 5.13 and 5.25 mm/day for Hargreaves and Penman method respectively. Statistical analysis was made to evaluate the performance of reference evapotranspiration methods by using standard deviation, was found 0.33 to 1.81 mm/day for Penman method and 0.24 to 0.89 mm/day for Hargreaves method. For Aurangabad district, its skewness coefficient value ranges between -1.30 to 1.64 during various meteorological weeks for Penman method and -2.05 to 1.07 for Hargreaves method.

Keywords: Evapotranspiration, software, standard deviation, meteorological week

Advances in Space Technologies for Agriculture

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Abstract

Space technologiesincluding Remote Sensing (RS), Global Positioning System (GPS) and Geographic Information System (GIS)enhance productivity, cut input costs, and build a robust and sustainable agri-food system, thus empowering stakeholders-from farmers to policymakers. The increasing availability of high-resolution datasets from ISRO missions (e.g., Cartosat, Resourcesat, RISAT, and recently launched NISAR sensors) in addition to UAV/drone-based data,make the technique of Remote Sensing and Geographic Information System applicable to agriculture. These data help monitor soil health, crop health, conserve soil and land resource, forecast weather,predict extreme conditions like drought etc.

RS platforms, equipped with sensors of increasing spatial, spectral, and radiometric resolutions, provide cost-effective data to monitor soil and land conditions over vast geographic areas. Through available high-resolution multispectral and hyperspectral imagery, microwave data, and thermal datasets and theirfurther analysis using Crop Moisture Index (CMI), Standardized Precipitation Index (SPI), Normalized Difference Vegetation Index (NDVI), Vegetation Condition Index (VCI), Temperature Condition Index (TCI), Normalized Difference Water Index(NDWI), Land Surface Water Index (LSWI), Moisture Stress Index (MSI), Vegetation Health Index (VHI);spectral characterization of soil, vegetation, water and rocks can be attained.

Whenelectromagnetic (EM)energy in incident upon any material, it may either reflect, get absorbed by the material surface or transmit through the material. These three interactions create unique spectral signatures. These distinct patterns of energy response, shaped by each material's properties, are the foundation for many remote sensing applications. Soil organic carbon, salinity, moisture content, and nutrient status can be quantified with the help of soil reflectance signature using spectral analysis of RS data. Similarly crop surface reflectance allows to discriminate between different crop types based on their spectral signatures.

Remote sensing data can be merged with tools like GIS, artificial intelligence (AI), and cloud computing.This enables effective decision-making in agriculture, environmental protection, and climate change mitigation.

Key words: Remote Sensing (RS), Global Positioning System (GPS), Geographic Information System (GIS), electromagnetic (EM) spectrum, artificial intelligence(AI)

Assessment of Plantation-Induced Variations in Soil Properties and Hydrological Processes

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Abstract

Understanding the influence of plantation crops on hydrological processes is essential for effective catchment management and sustainable development. The type and spatial distribution of plantations within a catchment can significantly modify rainfall partitioning into runoff by altering key hydrological components such as interception, evapotranspiration, infiltration, interflow, surface runoff, base flow, and groundwater recharge. In addition, plantation cover, combined with land management practices, acts as an extrinsic factor affecting soil properties, including hydraulic conductivity, pH, electrical conductivity (EC), nitrogen content, and organic carbon content.

This study investigates the impact of horticultural and forestry plantation crops on various hydrological processes through an experimental study conducted under controlled conditions at IIT Kharagpur. The research involved micro-watersheds with ten different plantation crops. Results revealed that variations in soil properties were statistically insignificant within the same plantation type at a 95% confidence interval; however, significant differences among plantation types indicated their influence on soil characteristics in micro-watersheds. Plantations also affected the basic infiltration rate, which ranged from 12 mm h?^{1} to 47 mm h?^{1} across treatments. Throughfall (TF) exhibited an inverse relationship with Leaf Area Index (LAI), ranging from 66% to 88% of total rainfall. Mean available soil moisture in the 10 cm to 140 cm soil profile varied between 10% and 25% among plantations during 2017. Additionally, runoff, sediment yield, and groundwater depletion were quantified for the study period, highlighting the critical role of plantation cover in regulating watershed hydrology.

Keywords: Soil properties, soil moisture, interception, Leaf area index, and runoff

Emerging Trends and Future Prospect of Biogas Generation from Agro-Waste

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Abstract

Biogas production from agricultural waste is becoming more popular as a sustainable solutionfor renewable energy generation and waste management. This study presents emerging trendsand recent advancements in biogas production from diverse agricultural residues. Theemphasis is on innovative pretreatment strategies that greatly increase methane yield anddigestive efficiency, such as microbial consortia, enzymatic-alkaline hybrid approaches, andnano-additive-enhanced digestion processes. Special attention is given to underutilized agricultural wastes that have remarkable potential but are yet mostly unexplored, such as ricestraw, sugarcane bagasse, maize stalks, fruit peels, and aromatic crop wastes. The latestadvancements in real-time monitoring, co-digestion techniques, and decentralized biogasplant designs are also covered. Precision farming and the incorporation of biogas systems into circular bio economy models are emphasized as potential future directions. Key researchgaps, challenges with implementation, and scaling-up potential in rural and peri-urban areasare highlighted in this review. It offers a current perspective on the state of agro-waste-basedbiogas technology and forms the basis for upcoming applied research and policy developmentin sustainable agriculture and renewable energy.

Keywords: Agro-Waste; Biogas; Pretreatment; Emerging Trends; Future Prospect

Water Neutrality Strategy for Sustainable Agricultural Water Management in the BurhiGandak River Basin under Changing Climate Scenarios

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Abstract

The BurhiGandak River basin, encompassing a catchment area of 12,000 km^2 in eastern India, faces mounting pressure on its water resources due to declining groundwater levels, inefficient irrigation practices, and increasing water demand for agriculture. This approach proposes an integrated water neutrality strategy aimed at conserving 1.0 cm of water annually across the basin, equivalent to 120 million cubic meters (MCM). It combines demand- and supply-side interventions to sustainably balance water availability and usage. The core of the strategy focuses on enhancing irrigation efficiency from 40% to 60% in the predominantly canal and groundwater irrigated agricultural areas. This improvement alone can yield potential water savings of approximately 4,542 MCM annually, far exceeding the neutrality target. Complementary supply side measures including constructing 20,000 farm ponds, check dams, rooftop rainwater harvesting structures, recharge shafts, and soil moisture conservation practices add another 60-80 MCM of water conservation potential. The strategy is to align with national flagship programs such as PMKSY, Jal Shakti Abhiyan, and MGNREGA, ensuring policy coherence and funding convergence. A robust institutional and implementation framework comprising policy incentives, community involvement, and real-time monitoring using remote sensing and IoT, to support long-term sustainability, needs to be evolved. An attempt at an integrated, scalable approach is presented to achieve water neutrality in the basin that contributes to both climate resilience and agricultural sustainability.

Keywords: Water neutrality, water budgeting, water balance, groundwater recharge, irrigation management.

Development of Crop Coefficient of Rabi Sorghum by using Automatic Weighing type Lysimeter

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Abstract

Crop coefficient is important for designing, planning and irrigation scheduling of agricultural crops. Hence, there is great need to develop the location specific crop coefficient (Kc) to apply the accurate irrigation to the crops as per crop specific growth stages which avoids the under or over application of irrigation water. The worldwide-developed FAO Kc values which leads over or under estimation of irrigation water. The crop like millets requires accurate application of irrigation to avoid the over application of irrigation water which leads a problem of wilting of millet. The results of automatic weighing-type lysimetric crop coefficients developed for semi-arid agro climatic zone of Parbhani, Maharashtra for Rabi Sorghum were differ to that of Kc reported in FAO 56. The developed Kc values of Rabi Sorghum for initial (1-3 CW), development (4-8 CW) were 0.38, 0.72, respectively. Whereas mid-season (9- 15 CW) and end (16-19 CW) stage Kc values were recorded 1.16 and 0.65 respectively. The stage wise crop water requirement for initial, development, mid-season and end stages were 41.39 mm, 170.95 mm, 285.75 mm and 102.62 mm respectively. The total seasonal water requirement during crop period for Rabi Sorghum was determined as 600.71 mm.

Keywords: Sorghum, Crop coefficient, Reference evapotranspiration

Design and Development of Small Size Tractor Operated Raised Bed Seeder-cum-Sugarcane Cutter Planter

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Abstract

Small and marginal farmers face significant challenges in adopting advanced farm machinery due to high costs, large equipment sizes, and incompatibility with small landholdings. To address these constraints, this project focuses on the design and development of a small-size tractor operated raised bed seeder-cum-sugarcane cutter planter, an integrated implement that combines the operations of raised bed formation, seed sowing, sugarcane set cutting, and planting in a single pass. The machine is specially designed for compatibility with mini and small-size tractors (15-25 HP), making it suitable for fragmented and narrow fields.

The system features adjustable bed shapers, a metering mechanism for sowing multiple crops (such as wheat, pulses, and oilseeds), and a rotary-type sugarcane cutter unit that chops cane into sets of desired length. These sets are then placed accurately in the furrows formed on raised beds, ensuring uniform planting depth and spacing. This multipurpose equipment reduces labour dependency, saves time, optimizes input use, and enhances field efficiency. The integration of raised bed technology further promotes better soil moisture management, improved root development, and efficient irrigation. The developed implement offers a sustainable and economical solution for improving the productivity of smallholder farms.

Keywords: sugarcane, planter, tractor, mechanization

Prediction of the standardized precipitation index based on the long short-term memory and empirical mode decomposition -extreme learning machine models: The Case of Bolangir district of Odisha

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Abstract

This study predicted meteorological drought in the Bolangir district of Odisha using a Long Short-Term Memory (LSTM) deep learning model. The Standardized Precipitation Index (SPI), derived solely from monthly precipitation data, was calculated for 1, 3, and 6-month time scales from records spanning 2000-2024. Precipitation values at time steps t, t-1, t-2, and t-3 were used as input variables to predict SPI at the respective time scales. Model performance was also compared with an Empirical Mode Decomposition-Extreme Learning Machine (EMD-ELM) hybrid approach to assess the advantages of the standalone LSTM framework. The LSTM achieved superior performance for SPI-1 (MAE = 0.10, NSE = 0.98, R^2 = 0.98) and SPI-3 (MAE = 0.10, NSE = 0.95, R^2 = 0.96), as well as competitive results for SPI-6 (MAE = 0.15, NSE = 0.94, R^2 = 0.94). The EMD-ELM model showed its strongest performance for SPI-6 (MAE = 0.22, NSE = 0.97, R^2 = 0.98). Overall, the high predictive accuracy of the LSTM indicates that drought time series modelling can be effectively performed without additional pre-processing techniques such as decomposition.

Design of an Intelligent Robotic Platform for Selective Spraying in Precision Farming Environments

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Abstract

Traditional pesticide application methods in Indian agriculture often result in excessive chemical usage, non-target exposure, and environmental contamination due to uniform spraying across entire fields. There is a critical need for a cost-effective, sensor-driven system that can perform targeted pesticide delivery based on real-time crop detection. This paper introduces Design and Development of Mobile Controlled Plant Target Automatic Prototype Spraying Robot, an innovative mobile-controlled, plant-targeted automatic spraying robot designed to revolutionize pesticide application in agriculture. The robot operates through a user-friendly mobile web interface accessible via the IP address 192.168.4.1, enabling remote control over its movements-forward, backward, left, and right. Equipped with advanced plant detection sensors, the robot identifies the presence of plants with impressive 90% detection efficiency, pauses for 2 seconds to ensure accurate targeting, and then activates its spraying mechanism for 3 seconds. This precise operation ensures that pesticides are applied only where necessary, achieving 90% plant coverage and significantly reducing chemical usage. The implementation aligns with findings from recent studies indicating that precision spraying technologies can reduce pesticide use by up to 80% while maintaining effective pest control. Moreover, by automating the spraying process, robot addresses labor shortages in agriculture, a concern highlighted by the increasing adoption of aggrotech innovations to tackle labor inefficiencies. Powered by a rechargeable battery, the robot offers an eco-friendly solution that minimizes human exposure to harmful chemicals and reduces environmental impact. By optimizing pesticide usage and enhancing labor efficiency, this paper contributes to the advancement of sustainable and precision agriculture practices.

Keywords: Precision Agriculture, Autonomous Spraying Robot, Mobile-Controlled Robot, Pesticide Optimization, IoT in Agriculture, Agricultural Automation, Sustainable Farming.

Development of Nano-Biofilm Reinforced with Sugarcane Bagasse Residue for Biodegradable Packaging Application

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Abstract

The growing environmental concerns associated with conventional plastic packaging have intensified the search for sustainable alternatives within the post-harvest and food processing sectors. In this study, a Nano Biofilm reinforced with cellulose nanofibers derived from sugarcane bagasse residue - a lignocellulosic by product of the sugar industry was developed for biodegradable packaging applications. The cellulose nanofibers were extracted through an alkaline treatment followed by acid hydrolysis, resulting in high-aspect-ratio fibers with enhanced mechanical properties. These nanofibers were incorporated into a biodegradable polymer matrix to improve tensile strength and barrier properties of the resulting biofilm. A total of sixteen nanocomposite films, reinforced with treated and untreated CNFs at loadings of 20, 30, 40, and 50 wt.%, were fabricated and systematically characterized. Fourier-transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), and thermogravimetric analysis (TGA) confirmed the structural integration and homogeneous dispersion of CNFs, with optimal reinforcement achieved at 40 wt.% treated CNFs under a 20-minute sonication period.

This formulation exhibited superior tensile strength (80.47 MPa), improved flexibility, and enhanced barrier properties compared to the neat polymer film. Antibacterial analysis revealed maximum inhibitory zones of 15.96 mm against Staphylococcus aureus and 15.57 mm against Bacillus subtilis, indicating strong antimicrobial potential. The use of sugarcane bagasse valorizes agricultural waste, aligns with circular economy principles, and addresses the pressing need to reduce plastic dependency offering a viable, eco-friendly solution for biodegradable food packaging applications.

Keywords: Ultra-sonication, Cellulose Nanofibers, Antibacterial Nano-Biofilm, Biodegradable Food Packaging.

Smart Agri-Linkages through Digital Innovation in India

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Abstract

India's agricultural markets have long suffered from post-harvest losses, middleman exploitation, inefficiencies, and restricted access to real-time pricing data. Due to a shortage of storage or quick buyers, farmers frequently experience distressed sales and only get a portion of the sale price. In this regard, digital transformation presents a game-changing chance to improve market connections and give farmers more leverage via inclusive, open, and effective platforms.

With an emphasis on facilitating improved price discovery, direct selling opportunities, and wise storage choices, this study examines the effects of growing digital marketplaces to improve market connections for agricultural producers. The report examines the current shortcomings in conventional market systems, evaluates recent digital initiatives (such as eNAM, AgriBazaar, DeHaat, and FPO-led platforms), and suggests a thorough framework for an integrated agri-digital ecosystem.

Three key features are integrated into the proposed model: (1) real-time digital marketplaces where farmers can list their produce and get competitive price offers directly from buyers, such as wholesalers, processors, retailers, and exporters; (2) logistics integration and storage mapping, which enables farmers to find nearby warehouses, cold storage facilities, and transportation services with information on space availability, rental costs, and quality standards; and (3) smart decision support that uses crop pricing forecasts, market trend analytics, and mobile alerts to help farmers decide when and how best to sell their produce.

A mixed-method approach has been used, integrating qualitative insights from surveys of more than 100 farmers, agri-startups, and market intermediaries in five states with quantitative data analysis from government databases and existing platforms. According to the research, having access to digital market connections can boost farm gate prices by 10% to 30%, lower post-harvest losses by 15%, and greatly strengthen farmer bargaining power. Digital literacy, last-mile connectivity, gaps in storage infrastructure, and confidence in online trading procedures are still issues, though.

In conclusion, by facilitating direct, open, and effective transactions, growing digital markets, and fusing them with storage and shipping services have the potential to completely transform agricultural marketing. In addition to improving farmers' price realization, these solutions support demand-responsive and sustainable agricultural supply chains. In the digital age, this essay promotes a scalable, farmer-centric digital ecosystem as a crucial facilitator of fair agri-market connections.

Keywords: AgriTech Platforms, Digital Supply Chains, Farmer Empowerment, Farm Gate Pricing, Smart Storage Solutions, Direct Selling, eNAM, Agricultural Market Links, Digital Agriculture.

From Crop Waste to Clean Fuel: A Review of Pretreatment Strategies for Production of Bioethanol

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Abstract

The world's growing dependence on fossil fuels has intensified the search for cleaner and renewable energy alternatives. Agricultural residues such as straw, husks, bagasse, and corn stover represent an abundant and underutilized biomass resource with immense potential for sustainable energy production. Converting these lignocellulosic wastes into bioethanol not only offers a clean fuel option but also addresses pressing waste management and environmental concerns. However, the rigid structure of lignocellulosic biomass, particularly the intertwined lignin and hemicellulose network, restricts enzymatic breakdown and limits conversion efficiency. Pretreatment is a vital step to dismantle this complex structure, improve enzymatic hydrolysis, and maximize fermentable sugar release. This paper reviews key pretreatment approaches including physical, chemical, physicochemical, and biological methods, while examining recent technological innovations, hybrid techniques, and their impacts on efficiency, scalability, and environmental sustainability. By emphasizing pretreatment optimization, the study outlines pathways for developing cost-effective and commercially viable second-generation bioethanol production from agricultural waste.

Enhancingsoil sustainability through management of prevailing land use systems: Assessment Using Soil Quality Indicators and Deterioration Index

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Abstract

Land use changesfrom forest to cultivated landsand inappropriate land management practices accelerate soil degradation, ultimately compromising soil sustainability. Sustainable land management decisions can be improved by tools that integrate soil test data, management objectives, and environmental concerns. Evaluating the impacts of different land use systems (LUSs) on soil sustainability using soil quality indicators and deterioration indices (DIs) offers an ecologically grounded approach to guide land users.This study assessed the effects of prevailing LUSs on soil nutrient status and degradation in the sub-humid southern plains of Rajasthan, India. A total of 120 composite soil samples were collected across six LUSs, four soil depths (0-20, 20-40, 40-60, and 60-80 cm), and five replications. Two-way ANOVA was used to analyse the effects of LUSs and soil depth on key soil properties, along with deterioration indices of soil.

Results of this study indicated that soil organic carbon (SOC), DTPA-extractable Zn and Mn, available nitrogen, and cation exchange capacity (CEC) were the most degraded parameters. However, barren lands showed the highest decline in Zn (~75%), SOC (71%), N (66%), Cu (62%), and Fe (57%), followed by agricultural lands, which showed SOC (53%), Zn (46%), N (43%), and Mn (38%) losses. Soil deterioration indices revealed slight deterioration under grassland and horticultural systems (-11.05% and -11.81%), moderate under agri-horticulture (-22.51%), and severe to very severe deteriorationunder agricultural (-28.11%) and barren lands (-47.50%).Horticultural systems closely resembled grasslands in maintaining essential soil properties, highlighting their potential to achieve land degradation neutrality (LDN). These findings suggest that transitioning barren and intensively cultivated lands to horticultural or agri-horticultural systems may reduce soil degradation and support long-term soil sustainability.

Key words: Land use changes, Soil nutrient, Deterioration indices, Soil depth

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