INRAE LISIS

ENABLING SUSTAINABLE FOOD SYSTEMS THROUGH NATURAL FARMING

ESFS-NF 2024

INTERNATIONAL CONFERENCE
Souvenir-cum-Invited Lectures

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NAUNI 173 230 SOLAN, HP INDIA

In Collaboration With

French National Research Institute for Agriculture
Food and Environment (INRAE), France
The Indian Ecological Society (Himachal Chapter)

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Souvenir-cum-Invited Lectures

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September 13-14, 2024

Solan, Himachal Pradesh

Editors

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Organized by

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राज्यपाल
हिमाचल प्रदेश

Shiv Pratap Shukla
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Himachal Pradesh

संदेश

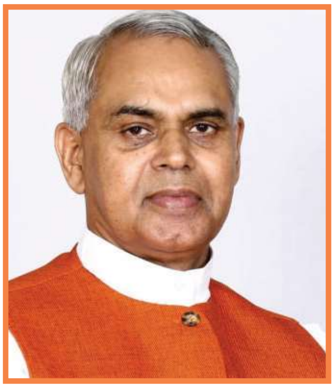
यह हर्ष का विषय है कि डॉ. यशवंत सिंह परमार औद्यानिकी एवं वानिकी विश्वविद्यालय, नौणी, सोलन 13-14 सितम्बर, 2024 को 'स्थायी खाद्य प्रणालियों को सक्षम बनाने के लिए प्राकृतिक खेती' विषय पर एक अन्तर्राष्ट्रीय सम्मेलन का आयोजन कर रहा है। इस आयोजन को फ्रेंच नेशनल रिसर्च इंस्टीट्यूट फॉर एग्रीकल्चर, फूड एंड एनवायरनमेंट (INRAE), फ्रांस एवं इंडियन इकोलॉजिकल सोसाइटी (HP चैप्टर), भारत के साथ सहयोग में किया जा रहा है।

प्राकृतिक खेती आज के समय की एक महत्वपूर्ण आवश्यकता बन गई है, जो न केवल कृषि के स्थायित्व को सुनिश्चित करती है, बल्कि हमारे पर्यावरण को भी संरक्षित करने में सहायक सिद्ध होती है। इस आयोजन का उद्देश्य न केवल कृषि को प्राकृतिक खेती के माध्यम से पुनर्जीवित करना है, बल्कि स्थायी खाद्य प्रणालियों के निर्माण में इस विधि के उपयोग को भी बढ़ावा देना है। यह आयोजन हमारे समाज, पर्यावरण और कृषि के सतत् विकास के लिए महत्त्वपूर्ण पहल है।

मुझे विश्वास है कि इस सम्मेलन के माध्यम से प्राप्त सुझाव और निष्कर्ष, कृषि को एक स्थायी और समृद्ध भविष्य की ओर अग्रसर करने में सहायक सिद्ध होंगे।

मैं इस अन्तरराष्ट्रीय सम्मेलन की सफलता की कामना करता हूँ और आशा करता हूँ कि यह आयोजन हमारे देश के किसानों, वैज्ञानिकों और नीति-निर्माताओं के लिए अत्यंत लाभकारी साबित होगा।

(शिव प्रताप शुक्ल)



आचार्य देवव्रत
राज्यपाल
गुजरात

Acharya Devvrat
Governor
Gujarat

संदेश

मुझे यह जानकर अत्यन्त गर्व हो रहा है कि डॉ. यशवंत सिंह परमार औद्यानिकी एवं वानिकी विश्वविद्यालय, नौणी, सोलन, हिमाचल प्रदेश ने देश में प्राकृतिक खेती के मिशन को सशक्त बनाने का बीड़ा उठाया है। इस दिशा में एक महत्वपूर्ण प्रयास के तहत, विश्वविद्यालय 13-14 सितम्बर 2024 को अपने परिसर में 'स्थायी खाद्य प्रणालियों को सक्षम बनाने के लिए प्राकृतिक खेती' विषय पर एक अन्तर्राष्ट्रीय सम्मेलन का आयोजन कर रहा है। इस आयोजन को फ्रेंच नेशनल रिसर्च इंस्टीट्यूट फॉर एग्रीकल्चर, फूड एंड एनवायरनमेंट (INRAE), फ्रांस एवं इंडियन इकोलॉजिकल सोसाइटी (HP चैप्टर), भारत के साथ सहयोग में किया जा रहा है। INRAE और IES की भागीदारी सतत खाद्य प्रणाली के प्रति वैश्विक रूप से बढ़ती रुचि को दर्शाती है, जो SDGs के लक्ष्यों को पूरा करने के लिए आवश्यक है।

प्राकृतिक खेती न केवल हमारे कृषि तंत्र को पुनर्जिवित करने की दिशा में एक बड़ा कदम है, बल्कि यह हमारे पर्यावरण और सामाजिक ताने-बाने के लिए भी दीर्घकालिक लाभकारी है। इस आयोजन का उद्देश्य न केवल प्राकृतिक खेती के महत्व को रेखांकित करना है, बल्कि इसे सतत् खाद्य प्रणालियों के निर्माण में एक सशक्त उपकरण के रूप में प्रस्तुत करना है। प्राकृतिक खेती के माध्यम से पर्यावरण, सामाजिक और आर्थिक स्थिरता को प्राप्त करना आज के समय की महती आवश्यकता है। यह सम्मेलन उन सभी मुद्दों पर गहन चर्चा करने का एक मंच प्रदान करेगा, जो कि हमारे कृषि, पर्यावरण और समाज के लिए दीर्घकालिक लाभ सुनिश्चित कर सकते हैं। यह आयोजन इस दृष्टि से भी महत्वपूर्ण है कि इसमें विभिन्न क्षेत्रों के विशेषज्ञ, किसान, विद्यार्थी और वैज्ञानिक एक मंच पर आकर विचारों का आदान-प्रदान करेंगे। मुझे पूरा विश्वास है कि इस सम्मेलन में प्रस्तुत किए गए विचार और सिफारिशें कृषि के भविष्य को और अधिक टिकाऊ बनाने में सहायक सिद्ध होंगी।

मैं इस अन्तर्राष्ट्रीय सम्मेलन की सफलता के लिए अपनी हार्दिक शुभकामनाएँ प्रेषित करता हूँ और आशा करता हूँ कि यह आयोजन हमारे देश के किसानों, वैज्ञानिकों और नीति निर्माताओं के लिए अत्यंत लाभकारी सिद्ध होगा।

(आचार्य देवव्रत)

सुखविन्द्र सिंह सुक्खू
मुख्यमंत्री
हिमाचल प्रदेश सरकार

Sukhvinder Singh Sukhu
Chief Minister
Government of Himachal Pradesh

Message

It gives me immense pleasure to know that Dr. Y.S. Parmar University of Horticulture and Forestry Nauni, Solan is hosting the International Conference on 'Enabling Sustainable Food Systems through Natural Farming' (ESFS-NF) on 13-14 September, 2024 in collaboration with French National Research Institute for Agriculture, Food and Environment (INRAE) and the Indian Ecological Society.

Himachal Pradesh has always been at forefront of promoting eco-friendly farming practices, and the University has been instrumental in advancing research, innovation, and education in natural farming. Our government is dedicated to supporting these initiatives, as evidenced by the newly launched HIM-UNNATI scheme, which aims to create self-employment opportunities for approximately 50,000 farmers. This initiative, a part of the Rajiv Gandhi Start-up Yojana, further reinforces our dedication to incentivize sustainable farming practices.

I hope this Conference will serve as a vital platform for exchanging knowledge, addressing challenges, and exploring innovative solutions that will shape the future of sustainable agriculture in Himachal Pradesh and beyond. The insights and outcomes from this conference will be crucial in advancing our shared vision of a resilient and sustainable agricultural system.

I extend my best wishes to the organizers and participants for a successful and impactful event. May this conference inspire new ideas, foster meaningful collaborations and contribute significantly to the advancement of sustainable farming practices.

(Sukhvinder Singh Sukhu)

जगत सिंह नेगी
राजस्व, बागवानी, आदिवासी विकास,
लोक शिकायत निवारण मंत्री,
हिमाचल प्रदेश सरकार

Jagat Singh Negi
Revenue, Horticulture,
Tribal Develpoment,
Redressal of Public Grievances Minister,
Government of Himachal Pradesh

Message

It is a matter of joy that Dr. YS Parmar University of Horticulture and Forestry Nauni, Solan is organizing an International Conference on 'Enabling Sustainable Food Systems through Natural Farming' (ESFS-NF) on 13-14 September 2024.

Being held in collaboration with the French National Research Institute for Agriculture, Food and Environment (INRAE) and the Indian Ecological Society, the earnest efforts of the university in the field of research and innovation have been commendable.

Himachal Pradesh is pioneering in natural farming, as the state was the first in India to offer a minimum support price for products grown through natural farming practices.

Himachal Pradesh is all set to become a leading state in natural and organic farming within the next five to six years. Certified Evaluation Tool for Agriculture Resource Analysis-Natural Farming (CETARA) certification system had been introduced, which was being implemented in the state to ensure fair prices for the farmers.

In line with innovative research activities, the Govt. launched HIM-UNNATI scheme with a cluster-based approach aiming to produce and certify chemical-free produce, with plans to establish 2,600 agricultural groups involving approximately 50,000 farmers. Furthermore, the state government was also taking significant steps to boost the dairy sector and enhance milk production.

I would like to appreciate Dr. YS Parmar University for introducing innovations in the field of agriculture from time to time. Besides educating farmers of the latest important technology in the field of agriculture and forestry.

I extend my best wishes for the success of the conference.

(Jagat Singh Negi)

सत्यमेव जयते

भारत सरकार
कृषि अनुसंधान और शिक्षा विभाग एंव
भारतीय कृषि अनुसंधान परिषद
कृषि एंव किसान कल्याण मंत्रालय, कृषि भवन, नई दिल्ली–110 001

डॉ. हिमांशु पाठक
सचिव (डी.ए. आर. ई.)
एंव महानिदेशक (आई.सी.ए.आर.)

Dr Himashu Pathak
Secretary (DARE) &
Director General (ICAR)

Message

I am happy to know that Dr. YS Parmar University of Horticulture and Forestry is organizing International Conference on 'Enabling Sustainable Food Systems through Natural Farming' (ESFS-NF) during September 13-14, 2024 at Solan, Himachal Pradesh in collaboration with French National Research Institute for Agriculture, Food and Environment (INRAE), France, and the Indian Ecological Society (HP Chapter). The conference marks a significant step forward in our journey towards promoting sustainable agriculture to meet aspirations of people in the country. As we strive for a future where agriculture is both productive and environmentally responsible, natural farming stands out as a promising solution, deeply rooted in ecological principles and aligned with India's vision for sustainable development.

I hope that the conference will serve as a platform for the exchange of knowledge and experiences and will be useful in understanding the intricacies of natural farming. The insights and outcomes from this event will play a crucial role in driving the widespread adoption of natural farming practices and shaping the future of sustainable agriculture. I hope that it will inspire new ideas, foster collaborations, and pave the way for a more sustainable and resilient agricultural future.

I wish the International Conference a grand success.

(Himanshu Pathak)

प्रो. राजेश्वर सिंह चन्देल
कुलपति
डॉ वाई.एस. परमार औद्योनिकी एवं वानिकी विश्वविद्यालय, नौणी
सोलन, हिमाचल प्रदेश

Prof. Rajeshwar Singh Chandel
Vice Chancellor
Dr. YS Parmar University of Horticulture and Forestry, Nauni
Solan, Himachal Pradesh

Message

In an era marked by growing environmental challenges and the urgent need for sustainable food systems, agroecology emerges as both a philosophy and a practice that offers hope for the future. As the global population continues to rise, the pressure on our agricultural systems intensifies. Traditional farming methods, heavily reliant on synthetic inputs, have led to widespread ecological degradation, loss of biodiversity, and the depletion of essential natural resources. It is clear that a transformative approach is needed—one that not only ensures food security but also restores and regenerates our ecosystems. Natural farming (NF), based on agroecological principles, has come up with a new hope in this direction.

NF, which is based on principles of agroecology, has shown potential to improve soil health, climate resilience and sustain agrifood systems. Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan (HP) India has established models on different cropping systems for scientific validation of NF practices and is associated in further development of Farmer's self-declared certification mechanism (CETARA). University is also working on establishment of circular economy model through standardization of a Sustainable Food Systems Platform for Natural Farming (SuSPNF), involving establishment and handholding of NF based Farmer Producer Company (FPCs). University has also started a model outlet for selling NF produce from its farms and that from the FPCs, and demonstrate the supply chain model from farm to fork.

I am delighted that Dr YS Parmar University of Horticulture and Forestry is leading the mission on Natural Farming in the country. In this endeavour, university is organising an International conference on 'Enabling Sustainable Food Systems through Natural Farming' (ESFS-NF) w.e.f.13-14 September 2024 in collaboration with INRAe, France and Indian Ecological Society (Himachal Chapter). The event focuses on advancing sustainable agriculture through natural farming.

I am confident that the discussions and results of this conference, enriched by the diverse perspectives of all stakeholders, will introduce new dimensions to ongoing efforts towards sustainable agrifood systems and promote agroecological initiatives. The event will help generate scientific evidence and international visibility for these initiatives, crucial for achieving Sustainable Development Goals (SDGs) and transforming agrifood systems. The insights and knowledge shared will play a crucial role in forging a path towards lasting sustainability, and I am optimistic about the positive impact this conference will have.

I wish ESFS-NF 2024 a resounding success!

(Rajeshwar Singh Chandel)

एलिसन लोकोंटो
उप निदेशक, एल.आई.एस.आई.एस,
आई.एन.आर.ए.ई., फ्रांस

Allison Loconto
Deputy Director, LISIS
INRAE, France

Message

I extend my warmest congratulations to Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan, for organizing the International Conference on 'Enabling Sustainable Food Systems through Natural Farming' (ESFS-NF) on September 13-14, 2024. This event marks a significant milestone in our collective efforts to promote sustainable agriculture and food systems.

The French Research Institute for Agriculture, Food and Environment (INRAE) is the public research organization dedicated to finalised research in the fields of agriculture food and the environment. It counts 14 scientific departments, employing nearly 13.000 researchers, engineers and administrative staff, organized into 18 research center's stationed across France and its overseas Territories. INRAE carries out its mandate from the Ministry of Agriculture and the Ministry of Research and Higher Education to advance knowledge, foster innovation and collaborate with stakeholders so to support agroecological transitions to sustainable agrifood systems as part of Agenda 2030. The Interdisciplinary Laboratory for Science, Innovation and Society (LISIS) brings together social science researchers from INRAE, the National Centre for Scientific Research (CNRS) and Gustave Eiffel University that study the societal transformations catalysed by science and innovation. Our internationally renowned scholars are at the cutting edge of research on co-innovation approaches for agroecological crop protection, including policies, standards, certification and innovative market and research infrastructures. It is thus an immense honor to be able to collaborate with institutions like Dr. YS Parmar University in India, which shares our vision of harmonizing agricultural practices with ecological principles so to create agrifood systems that are safe, inclusive, and equitable, particularly for farmers and consumers.

This conference comes at a crucial time when the global community increasingly recognizes the need to reduce agrochemical dependency and support local, resilient farming systems. France and India have been at the forefront of these efforts internationally, and the discussions and outcomes of this event will undoubtedly contribute to the scientific evidence needed to inform our countries as they strive to achieve the Sustainable Development Goals (SDGs). Moreover, the important cross-continental exchanges will contribute to guiding agrifood systems transformations worldwide.

I am confident that this conference will serve as a platform for exchanging ideas, forging new collaborations, and advancing our understanding of how natural farming can lead to more sustainable and equitable food systems. I extend my best wishes for the conference's success and look forward to the learning more about the innovations already underway that promise positive impacts for the future.

Allison Loconto

डा. ए. के. धवन
अध्यक्ष
इंडियन इकोलॉजिकल सोसाइटी

Dr A K Dhawan
President
Indian Ecological Society

Message

It gives me immense pleasure to extend my best wishes to the organizers and participants of the International Conference on 'Enabling Sustainable Food Systems through Natural Farming' (ESFS-NF), scheduled to take place from 13-14 September, 2024 at Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh. This event is a significant collaborative effort between the Indian Ecological Society (HP Chapter), Dr. YS Parmar University, and the French National Research Institute for Agriculture, Food, and Environment (INRAE), France.

The Indian Ecological Society has long been committed to fostering ecological awareness and promoting practices that align agricultural productivity with environmental stewardship. Our role in this conference is to underscore the importance of integrating ecological principles into agricultural systems, thereby ensuring that food production does not come at the expense of our planet's health.

This conference is not just an event, but a vital forum where the latest research, innovations, and practices in natural farming will be shared, discussed, and refined. It is a testament to our shared vision of a future where farming practices contribute to humanity's and the environment's well-being.

As we gather to explore the potential of natural farming in achieving sustainable food systems, I am confident that the insights gained and the collaborations formed will have a lasting impact. The Indian Ecological Society is proud to support and be part of this significant endeavor which aligns with our mission to promote ecological balance and sustainable development.

I wish the conference every success and look forward to the valuable contributions that will emerge from these discussions.

(A.K. Dhawan)

Foreword

Natural farming, rooted in the wisdom of traditional practices and reinforced by modern scientific principles, has proven to be a viable path toward sustainability. India, with its diverse ecosystems and rich agricultural heritage, is well-positioned to lead this movement. The relevance of organizing the 'International Conference Enabling Sustainable Food Systems through Natural Farming (ESFS-NF)' in the present-day context is paramount. Hosted by Dr. YS Parmar University of Horticulture and Forestry in collaboration with French National Research Institute for Agriculture, Food and Environment (INRAE) and The Indian Ecological Society, Himachal Chapter, this event addresses the critical challenges of sustainable agriculture and natural farming, with an emphasis on advancing agro-ecological crop protection. The conference explored the essential themes such as natural resource management for climate resilience, nature-based solutions for crop protection, natural farming for socio-economic transformation, and innovations in sustainable food systems. These themes are vital for enhancing climate resilience, promoting ecological balance, and showcasing the socio-economic benefits of natural farming.

The ESFS-NF conference promises substantial utility for a diverse group of stakeholders, including international experts, academicians, professionals, extension experts, students, local farmers, and other key participants. By facilitating knowledge exchange and capacity building, the conference aims to foster collaboration, innovation, and the co-design of agroecological strategies. The event aligns with global efforts to promote sustainable development by supporting the implementation of sustainable agricultural practices that improve food security, enhance environmental sustainability, and contribute to the socio-economic well-being of rural communities. Additionally, the conference highlights the latest research and innovations in sustainable agriculture, producing scientific evidence of the sustainability of agroecological crop protection systems and connecting local initiatives to global research teams. By integrating sustainable agricultural practices into policies and practices, the conference provides valuable insights for achieving long-term sustainability goals and addressing climate change impacts on agriculture.

We consider it our privilege to thank all the farm science luminaries for their presentations to the participants and text contributions to this souvenir collection. Our efforts will only be rewarded with healthy crops and a revitalized sense of stewardship towards our earth through inspirational gain from the simplicity of natural farming and sustainable agricultural systems. Let's nurture a way of life that respects the environment and feeds future generations, not simply crops.

We sincerely acknowledge the advisory committee of the conference for their advice, conference partners and all sponsors from the government, public and private organizations to support this international event in a wholehearted manner.

Editors

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Natural Farming: Cultivating Resilient and Sustainable Food Systems for the Future

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Abstract
Over the years, adoption of Green Revolution in the 1960s has resulted in multiple negative impacts on ecology, economy and on existence of many smallholders. Natural farming (NF) is an innovative agricultural approach that emphasizes ecological balance, biodiversity, and sustainability to address the pressing challenges of food security and environmental degradation. Natural farming advocates for practices that enhance soil health, such as the use of agro residues and minimal disturbance, while fostering a balanced ecosystem through crop rotation and intercropping.

Introduction
Over the years, adoption of Green Revolution in the 1960s has resulted in several adverse impacts related to ecological, economic and farmers' existence mainly of smallholders. This focuses on promoting sustainable practices (NF) that provides nutritious food, ensures regenerative soils, enhance biodiversity and health of our ecosystems. By integrating ecological principles into agricultural practices, we can create systems that are resilient, productive, and beneficial to both farmers and consumers. By promoting NF, we can work towards creating Sustainable Food Systems (SFS) that nourish people and protect our planet for future generations.

Need for Sustainable Food Systems
India has underscored the urgent need to transform agri-food systems globally. This transformation aims to enhance food and nutrition security to mitigate the environmental impacts. Chemical intensive agricultural practices are one of the biggest sources of CH_4 and N_2O emissions. As per the 3rd Biennial Report submitted by India to UNFCCC, N_2O is principally emitted due to the application of fertilizers to soils. During 2016, the sector emitted 4,07,821 Gg of CO_2, amounting to around 14% of the total emissions. Pesticide consumption has been increasing year by year (62,193 MT during 2021) (http://ppqs.gov.in/statistical- database). Fertilizer application intensity has increased from 12.4 Kg/ha in 1969 to 137 Kg/ha in 2021 (about 11 times) (https://www.ceicdata.com). Fertilizers subsidy was provisioned as Rs 79,530 Cr in 2021-22, which finally increased to Rs 2.25 lakh Cr in 2022-23. However, this increase has not been found inconsonance with proportionate increase in productivity. In India, per capita water availability declined from 5178 m^3/yr in 1951 to 1544 in 2011 and expected to be 1140 m^3 by 2050. Agriculture uses 89% of ground water and as per Economic survey (2019), the focus is to be shifted from 'Land Productivity' to 'Water Productivity'. At present, if India's path of structural transformation seems unsustainable, NF presents a paradigm shift in Indian agricultural practices through the adoption of agro-ecological principles at scale and offers a potential solution to the supposed tradeoff between productivity and sustainability.
UN's Sustainable Development Goals (SDGs) provide a framework for this transformation, with SDG 1 (no poverty), 2 (zero hunger), 6 (clean water and sanitation), 8 (decent work and economic growth), 9 (industry, innovation and infrastructure), 12 (responsible production and consumption) and 15 (life on land) emphasizing the need to end hunger, achieve food

security, and improve life on land through sustainable agriculture. Furthermore, SDG 12 (responsible consumption and production) highlights the importance of sustainable practices in managing resources efficiently and minimizing waste, promoting a circular economy within agricultural systems. These 7 goals are being mapped through Natural farming initiatives. Sustainable food systems are essential for addressing the interconnected challenges of food security, environmental sustainability and climate change. This holistic approach is, therefore, vital for achieving the SDGs and fostering a healthier and equitable global food system.

Principles of Natural Farming

NF practices includes cover crops, crop diversity, low tillage, integration of animals, use of bio stimulants, increase in organic matter by adding dry grass mulch, use of local seeds, management of insect-pest complex of crops with plant decoctions prepared in cow urine and no use of agrochemicals is the basic principle of Natural Farming,

Strategies

By relying on natural processes, a resilient agricultural system that maintains productivity while minimizing negative environmental impacts can be created. Biological pest control will help to minimize external inputs in agriculture. This not only protects non-target organisms and biodiversity but also enhances the sustainability of agricultural practices. By adopting practices that prioritize natural processes, these environmental impacts can be mitigated and promote cleaner, healthier ecosystems. This approach supports sustainable food production and contributes to the resilience of agricultural systems in context to climate change and other environmental challenges.

Ecological Balance in Sustainable Agriculture

Fostering ecological balance is a critical aspect of sustainable agriculture that contributes to the health and resilience of agricultural systems. This approach emphasizes the importance of biodiversity and ecosystem services which leads to more sustainable and productive farming practices. In a diverse agricultural ecosystem, beneficial insects such as ladybugs, lacewings, and predatory wasps can thrive alongside crops. A diverse ecosystem with a variety of plants, and animals promotes competition and symbiotic relationships that strengthen the overall health of the agricultural system. A diverse range of plant species can contribute to a more complex root structure, which enhances soil aeration and water infiltration.

Benefits of Natural Farming

A transformational process towards holistic approaches such as agro-ecology, agro-forestry, climate-smart agriculture, and conservation agriculture is a necessity. Zero Budget Natural Farming and Natural Farming both signify a significant shift in relations with markets and nature. The Zero Budget is a drive for complete independence from input based external markets (input suppliers, capital, credit and indebtedness). Mr. Subhash Palekar compares the sustainable farm to the 'self-sufficient forest', which needs no external inputs in order to thrive. Different benefits derived from Natural Farming are:

Improve yields

Natural Farming aims to increase yields by balance use of production factors like labour, soil, equipment and by avoiding the use of non-natural inputs like fertilizers, herbicides, pesticides and even without externally imported bio inputs. Independent Assessment in Crop Cutting Experiments by Centre for Economic and Social Studies (CESS), Gurukul Farm at Kurukshetra, RySS experiments in Andhra Pradesh and YSP University of Horticulture and

Forestry, Nauni (HP) have reported no significant yield differences between NF and non-NF farms.

Minimize cultivation cost and increased farm income

Natural Farming cut down crop cultivation costs by preparing all essential inputs required either as soil nutrient enhancers or plant protection materials with non-chemical based and locally available resources. This farming practice makes farming viable and ambitious by increasing their net incomes and sustainability. Studies conducted by CEEW, have observed that the cultivation rice using chemical inputs spend Rs. 5,961/acre on average, while one using NF techniques incurred Rs. 846/ acre on natural inputs. A similar pattern has been observed with respect to maize and groundnut cultivation. For maize, NF farmers spent Rs 503/acre on natural inputs whereas chemical farmers, on average, spent Rs 7,509/acre. For groundnut, a chemical farmer spent Rs 1,187/acre as against Rs 780/acre by a NF farmer (Gupta et al. 2020).

Ensure better health

Agrochemicals have shown adverse impacts on health. Natural farming practices replaces external inputs with locally made natural concoctions, inoculums, and decoctions, hence reduces the incidence of non-communicable diseases. Pesticides contain endocrine-disrupting chemicals (EDCs), which enter humans through diet and can have negative health impacts such as breast cancer, reproductive disorders, and poorer intellectual development in children. Chemical residue such as nitrate is undetectable in NF produce.

Environmental conservation

Excessive use of fertilizers in conventional farming has significantly contributed to greenhouse gas (GHG) emissions and climate change. The greenhouse gas (GHG) emissions from 'Agriculture, Forestry and Other Land Use' (AFOLU) have nearly doubled during last five decades (Smith et al. 2014). The number of greenhouse gases (GHGs) emitted per nutrient ton of fertilizer produced is 1.1 metric tons of CO_2/nutrient ton in 2016. NF reduces risks associated with uncertainties of climate change by promoting the adoption of an agroecology framework. Natural Farming has shown evidence of increased resilience of farmlands along with protecting crops against extreme weather by improving the fertility and strength of the soil.

Employment generation

Natural Farming has the proven evidences of increasing the financial viability of small farms. NF has the potential to generate employment opportunities across the agricultural value chain, from production, distribution, and retail of natural mixtures to market linkages for such produce. Further easy accessibility to natural inputs would bring in gender equality in the sector.

Reduce water consumption in agriculture

We use approximately 70 percent of freshwater withdrawals for agriculture (Boretti and Rosa 2019). Groundwater irrigation accounts 60 per cent of the total irrigated area in India and is leading to over-exploitation and falling water levels in aquifers. NF is a pre-eminent practice that requires minimum water consumption and also reduces the dependency on resources like water and electricity. Practices like *Whaphasa* have a positive effect in improving fertility and improving water retention capacity of soil. Similarly, contours and bunds preserve rainwater and allow soil moisture to retain for a longer period.

Enhancing soil fertility

Soil health is a critical component of sustainable agriculture, serving as the foundation for productive and resilient food systems. The incorporation of cover crops, and crop residues,

significantly enriches the soil's nutrient content and improves its overall fertility. Crop residue is a vital source of essential nutrients for plants, providing macronutrients like nitrogen, phosphorus, and potassium and micronutrients that are crucial for plant health. As this decomposes, it enhances soil structure by promoting the formation of soil aggregates. Furthermore, it fosters a diverse microbial community, which contributes to nutrient cycling and enhances the soil's resilience against pests and diseases. Healthy soils play a crucial role in C sequestration, acting as vital carbon sinks. The results of studies conducted on ZBNF revealed a significant enrichment of soils in terms of organic carbon (OC), available phosphorus and potash, micronutrients, soil moisture contents and biological health with the adoption of ZBNF practices (Rana et al. 2021; Saharan et al. 2023; Verma et al. 2018; Yankit et al. 2024).
The impact on soil OC was more pronounced in rice-wheat system than in other cropping systems. The microbiological studies indicated unto 528 times more colony forming units of bacteria per gram of soil in the Natural Farming soil samples compared to that recorded in the in chemical farming soils in various studies conducted by different institutes. Interestingly, total microbial count in the dung of native cow breeds was 363 and 25 times more than in the dung of buffalo and native breed of bull. The crop yields obtained were highly comparable to the level achieved by the farmers under different experiments

Livestock sustainability
Cow dung and urine are the most essential components in Jeevamrit and *Beejamrit*. A study conducted by Kumar (2020) shows that the population of indigenous cows among NF cultivators was highest compared to crossbred cows, bullocks, and buffaloes in Karnataka, Maharashtra and Andhra Pradesh. The study revealed that 91 per cent of the sample obtained from farmers in Karnataka, followed by Maharashtra and Andhra Pradesh, have at least one indigenous cow.

Biodiversity
The industrial and intensive farming practices caused several negative environmental impacts such as decreasing biodiversity, in the rhizosphere and above the ground including natural enemies, pollinators, birds etc. Intercropping of short duration two or more crops in contiguity further enhances biodiversity and ecosystem resilience. This approach leads to more efficient resource use, as different crops utilize nutrients, water, and sunlight differently. For example, putting together legumes with cereal crops allows legumes to fix atmospheric nitrogen, enriching the soil for the companion crop. These mixed crops also provide habitat for beneficial insects and pollinators. Native species also promotes nutrient cycling and beneficial microbial activity leading to soil fertility. It is possible to design farming systems that are equally productive and maintain or enhance the provisioning of ecosystem services i.e., biodiversity, soil quality, nutrient management, water-holding capacity, control of weeds, diseases and pests, pollination services, carbon sequestration, energy efficiency and reduce global warming potential, as well as resistance and resilience to climate change and crop productivity and thus agroecosystem resilience and sustainability.

Climate Resilience
Natural farming systems enhance biodiversity and improve soil health, equipping them to better withstand these challenges. By adopting practices that promote ecological balance and strengthen the health of the agricultural ecosystem, NF plays a vital role in building resilience against climate variability. This biodiversity in NF contributes to greater resilience by reducing the risks associated with pest outbreaks, diseases, and extreme weather conditions. For instance, varied root structures and growth patterns help to stabilize the soil,

preventing erosion and maintaining moisture levels during droughts. Diverse plant communities can support a wider range of beneficial insects and pollinators. By fostering a rich diversity of life, natural farming systems can better adapt to changing climate conditions and minimize the impacts of environmental stressors. Natural farming practices that promote ecological balance help to create an environment where crops can thrive under a range of conditions. For example, agroforestry systems, which integrate trees with agricultural crops, can provide shade, reduce temperature fluctuations, and create microclimates that protect plants from extreme weather. These systems also improve water retention and enhance soil fertility, making them more resilient to the impacts of climate change. Climate resilience is a fundamental advantage of natural farming systems that prioritize biodiversity and soil health.

Economic Viability

Natural farming presents significant economic advantages for farmers by reducing input costs and enhancing resilience to market fluctuations. This economic efficiency is particularly beneficial for smallholder farmers, who often face financial constraints and struggle to compete in conventional agricultural markets. The resilience that natural farming provides against market fluctuations is a crucial economic benefit. Natural farming practices enhance soil health and biodiversity, allowing crops to thrive under a wider range of conditions. This resilience translates into more stable yields, even in the face of climate variability or pest pressures. This stability can provide farmers with a more predictable income stream, helping them to manage their finances effectively and invest in their farming operations. This trend creates opportunities for farmers to command higher prices for their produce, which can significantly enhance their economic prospects. By transitioning to natural farming, farmers can tap into this lucrative market, contributing to their financial sustainability and encouraging the growth of local economies. By fostering a more sustainable agricultural model, natural farming not only benefits farmers economically but also contributes to the overall health of local and regional economies.

Challenges and Solutions

Despite its potential, the adoption of natural farming faces several challenges:

Awareness and Education

Awareness and education are pivotal in the successful adoption of natural farming practices among farmers. Therefore, targeted educational programmes and workshops are essential to disseminate accurate information about the benefits and methodologies of natural farming. Educational initiatives play a significant role in bridging the knowledge gap by providing practical training and resources. Moreover, collaboration with local agricultural institutions, universities, and non-governmental organizations can further enhance educational outreach.

Policy Support

Policy support is crucial for the successful implementation and widespread adoption of natural farming practices. Government plays a vital role in creating an enabling environment that encourages farmers to transition from conventional agricultural methods to more sustainable practices. To facilitate this shift, supportive policies and incentives must be established, addressing the barriers in adopting natural farming. Governments can also incentivize the development of local supply chains for these resources, making them more accessible to farmers, particularly those in remote or underserved areas. Policies that encourage research and development in natural farming practices can provide latest knowledge and innovations to optimize the production methods. The example of '*Prakritik Kheti Khushhal Kisan Yojana* (PK3Y) a policy support of Government of Himachal

Pradesh, India has shown a way to vision, implement and ensure its continuity, resulting into a massive transformation of smallholder farmers into NF practices. State's Public awareness campaigns highlighting the benefits of NF as a part of policy initiatives, helped to shift public perception and encourage consumer support for sustainably produced food.

Research and Innovation
As environmental and economic conditions vary significantly across regions, ongoing research is essential to tailor natural farming techniques to specific local contexts. This includes understanding the soil types, climatic conditions, biodiversity of different areas, allowing for the development of strategies that optimize productivity while preserving ecological integrity. Collaboration between researchers, agricultural institutions, and farmers is crucial for fostering innovation in natural farming. Participatory research approaches, can further lead to more relevant and effective innovations. Integrating technology into natural farming practices such as precision agriculture tools, data analytics, and digital platforms can improve resource management and in decision-making. These innovations not only increase agricultural productivity but also contribute to sustainable practices that protect the environment. The collaboration between PK3Y of Government of Himachal Pradesh, YSPUHF and NABARD, Government of India has been a unique example of collaboration which has shown the way forward for this transformation. The commitment to research not only supports the growth of natural farming but also contributes to the broader goals of sustainable agriculture, ecological health, and food security.

Conclusion
Natural farming not only addresses the challenges of food security and environmental degradation but also enhances soil health, promotes biodiversity, and fosters economic viability. To harness the potential of natural farming, it is essential to prioritize awareness and education, policy support, and ongoing research and innovation. While, supportive policies and financial incentives have shown an enabling environment to transition to these practices, the research and innovation at university and localized levels have exemplified the co innovation of localized solutions that enhance productivity without compromising ecological integrity. By embracing NF principles and practices, we can work towards achieving the Sustainable Development Goals, promoting healthier ecosystems, and ensuring food security for generations to come. Together, we have the opportunity to redefine agriculture in a way that nurtures the planet, supports farmers, and enhances the quality of life.

Future Prospects
The future prospects of natural farming are promising, driven by the growing recognition of its potential to create sustainable agricultural systems that prioritize environmental health, social equity and economic viability. This shift is likely to be supported by various factors that will shape the trajectory of NF in the coming years. Ongoing research will focus on developing innovative solutions that are tailored to local conditions, improving crop resilience, and optimizing resource use. Technologies such as precision agriculture, digital farming tools, and data analytics can further support farmers in implementing NF methods, allowing for better management of inputs and resources. This integration of science and technology with traditional ecological knowledge will certainly lead to more productive and sustainable farming systems. The future prospects of natural farming are bright, driven by changing consumer preferences, technological advancements and supportive policies from the respective governments at Centre and state levels.

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Sustaining Mountain Agroecosystems through Natural Farming

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Introduction

The Indian Himalayan Region has been home to 46 million people spread over an area of around 5000 sq. km. The region is providing water and food to a large part of the Indian subcontinent and contains various flora and fauna. This region is also an important centre of crop plant diversity due to high ecological heterogeneity and high local socio-cultural integrations. Agriculture is the mainstay of resource poor mountain farmers and it plays a major role in the economy of Himalayan region. It consists of diverse farming activities in a wide range of production regions because of the diverse micro-climates and soils. About 85 per cent of the Himalayan populace is directly or indirectly dependent on traditionally practiced integrated hill agriculture, animal husbandry, agroforestry and forestry for livelihood. The horticulture sector has now become a significant factor in the economic progress and accomplishments in most of these mountainous states. However, change in the climatic variables in the recent past has influenced quantity and quality of crop produce. The Himalayan regions have a fragile ecology and the mountain ecosystems are more vulnerable to the specter of climate change because of inaccessible and marginal areas and residents being totally reliant on natural resources for their food, shelter and incomes. These regions are experiencing varied changes in warming and precipitation due to global warming, and the situation is likely to worsen in future.

The current industry driven farming systems have been reported to cause negative impact to climate change due to unsustainable human interventions. Agriculture is the second largest emitter of greenhouse gases (GHGs) after the energy sector, being responsible for about 25 percent of emissions (Smith et al. 2014). The agriculture sector also suffers from the impacts of climate change, which are more pronounced in the fragile and vulnerable mountain agroecosystems. Himachal Pradesh (HP), that represents the Himalayan region, also has diverse agro-climatic situations. Mountains of HP are particularly sensitive to climate change, and falls in the very fast degrading category. The average mean minimum and mean maximum temperature during winter (2021-2050) in subtropical– sub-temperate regions on HP are likely to increase by 2.43°C and 1.74°C with a seasonal average of 2.08°C (Verma et al. 2013). Changes in the climatic variables has also led to challenges of emerging insect-pests and diseases, increasing pesticide residues in horticulture crops, and affect the diversity of pests, diseases, soil microbes, and the crop productivity.

Soil and crop management practices affect the relationship between soil processes and agro-ecosystem function to a great extent, and thus affect the sustainability of agricultural production systems (Jernigan et al. 2020; White et al. 2012; Parikh and James 2012). Indiscriminate use of chemical inputs has adversely affected the soil quality and crop ecosystem, and threatens future food production by reducing biodiversity, declining factor productivity and contributing to environmental degradation of the existing system (Kotschi 2015; Chandini et al. 2019; IPBES 2019). In HP also, use of agro-chemicals has increased tremendously especially in fruits and vegetables (cash crops). The farm products in HP carry ~1% higher pesticide residue (3.47%) than the national average (2.4%).

Transforming agrifood systems is critical in the face of climate change. In the present scenario, ensuring food security, producing more with less resources and building the resilience of resource poor farmers are important in creating a food-secure future. However, the ever-increasing input costs, even in organic production systems, are a concern to the sustainability of the production systems. There is a need to adopt eco-friendly climate resilient soil and crop management practices, so as to make the farming systems sustainable and ensure growth of the agricultural sector. The subsequent focus on developing sustainable and equitable approaches to agriculture underpin the Natural Farming (NF) approach, which aims to address both environmental and socio-economic concerns within the agricultural sector. Subhash Palekar Natural Farming (SPNF) earlier known as zero budget natural farming (ZBNF) is being widely accepted by farmers (Khadse and Rosset 2019; Neelam and Kadian 2016; Fitzpatrick et al. 2022; Behl et al. 2023). The NF, which is based on principles of agroecology, has shown potential to improve soil health, climate resilience and sustain agrifood systems. Low cost and sustainable climate-resilient NF practices can be a boon for maintaining the agroecology (HLPE 2019).It offers a suitable perspective on multiple fronts from production to consumption while addressing wholesome aspects of health (ecological, human and economic). This indigenous cow based holistic farming aims to reduce crop production costs and market dependency for farm inputs by utilizing cheap and locally sourced inputs, and increase farm carrying capacity to sustain the vital livelihood source of resource-poor farmers.

Natural Farming- Present Status

NF is a form of agroecology that addresses the root causes of farmers' problems in an integrated way by providing climate resilient and holistic long-term solutions, which includes a precise focus on social and economic dimensions of food systems. Even before institutional support to NF, as it exists today in various states, farmers have been practicing these tenets for decades led by various innovators. The NF practices, as propounded by Mr. Subhash Palekar, a *Padam Shri* Awardee by the Government of India (Palekar 2013) and promoted by Acharya Dev Vrat Ji, Ex-Governor of HP and present Governor of Gujarat, enables farmers to improve soil health, drastically reduce costs and risks, reduce irrigation requirements and increase yields (Barakzai et al. 2021; Chandel et al. 2021). The four principles of NF being employed by the farmers to enhance productivity at low cost are *Beejamrit* (Seed treatments using local cow dung and urine); *Jeevamrit* or *Ghanjeevamrit* (soil inoculant made of cow dung and urine); *Aachhadan* i.e. Mulching (covering the whole soil surface with crop residue or live intercrops to create favourable microclimate in soil); and *Waphasa* (soil aeration i.e. creating a condition of moisture and air in 50:50 proportion). Some other associated pillars are simultaneous growing of short duration intercrops, including atleast one legume, and use of local resource-based decoctions for plant protection. Several states are practicing NF, and prominent among them are Andhra Pradesh, HP, Gujarat, Chhattisgarh, Kerala, Jharkhand, Odisha, Madhya Pradesh, Rajasthan, Uttar Pradesh and Tamil Nadu (Niti Aayog, 2024). An overall area of more than 6.5 lakh ha is presently under NF, with Andhra Pradesh leading with more than 2 lakh ha.

Mountainous agro-ecosystem of HP, a mountainous state in the lap of north western Indian Himalaya, being one of the most vulnerable ecosystems, needs to be supported by sustainable farming practices without any adverse effect on soil and environment. Keeping this in view, the state has initiated pioneering work in promotion of NF. The Government of HP (GoHP), where 69 per cent of population is dependent on agriculture/horticulture, started a flagship programme *'Prakritik Kheti Khushhal Kisan' Yojana* (PK3Y) in 2018-19 for the implementation of NF and doubling farmers' income as envisioned by Mr. Narender Modi, Hon'ble Prime Minister of India. This scheme emphasizes on exclusion of synthetic chemical inputs and includes a significant initiative to sustain farming of mountainous smallholders through adoption of SPNF/ZBNF. The smallholders of HP have been working hard and are now emerging as leaders in transforming the present input intensive farming including horticulture to non-market driven NF practices. Since its launch, PK3Y has witnessed success among the smallholder farmers of this hilly State, who have successfully raised crops using NF practices. NF has gained prominence, with adoption by about 1.7 lakhs farmers on ~20,000 ha of land across all agro-climatic zones of the state. Out of 99% panchayats (cluster of few villages and the lowest administrative unit) covered under this programme in the entire state, women comprised over 60% of the trained and practicing farmers. The present government has also announced minimum support price for NF produce in the state and announced a new scheme ‘Rajiv Gandhi Natural Farming Startup Scheme’ in July 2024 to further promote NF in the state.

Natural Farming and Soil Health

Healthy soil is the foundation of productive, profitable and environment friendly agricultural systems. Sustainability of a farming system is related to its effect on changes in soil quality over time (Karlen et al. 1997). Changes in farming practices are foremost reflected in the changes in biological properties such as microbial populations and soil enzymatic activity. Soil enzymes have been suggested as one of the important indicator of soil quality, and for evaluating the degree of alteration and assessing the effect of different cropping systems on nutrient dynamics and soil quality (Dick et al. 1994; Bandick and Dick 1999). The soil microorganisms perform various biogeochemical functions and help in replenishing soil fertility, as they are involved in nutrient cycling (Sreenivasa et al. 2009, Jacoby et al 2017).

Plants growing in healthy soils are part of a rich ecosystem including numerous and diverse microorganisms in the soil. It has been long recognized that microbes play important roles in plant nutrition. However, the full range of microbes associated with plants and their potential to replace synthetic agricultural inputs has only recently started to be uncovered. Various researchers have studied effect of individual inputs on crop yields, but information is scarce on the effect of NF package as a whole. NF has positively affected soil quality and microbial community composition within sustainable farming systems (Liao et al. 2019; Verma et al. 2018; Smith et al. 2020; Rana et al. 2021). Yankit et al. (2024) observed a significant increase in the soil microbial (bacteria, fungi and actinomycetes) population under tomato based NF system in comparison to organic (OF) and conventional (CF) system. Another study conducted at Dr YS Parmar University of Horticulture and Forestry (UHF) at Nauni, Solan (HP) reported a higher population of microflora i.e. bacteria (11.36%), fungus (2.04 times) and actinomycetes (8.72 times) under NF practices in comparison to CF (Barakzai et al. 2021). Activity of soil enzymes viz., dehydrogenase, phosphatase and urease under NF increased by 3.01, 0.81, 3.84 per cent, respectively, as compared to the CF system.

Soil organisms like earthworms and micro-arthropods remain under-represented in soil processes. Earthworms are a major component of soil faunal communities in the NF ecosystem. Soil fauna is crucial to soil formation, litter decomposition, nutrient cycling, biotic regulation, and for promoting plant growth. Soil microarthropods have been found to be sensitive to changes in land management practices (Parisi et al. 2005) and are thus being used as indicators of soil quality. NF has also shown increase in soil faunal communities (earthworms and microarthropods). Barakzai et al (2021) reported an increase in soil microarthropods from Hymenoptera, Hemiptera, Coleoptera, Isoptera, and Isopoda orders under NF. They also reported order Geomorphaunder NF, which was not found under CF. Total soil microarthropod population increased by more than 3 times under NF in comparison to CF. The abundance of soil micro-arthropods has been observed to be positively correlated with soil C and N (Wang et al. 2015). Earthworms move the soil around and, in the process, creates tunnels that alter soil in a beneficial way. Earthworm tunnels bring in oxygen, drain water and create space for plant roots. The natural feeding habits of earthworms involve ingestion of small amounts of soil through their bodies and then they excrete it in the form of earthworm casts, which improve soil fertility status (Avant 2017). Earthworms improve soil structure by dragging down organic matter, mixing soil and creating tunnels that improve drainage. Worm casts are rich in recycled plant nutrients, and can contain up to 40% more beneficial humus than the plough layer. Research has shown that a fresh worm cast can hold as much as five times more accessible nitrogen, seven times more accessible phosphorous and 11 times more accessible potash than the surrounding top soils (Farming Connect 2019). Tillage, chemical fertilization, and pesticide usage regularly influence earthworm populations. However, NF practices allow earthworms to proliferate. Cabbage intercropped with fenugreek, pea and coriander under SPNF had higher population count of earthworms (183.33 m^{-2}) as compared to CF (41.67 m^{-2}) (cabbage as sole crop). The result showed that the application of cow urine and dung based inputs help in promoting earthworm activity in soil. Similarly, earthworm cast weight was also higher in SPNF (57.23 gm^{-2}) than CF system (14.87±0.56 gm^{-2}) during the rainy season (Vipul 2021). A systematic comparison between NF and non-NF fields conducted in Andhra Pradesh reveals that the NF fields host average 232 earthworms per square meter compared with just 32 on non–NF fields (Bharucha et al. 2020). Earthworms affect the SOM dynamics. There is sharp increase of mineralization during digestion.

Studies have shown an increase in soil organic carbon (SOC) under NF systems. The amount of SOC is greatly influenced by *jeevamrit*, *ghanjeevamrit,* and other NF practices (Saharan et al. 2023). NF involves addition of microbial formulation based on cow urine and dung which enhance the activity of soil microbes, earthworms and other soil fauna. Increase in SOC has been reported under NF in comparison to CF (Kumar 2024). Survey of apple orchards in HP during 2022 showed higher SOC under NF in comparison to CF (Verma et al. 2024). Zhu et al. (2020) reported changed perception about contribution of microbes towards SOC pools. Further reports (Scullion and Malik, 2000) suggest enhanced SOC with increase in earthworm activity.

Increased microbial activity contributes to nutrient availability in soil. Saharan et al (2023) investigated the effect of *Jeevamrit*-cow-dung- and urine-based formulation—on soil chemical and microbial properties of the ZBNF field coupled with metagenomic analysis and the economics of ZBNF. The percentage increase in soil properties, such as organic carbon, available phosphorus, and available potassium, was recorded up to 46%, 439%, and 142%, respectively, while micronutrients, such as Zn, Fe, Cu, and Mn, also increased up to 98%, 23%, 62%, and 55%, respectively, from 2017 to 2019. Whole genome metagenomic analysis revealed that Proteobacteria were dominantly present, and bacterial phyla including *Bacillus*, *Pseudomonas*, *Rhizobium,* and *Panibacillus*. On the other hand, Ascomycota was the dominating fungal phyla present in the soil sample. Further, functional analysis showed a high representation of genes/enzymes involved in amino acids and carbohydrate metabolism contributing to soil fertility, plant growth, defense, and development. Ladha et al. (2016) constructed a top-down global N budget for maize, rice, and wheat for a 50-year period (1961 to 2010). They reported that non-symbiotic nitrogen fixation appears to be the major source for crop N uptake. An estimated 48% (737Tg) of crop N, equal to 29, 38, and 25 kg ha-1 yr-1 for maize, rice, and wheat, respectively, was contributed by sources other than fertilizer- or soil-N. Around 370 Tg or 24% of total N in the crop has been estimated to through Non-symbiotic nitrogen fixation. Smith et al. (2020) reported that NF is likely to reduce soil degradation and could provide yield benefits for low-input farmers. Nitrogen fixation, either by free-living nitrogen fixers in soil or symbiotic nitrogen fixers in legumes, is likely to provide the major portion of nitrogen available to crops. They also worked out maximum potential nitrogen fixation and release and reported that 52–80% of the national average nitrogen applied as fertilizer is expected to be supplied by biological fixation.

Higher SOC and microbial diversity (fungal hyphae or bacteria) helps in the formation of porous spaces, thereby leading to increase in the absorption of water. Therefore, water adheres to the surface of particles or organic matters leading to water infiltration and increase in the holding capacity. NF practices enhance the soil microbial diversity and soil fauna, and thus lead to improved soil structure and porosity, which leads to better soil physical environment and thus improvement in soil-water-air relations. Study in dry temperate zone of HP under Apple based NF system showed higher soil moisture content (SPNF 2021). The straw mulch under SPNF maintained higher soil moisture (upto 4.9 %, w/w) throughout the season, in comparison to that in CF without mulch. NF practices also moderated the soil temperature. Soil temperature was lower in the afternoon under SPNF in comparison to the plots under CF without mulch, and thus maintained a favourable hydro-thermal regime in the root zone.

Natural Farming-Sustaining livelihoods

Multi-cropping is an integral component of NF systems. Up to 09 crops are being grown concurrently by the NF farmers leading to crop intensification and thus increasing biodiversity. UHF has developed package of practices for different vegetable based NF systems (Tomato+ French bean+ Brinjal; Capsicum + French bean + Brinjal; Pea+ Spinach+ Fenugreek; Cabbage+ Fenugreek+ Coriander) and standardized complete set of high-density apple-based practices based on this low cost, local resource based, non-chemical and climate resilient farming model.

Due to the rising consumer awareness about the ill effects of chemical laden farming products on their health, the demand for NF products is increasing. Orchardists of HP have successfully demonstrated the worth of NF practices for producing good quality apples, and apprehensions cast against the efficacy of NF practices in sustaining the apple productivity are overhyped. Several studies have reported that there is no yield penalty and decrease in income under NF (Vashishat et al. 2021; Duddigan et al. 2022; Laishram et al. 2022). Studies have shown that cost of cultivation has decreased and net income increased under NF. Laishram et al. (2022) studied the impact of NF System on rural households in Solan District of HP. Their study focused mainly on the different cropping systems of NF and comparing the economics of NF with CF systems. Study shows that farmers adopted five major crop combinations under NF system including vegetables-based cropping system (e.g., tomato + beans + cucumber and cauliflower + pea + radish) and vegetables-cereals-based cropping systems. The results indicated that vegetable-based cropping system had 19.68% more net return in *kharif* season and 24.64% more net return in *rabi* season as compared to sole vegetable cultivated under CF. NF maximizes land use and reduces the chance of crop yield loss. NF has resulted in increased returns especially in the vegetable cropping system where reduction in cost was 30.73 per cent (*kharif*) and 11.88 per cent (rabi) across all crop combinations in comparison to CF. There was cost savings from eliminating chemical fertilizers and pesticides as well as higher benefit from intercrops under NF. Chandel et al. (2021) compared the yield potential, input cost and net returns in major crop combinations under SPNF during 2018-19 and 2019-20 with CF. The cereals-pulses, cereals-vegetables, fruit+pulses-vegetables and vegetables-pulses were found as the four major crop combinations followed under SPNF on an average area of 0.26 ha, in HP. The fruit based SPNF farming combination was the most popular (40.6%) and profitable (REE=21.44%). A reduction of 14.34- 45.55 per cent in cost of cultivation and an increase of 11.8-21.55 per cent in the net returns, over CF, validate the superiority of SPNF over the CF. Recent studies by National Institute of Agricultural Extension Management (MANAGE), Hyderabad and Academy of Management Studies (AMS), Lucknow on the impact evaluation of PK3Y have shown positive results of the scheme. The studies shows significant reduction in the use of chemical pesticides and fertilizers, and thus input costs. Almost 45% beneficiaries have adopted NF fully and adoption has percolated to non-beneficiary farmers also. The keeping quality/shelf life has increased substantially and the practice supports the risk resilience in agriculture. According to a survey conducted by the university, farmers have adopted NF for a number of reasons, including family wellbeing, food self-sufficiency, environmental issues, and cost-cutting. Around 99.1% of the farmers conveyed that they are getting better drought resistance in crops and the quality of produce by using NF practices. This clearly shows that NF can be an effective tool in the hands of farmers against otherwise inevitable ill impacts of climate change. Around 99.1% of the respondents reported a better taste of the food produced through NF practices. Critics have expressed major apprehension about windfall decline in crop productivity under NF. But 59.1 per cent respondents reported improvements in yield levels by turningto NF. Saving on account of reduced cultivation cost under NF was confirmed by 89.1 percent apple orchardists.

New Initiatives and Scope

HP has initiated steps towards establishment of circular economy model through standardization of a Sustainable Food Systems Platform for Natural Farming (SuSPNF). This will create loops required to regenerate, recycle and reduce through the value chains for social, ecological and business benefits. The UHF has been working in close coordination and collaboration with NABARD/Department of Agriculture, GoHP to establish SuSPNF model. At the heart of the circular economy is the environment. All economic activity is aligned to ensure that overall systems health is rebuilt. Therefore for a farm, this also means all activity which brings loops of regenerating the farm ecology, recycling natural biomass available and providing the correct or 'true' economic benefits for the farmers e.g. considerations in True Cost Accounting. Circular Farm Economy addresses Net-Carbon Neutrality in all operations of goods and service supply. It involves three aspects viz. regenerating Farm Systems to sequester carbon in soil and produce, products resulting as output from agriculture are reused, recycled or reduced (optimized) to allow net energy savings, and designing value chains from the products to ensure there is no loss or wastage, and reduction in GHG emissions over time. UHF is acting as POPI to establish and hand-hold the FPOs and executing blended financing and facilitating the venture based activities in the campus. In this endeavour, UHF has established a model outlet for selling the NF produce from its farms and that from the FPCs, and demonstrates the supply chain model from farm to fork.

Another innovation is for certification of NF produce. Existing third-party certification has some challenges as it is expensive for the individual farmer. Moreover, it certifies the product and not the producer and therefore requires extensive planning and documentation for initial as well as any revisions in crops sown and grown – thus making it difficult for farmers to apply and avail certification. Under PGS certification, individual farmers cannot apply unless the group of farmers are living in a similar geographical area and Regional Councils (RCs) require funds for data collection, and management and the absence of funding have led to many RCs becoming defunct and non-operational. Although, PGS certificate is free to obtain and the documents needed are basic, its operation and procedure are difficult to be used by an individual farmer/ group of farmers as it does not provide any local language support. This is highlighted by the fact that governments usually rely upon services from Implementation Agencies (IAs) which are tasked to register farmers and groups on the PGS-India platform. Thus, a unique and Innovative Self-Assessed Certification mechanism (CETARA-NF) accessible through a Web portal and mobile application is also being put in place for NF produce (Chandel et al. 2022). The ultimate purpose is to provide an inexpensive and easy process for farmers to certify and for consumers to gain confidence on the food they are consuming. Nearly 1,40,000 farmers have registered for the CETARA Certificate on the web portal till July 2024 (www.spnfhp.in).

NF practices are also a step to meet the sustainable development goals (SDGs). Of the 17 SDGs the most important goals for Agriculture are 'End poverty in all its forms everywhere' (SDG 1), 'End hunger, achieve food security and improved nutrition and promote sustainable agriculture' (SDG 2), 'Ensure availability and sustainable management of water and sanitation for all' (SDG 6), 'Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all' (SDG 8) , 'Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation' (SDG 9), 'Ensure sustainable consumption and production patterns' (SDG 12) and 'Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss' (SDG 15). Moving towards a progressive vision, the NF programme envisions mapping these 7 SDG Goals, 15 Targets and 18 indicators through creation of a SuSPNF. Thus, as per holistic metrics of sustainability, NF endeavours to meet all criteria and aspects of sustainability of farming systems and mitigating the effects of climate change that CF fails to deliver for the future. It also has the potential to sequester upto 1 Tonne of CO_2-equivalent per ha every year.

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Social Innovations for Sustainable Food System Transformation

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Introduction

The sociological imagination is one of the founding principles of the discipline (Mills 1959). It is about the importance of looking beyond individuals to systems and from the systems back to the roles of individuals within them. Looking at a balance between systems and the individuals within them is essential to understanding their collective relationship. These relationships are formed over time and thus in order to build a sociological imagination, we must look at how what we see today has come to be; it is only then that we can see what could be tomorrow.

In line with the sociological imagination, a common practice in sociology is to propose a complex title for one's work and then deconstruct it. Therefore, in this short text, I first deconstruct what is meant by "social innovations for sustainable food system transformation" by providing some definitions. Then I introduce a participatory study of social innovations for sustainable food systems and the key findings and policy recommendations. I conclude with insights about a particular type of interaction – intermediation – that bridges the gap between individuals and systems in transformative change.

Local experiences in agrocology from around the world

'Neither the life of an individual nor the history of a society can be understood without understanding both'

(C. Wright Mills, The Sociological Imagination, 1959)

What are Food Systems?

When the term food system is used in both everyday parlance and scientific publications, there is often a confusion with the word farming system (Dixon, Gulliver, Gibbon, & Hall, 2001). Whereby, the agricultural production, extension and inputs services are imagined. However, emerging from the social sciences in the 1980s, and stabilizing in 2014, the notion of food system (sometimes also referred to as agrifood system) is shorthand for a complex array of relationships from farm to fork and back again (FAO 2020; Loconto & Constance 2024). According to the High-Level Panel of Experts of the World Committee on Food Security (HLPE-CFS), the food system includes the full range of activities, goods, and services associated with the production, trade, processing, marketing, consumption, and disposal of commodities whose origin is in agriculture, forestry, or fisheries, including the necessary inputs and outputs obtained at each stage. The basic building blocks of the food system are the food supply chains, food environments, and consumer behavior – which are all influenced by internal dynamics and external drivers coming from nature, knowledge, politics and cultural (HLPE 2014).

What Makes Food Systems Sustainable?

Food systems are at the core of the 2030 Agenda for Sustainable Development and are an important factor in achieving the Sustainable Development Goals (SDGs) (UN 2015). The way food is currently produced and consumed affects the health and the well-being of people, the environment and natural resources, raising concerns about loss of biodiversity, pressure on water resources, deforestation, increased emissions of greenhouse gas emissions, food waste and food waste. Inequalities and imbalances that exist throughout the food system are caused by the inability of people to access markets, as well as the weak negotiating capacity of actors in the value chain and the difficult access of the urban and rural poor to nutritious and diverse foods. Sustainable food systems are thus those food systems that aim at achieving food and nutrition security and healthy diets while limiting negative environmental impacts and improving socio-economic welfare and good governance (de Olde et al. 2017). Sustainable food systems are therefore protective and respectful of biodiversity and ecosystems, as well as human well-being and social equity. As such they provide culturally acceptable, economically fair, affordable, nutritionally adequate, safe and healthy foods in a way that balances agro-ecosystem integrity and social welfare. A sustainable food system (SFS) is a food system that delivers food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition for future generations are not compromised (Mink et al. 2020).

Social Innovation, how do we define this concept?

We use the official French legal definition of social innovation, which claims that:

'Social innovation consists of developing new responses to new or poorly satisfied social needs in current market conditions and social policies, involving the participation and cooperation of the stakeholders concerned, in particular users. These innovations concern both the product or service, and the method of organization, distribution, (...). They go through a process in several steps: emergence, experimentation, diffusion, evaluation' (CSESS 2024).

In terms of research, social innovation has increasingly become an object of study as the multiplication of prolonged crises at the beginning of the 21st Century as we have witnessed a renewed interest in participatory innovation among multiple actors (Klein et al. 2014), particularly in agrifood systems (Chiffoleau & Loconto 2018), but also a disengagement of States from social policies (Klein et al. 2014).

Are current food systems sustainable?

The past ten years have witnessed a growing public consensus that agricultural production systems are unsustainable (Conway 2012; FAO 2011). However, how to farm sustainably remains open to debate (Constance et al. 2018; Sumberg & Thompson 2012), and there remain concerns about the feasibility of some proposed solutions to also meet societal grand challenges such as 'food security for all' (Garnett et al. 2013; Levin et al. 2012). Traditionally, agri-food system innovation has focused on developing and advocating the adoption and diffusion of productivity-enhancing technology, underpinned by improved research and development, but without much attention paid to system components beyond the technology (Lyson & Welsh 1993). Advances in theories of innovation and socio-technical change recognize the importance of institutions (including markets) and techno-economic networks in the adoption and diffusion of innovations that go beyond the introduction of new technologies and create linkages to individuals and systems that link production and consumption of goods (Callon 1991; Grin et al. 2010; Smith et al. 2005).

In 2020, FAO introduced via their State of Food Security and Nutrition in the World 2020 Report (SOFI) a new metric in line with the Sustainable Development Goals that enabled a more accurate picture of how all countries around the world are achieving a contextualized version of food security in their countries (FAO, IFAD, UNICEF, WFP & WHO 2020).

They referred to this metric as a healthy diet,[1] which they found costs 60% more than diets that only meet essential nutrient needs and nearly five times more than diets that only meet dietary energy needs through a starchy food. According to the 2023 SOFI Report, healthy diets - which reflect global guidelines and include foods from several groups and have greater diversity in food groups - are unaffordable for 2.83 billion people, and more than 1.5 billion cannot even afford a diet that only meets the necessary levels of essential nutrients. The inaccessibility of healthy diets is due to their high costs relative to people's incomes, a problem that was exacerbated by COVID-19, but has since recovered unequally across country income groups. In 2022, the number of people unable to afford a healthy diet dropped below pre-pandemic levels in the group of upper-middle- and high-income countries as a whole, while the group of low-income countries had the highest levels since 2017, the first year for which FAO published estimates. This suggests that limited fiscal capacity in low-income countries provided only partial protection from the negative impacts of these crises.
In other words, no, the current global food systems are not sustainable. A number of social innovations have emerged over the past 20 years as a means to rectify this issue. We now turn to an international study of social innovations for sustainable food system transformation, which will enable us to define what transformation may finally mean in this context.

Methods
Led by INRAE, FAO and local food systems initiatives in more than 25 countries we constructed a multi-actor participatory research process aimed to answer the following problematic: How are farmers and consumers moving towards the use of sustainable practices? What are the motivations and driving forces that enable farmers to maintain their sustainable practices? Specifically, we asked the following research question: *What are the institutional and social innovations that link sustainable farming practices to the market?*
Our timeline was as follows:

- 2013 - Call for innovations linking sustainable agriculture with markets
  - Selection of cases written by local innovators themselves (15/87 - via multi-criteria selection)
- 2014-2016 - field visits, interviews with innovators and their partners, peer review, 2 Researcher-Actor Workshops (Bogotá 2015, Chiang Mai 2016), Virtual Discussion for 6 months
  - Collective writing of 1 Policy Brief and 2 empirical studies
- 2017 - Virtual writing groups, WhatsApp group, 1 researcher-actor workshop in New Delhi.
  - Collective writing of a handbook for navigating local sustainable food system transitions.
- 2018-2019 - Manual testing in 2 countries (India and Senegal), peer review, translation and publication.
  - Sustained collaboration in the community of practice
- 2020-2023 - Presentation and operationalization of the manual

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[1]The three reference diets (energy sufficient, nutrient adequate and healthy diet) are compared with the international poverty line (USD 1.90 purchasing power parity (PPP) per day) for 170 countries. A diet is considered unaffordable when its cost exceeds USD 1.20, i.e., 63 per cent of USD 1.90 PPP per day. This accounts for a portion of the poverty line that can be credibly reserved for food.

  - Presentation in English at the One Planet Global Conference (Virtual Bangkok, Thailand), Nov. 2020
  - Adoption of the manual by the State Government of Himachal Pradesh, India, Dec. 15, 2020
  - Adoption by the IIABA project in Morocco, Dec. 18, 2020
  - Presentation in Spanish in Latin America, April 30, 2021
  - Training on the manual at the World Organic Congress (OWC), Rennes, France, September 08, 2021
  - Presentation in French in Africa, November 26, 2021
  - Development of an e-learning training course in 2022 - deployed in 2023
- 2024-Adoption and expansion by the ACROPICS project and Future Food Partnership

This process resulted in the formulation of a participatory project to study (and do) intermediation. I position the analysis of intermediation within the broader framework of institutional innovation as described by Hargrave and Van de Ven (Hargrave & Van De Ven 2006). By comparing models of institutional design, institutional adaptation, institutional diffusion, and collective action of change, generative mechanisms that might explain this change over time were developed. Consistent with my interactionist approach, the actions of "distributed, partisan, and embedded" actors are important in technological and institutional trajectories (Garud et al. 2002). In other words, different actors play key roles and no one actor controls a path (distributed), actors participate based on their own interests and solutions emerge through committed mutual adjustment (partisan), and actors become dependent on the paths they create, and they learn as the process unfolds (integrated).

Results

Knowledge Intermediation

This first policy recommendation that we came up with in Bogotá in 2015 was that Interactive learning is essential to adapt sustainable agricultural practices and sustainable technologies to a specific local context. The most frequent approach in these cases is to create and disseminate knowledge in farmer-led experimentation, i.e. knowledge about good agricultural practices is adapted to local contexts through a 'learning-by-doing' approach like participatory experiments in farmers' fields. This way, technical knowledge (such as Integrated Pest Management (IPM) methods) combines with traditional knowledge of local farming systems (such as integrated systems with local crops) and individual farmer knowledge of the agro-ecosystem. This result is exemplified by the experience of 'Familia de la Tierra', a network of more than 20 social organizations of agroecological producers, approximately 1,000 rural and indigenous families from different villages in Colombia. The organization is based on a variety of ecological products from sustainable production systems, a common aggregation of value, community reserves of indigenous and creole seeds, and the marketing of products. 'Familia de la Tierra' has carried out projects financed by public institutions in the areas of agroecological production, community seed reserves and the establishment of market channels for the indigenous and rural economy. Today, the organization has an economic sustainability that allows it to continue its activities autonomously, generating a productive model of transition for small producers from conventional systems to sustainable and competitive systems, through forms of social organization and collective planning systems with the market. The social innovation laboratory set up by Familia de la Tierra and the ecotherapy program of one of its members - Parque Temático Chaquen - explain the intermediation of knowledge.

Value Intermediation

Those farmers who could engage in strategic marketing increased their bargaining power in new and existing markets. By establishing semi-formal price-setting committees that include farmers, intermediaries and consumers (particularly through the PGS mechanism), organizing collective sales, and creating physical spaces where new markets can be held, institutional innovations increase farmers' capabilities to negotiate prices that reflect the value-added in sustainably produced products. Therefore, greater support for capacity building and infrastructure that helps farmers to become more strategic about exploiting market opportunities is critical for improving farmers' capacity to benefit from the monetary advantages found in new markets. When farmers, intermediaries and consumers have direct interaction outside of the market, they build trust that carries over into market interactions. These interactions occur through collaboration in some of the participatory research approaches, through membership in participatory guarantee systems (PGS), through consumer study visits to farms, and through community events. When these approaches are also linked to direct markets or increased consumer knowledge about current farming practices, we see an expansion of consumer demand.

This type of value intermediation is well developed in Chile. Informally founded in 1979, Kom Kelluhayin Corporation (CKK) is the first all-indigenous Mapuche (mapu = land, che = people- or people of the land) farmers' association to bring together Mapuche families in the Araucanía region of southern Chile to preserve indigenous gastronomic and cultural traditions through the marketing of products made by Mapuche farmers. In this first period, the focus was on adult education and awareness of the environmental problems (especially the plantation logging industry) that were taking hold in their region and threatening their livelihoods and environment. In 1999/2000, the first legal structure of CKK was established. It consists of 11 farmers' committees (10 in the municipality of Villarrica and 1 in the municipality of Panguipulli) that cover the territories of Putue, Calfutúe, Afunalhue, Malloco Lolenco, Hualapulli, Liumalla Sur, Liumalla Centro, Chaura, Quetroco, Challupen y Traitraico. Approximately 250 families participate in this initiative. The initial motivation for the creation of the cooperative during the Pinochet regime was to protest against the lack of state support in the region. In 2003-2005, CKK decided to distinguish itself in a growing market by creating an ethical label for its products (Sello Etico Mapuche). In 2010, CKK was officially registered as an NGO and farmers' cooperative. That same year, the Ministry of Agriculture issued a call for proposals under its "innovation fund.

The Kom Kelluhayin Cooperative responded with a project to connect the indigenous farming community with local restaurants and consumer groups. Its goal was to increase the availability of organic quinoa for the development of local tourism and the promotion of traditional Mapuche cuisine. The funded project allowed Kom Kelluhayin to build a quinoa processing facility that serves as the cooperative's office, a jam processing facility, and storage space for other farmers' products. It also provided Kom Kelluhayin with the basic funds needed to create local consumer demand. In particular, they invested in renting a stand for the local tourist market and developing the We Mapu label for their members' products.

Infrastructure intermediation

The consumers of sustainable products in our cases are mainly looking for the qualities of freshness, reasonable shelf-life and 'safety' (lack of toxins, microbes and pesticides) in their food. Good logistics management can make all the difference in ensuring that the food that arrives on retailors' shelves meets these quality requirements. Logistics are also important for ensuring on-time delivery of sufficient quantities of the desired products, even for direct sales and particularly for box schemes. Good logistics management is about getting the timing right between on-farm harvest and arrival to the market. Public actors can support local level private initiatives for collective transport, storage and processing of sustainable products (e.g., in Tanzania the public research institute collaborated with a private transport company to coordinate tea plucking schedules with pick-up times, resulting in higher quality tea). This can be facilitated by integrating sustainable products into public purchasing systems or again by making investments in public logistics infrastructures (roads, rail, ports, warehouses, wholesale hubs and retail points).

The Ecovida Agroecology Network (Rede Ecovida de Agroecologia, EAN) is a multi-stakeholder network of more than 5,000 family farmers in 400 municipalities in the three southern states of Brazil (Rio Grande do Sul, Santa Catarina and Paraná). In 2020, these farmers were distributed in 450 groups and associations, which form 29 regional poles (nucleo). The network also involves 250 farmers' markets (feiras ecológicas), 35 NGOs providing research and extension services, 15 commercial vendors, and 30 other organizations (processors, universities, etc.), including 8 consumer cooperatives. Their distributed organic production and consumption network covers more than 1,600 km and has recently expanded to the northern state of Bahia. EAN has disseminated agroecological technologies through an interactive innovation model whose key orchestrating element is its participatory guarantee system. This farmer-led certification model coordinates disparate actors in a network and has been recognized by the state, which has linked it to agricultural and public health policies. Over the past two decades, EAN has taken advantage of its close ties with other social movements and state actors to shape a flexible institutional framework that values farmers' knowledge and experimentation in organic and ecological agricultural innovation. I draw on an analysis of EAN's logistics network to explore infrastructural intermediation.

Regulatory intermediation

Although most innovations are created by private actors and rely on voluntary systems, public support is essential to scale them up by providing an enabling environment that legitimizes both the sustainable agriculture practices and marketing innovations. Indeed, this was found to be the most important role of public actors in the study. Actions need to be taken at sub-national, national and international levels. Nationally, public actors create enabling institutional environments by ensuring that their existing policies and incentive structures do not discourage market-driven approaches to sustainable agriculture. Internationally, public actors can collaborate with trade partners to build regional and international alliances around sustainable agriculture through trade policies and equivalency agreements for existing food safety and sustainable production standards.

After three years of consultations guided by the Ministry of Rural Development, Agriculture and Environment - with the participation of AOPEB and other national organizations as well as the United Nations Development Program, the Food and Agriculture Organization, the United Nations Industrial Development Organization, the United Nations Children's Fund, the World Food Programme and the International Labour Organization - the Environmental Law 3525 was passed in 2006 and the public agency CNAPE was created to administer and promote the Environmental Law, the United Nations Children's Fund, the World Food Programme and the International Labour Organization - the Ecological Law 3525 was passed in 2006 and the public agency CNAPE was created to administer and promote the law with the National Food Safety Authority (SENASEG) as the competent national authority on control systems. The law also creates a means of integrating agroecology into its institutions by requiring governments at the municipal level to incorporate programs and/or projects for training, technology dissemination, promotion, research and/or development of ecological production in their municipal development plans according to the needs or production potential. It is also required that the Ministry of Education incorporate relevant information on the environmental, nutritional, economic and cultural benefits of ecological production in its educational programs. The CNAPE is also charged with creating and strengthening research and technological innovation centers specializing in ecological production and providing incentives to increase research and innovation in this area. This case explains regulatory intermediation.

Conclusion

In this paper we have presented some of the key findings from a ten-year study of social innovations in more than 25 countries on 5 continents that are transitioning their local food systems towards sustainable food systems. We found that a common theme runs across all of these cases. That is, the need for intermediation between the production and consumption side of food systems.

Based on a conceptualization of interactions among individuals and systems, we could characterize a range of actions as consisting of four types of intermediations. These are: i) Knowledge Intermediation, which influences how food system actors gain access to and communicate knowledge about sustainable production, distribution and consumption; ii) Value(s) Intermediation, which consists of the institutional and practice elements of how food is accessed, consumed and valued; ii) Regulatory Intermediation and the use of standards by diverse actors to clarify what the sustainable practices are, who can provide assurance, how to communicate, and iv) Infrastructural Intermediation, or the negotiation of those elements that tie the system and individuals together (e.g., inputs, logistics and finance). Maintaining transparency and patience throughout these complex interactions has resulted in changes towards sustainability and autonomy of producers (cf. van der Ploeg & Schneider 2022).

One of the key questions that farmers, scientists and policy makers alike are asking themselves is whether or not these types of intermediation and local level change are transformative. Our research suggests that transformation can occur once all actors in the food system take into account the situations from which they are starting and focus their collective energies on dealing with multiple small changes across the entire complex.

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The French 0-pesticides Mission and Effectiveness of Formative Evaluation

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Zero (0) pesticides future in France

What if farmers stopped using pesticides? Since World War II, agricultural systems have been intensified through the use of pesticides, with the aim to increase food production. Despite the awareness of the negative impacts on society this has caused, pesticides sales did not decrease over the past decade. Today's conventional farming systems heavily depend on the use of pesticides to protect crops against pests. Therefore, simply eradicating them from agricultural systems is a major challenge. This requires appropriate alternatives to control pests instead (Jacquet et al. 2022). Within Europe, on national and international level, governments have been aiming to reduce pesticides use. For instance, the French government launched a national policy plan called 'Ecophyto' in 2008, with the aim to reduce pesticides use with 50% by 2018. Despite the ambition, its mid-term assessment showed that pesticides use did not decrease, but increased instead (Hossard et al. 2017). As a response, the French government presented a revised 'Ecophyto II plan' in 2015, and the 'Ecophyto II+ plan' in 2019. As part of the revisions, Research and Innovation (R&I) efforts were reinforced through a dedicated research programme with the objective of identifying alternative options to the use of chemical pesticides. Consequently, in June 2019, the French Ministry of Higher Education, Research and Innovation launched the national Priority Research Programme 'Growing and Protecting Crops Differently' (PPR-CPA). The PPR-CPA is a six-year research programme with an ambitious mission: a French agricultural system without pesticides by 2040. In contrast to the Ecophyto plan that aimed for a reduction of pesticides, the PPR-CPA has set the goal of their full eradication in France (Jacquet et al. 2022).

The programme is funding ten research projects (30 million euros over 6 years), which are required to conduct research on alternative solutions to pesticides. This reinforcement of research efforts highlights the responsibility that the French Government attributes to researchers to contribute in resolving the problem of the overuse of pesticides. The researchers are encouraged to think about their contributions to the constitution of a society without pesticides as they study alternative solutions. This is an example of a so called 'Mission-Oriented Innovation Policy'. While it highlights the governments' belief in the capacity of researchers to address ambitious societal goals, it also leads to the question how research could be directed in contributing to desired futures.

European Policy Approach: Mission-Oriented Research and Innovation

At the European and National level, mission-oriented research programmes fund researchers to study alternative solutions in an effort to achieve societal missions. Over the past 15 years, societal missions have been developed by governments in Europe, in an attempt to solve complex problems in society through R&I. However, missions have not always been about addressing challenges in society. The United States of America (USA) already led a mission about a century ago through their Manhattan project and the Apollo moon-landing mission in the 1960s. Such Technology-led missions are difficult from an engineering point of view, but are less complex than societal challenges-led missions (Wanzenböck et al.

2020). On the European level, R&I efforts addressing societal challenges got popularised through the EU's research framework programmes. The EU's H2020 programme (2014-2020) emphasized the need for R&I to respond to what they call Grand Societal Challenges (GSCs). The programme aimed to couple R&I efforts through its three pillars of implementation: 1) Excellent Science; 2) Industrial Leadership; and 3) Tackling Societal Challenges[2]. The EU's current R&I programme 'Horizon Europe' (2021-2027), the three pillars changed as follows[3]: Open Science (Pillar I); Global Challenges and Industrial Competitiveness (Pillar II); and Open Innovation (Pillar III). As part of Pillar II, the EU added the so-called 'EU missions' framework to address societal challenges, by supporting collective effort. Societal challenges are complex and require coordinated cross-cutting actions with clear goals. In addition, missions go beyond the efforts of R&I, but bring together different stakeholders in innovative ways and actively engage citizens.

Five missions have been identified by the EU to support the Horizon Europe R&I programme[4], which are defined as 'ambitious goals to deliver concrete results by 2030'[5]. The missions' framework is largely influenced by the various experts reports developed by the economist Mariana Mazzucato (e.g., Mazzucato 2018, 2019) for the European Commission, which popularised the concept of 'Mission-Oriented Research & Innovation' (MOIP)[6]. According to Mazzucato (2018) *"Missions provide a solution, an opportunity, and an approach to address the numerous challenges that people face in their daily lives" (p.4).* Mazzucato (2018) defined five criteria for a mission, which illustrate that societal challenges-led missions are about setting R&I directions for tackling specific problems in society:

- Bold, Inspirational with wide societal relevance
- A clear direction: targeted, measurable and time-bound
- Ambitious but realistic research and innovation actions
- Cross-disciplinary, cross-sectoral and cross-actor innovation
- Multiple, bottom-up solutions.

For researchers to address such societal challenges that missions represent, scholars argue that R&I activities should go beyond just setting new objectives. It requires researchers instead to contribute to change socio-technical systems (e.g., Weber & Rohracher 2012; Schot & Steinmueller 2016, 2018; Kuhlmann & Rip 2018). While this literature stresses the need for and the importance of transformative and systemic change ('unravelling business as usual'), it also highlights the difficulties in directing R&I efforts towards societal goals. Mission-oriented programmes can help navigating R&I towards transformative change in society, by allowing to define a specific societal problem and how solving this problem unites a diversity of actors (Mazzucato 2018; Hekkert et al. 2020; Janssen et al. 2021). Hence, for researchers to contribute to a societal mission requires them to envision a desired

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[2]Pillar III embedded seven domains of societal challenges: i) Health and wellbeing ii) Food and Sustainable agriculture, iii) Energy, iv) Transport, v) Climate action, vi) Reflexive societies and vii) Secure societies

[3]https://www.horizon-eu.eu/

[4]Adaptation to i) Climate Change, ii) Climate-neutral and Smart Cities, iii) Cancer, iv) Soil deal and Europe, and v) Restore our Ocean and Waters

[5]https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe_en;

[6]https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe/mission-oriented-policy-studies-and-reports_en;

future that can be realised with the alternative solutions they study, and the transformative change in society that is needed to achieve this future.

Need for guidance: a formative evaluation approach

The achievement of a mission is not the direct outcome of a research programme or project. Instead, it is a complex and uncertain process, which needs more time, more actors, more resources, and visions of changes in society that are required. Conducting research in a mission-oriented context thus need researchers to rethink the associations between their science and society, by involving others actors and by proposing alternative solutions that can advance a collective effort. As societal missions are very complex, how can research efforts be directed towards societal goals (problem-solving)? The problems that societal missions are meant to solve are not engineering problems such as the 'moon-landing' mission. Instead, it asks researchers to solve problems that are about society as a whole. This means that we do not only need change in how we conduct research, but it also needs change in society. Hence, directing research to achieve a mission requires research assessment frameworks so to align R&I efforts with visions of broader societal change and impacts (Matt et al. 2023). In this regard, formative evaluation is a potential means to guide researchers, which involves the evaluation of real-time impact as a learning process involving all actors in the R&I programme (Molas-Gallart et al. 2021).

Hence, we questioned how a real-time impact assessment approach (formative evaluation) can support researchers in finding solutions that can contribute to societal missions. For this, we studied the empirical case of the PPR-CPA with the French mission to eradicate pesticides. The PPR-CPA is an innovative research programme as it is subdivided into various activities:

- Funding of ten research projects for 6 years (30 million euros);
- A foresight study on "a European agriculture without pesticides";
- A real-time assessment of the impact of the PPR. This will consist of an assessment of the real-time 'Impact Pathway' (ASIRPA Real-Time method);
- Synthesis of scientific knowledge on pesticides and alternative practices;
- International symposia.

This highlights the unique combination of foresight exercises, research operations and impact assessment, while they are normally decoupled from one another. These activities have been integrated in the programme with the aim to increase reflexivity in the design and implementation of R&I for the mission of a 0-pesticides future (Jacquet et al. 2019).

This research for this paper is conducted within the context of the implementation of the ASRIPA Real-Time (RT) approach in the PPR-CPA. The ASIRPA approach was launched at INRAE in 2011 as an '*ex post* tool' for INRAE's research impact assessment (Joly et al. 2015). ASIRPA's central tool is the 'impact pathway' (IP). The IP describes the non-linear process of how scientific knowledge is translated into impacts. This IP goes from scientific knowledge, into outputs, and through the intervention of intermediary actors and eventually translates into impacts. There are five dimensions of impacts: 1) economic; 2) health; 3) social; 4) environmental; 5) political (Matt et al. 2017; Joly et al. 2015).

Building upon almost 10 years of experience, the ASIRPA RT (real time impact assessment approach) is being developed since 2018. It is a formative evaluation tool, with the aim of accompanying researchers to envision desired futures and to navigate research in that direction (Matt et al. 2023). The ASIRPA RT approach is included in the PPR-CPA as a means to support researchers in considering their contributions to pesticides eradication and the societal impacts that this eradication could bring. Through webinars, workshops and an online course, with the ASIRPA team we guided the PPR-CPA researchers in constructing their impact pathway. This started with envisioning the projects' contribution to societal impacts and transformations. The second step was to identify the R&I activities linked with the envisioned societal impacts and transformations, and the third step was to envisions the context of intermediation (actors to involve, blocking and facilitating factors, what should be in place to achieve the envisioned impacts etc.).

Change in vision

For the ten funded projects of the PPR-CPA it was a requirement to participate in the ASIRPA RT activities as part of the research programme. We wanted to understand how ASIRPA RT enabled the researchers to envision their contributions to the eradication of pesticides. Therefore, we studied a change in visions between two phases - before and after the researchers' participation in ASIRPA RT:

- **T_0-phase**: This represents the phase before the PPR-CPA researchers participated in the ASIRPA RT activities. It allowed us to analyse the researchers' envisioned contributions to the 0-pesticides mission in the construction of their projects, to obtain a baseline.
- **T_1-phase**: This represents the first phase of the participation of the PPR-CPA researchers in ASIRPA RT – starting in February 2021. In this phase, through various activities, the projects' researchers collectively developed and discussed their first IP. This allowed us to analyze the researchers' envisioned contribution to the 0-pesticides mission when ASIRPA RT supported them.

At the T0-phase, our results show that the PPR-CPA projects demonstrate renewed and more ambitious scientific questions so to respond to the 0-pesticides mission. However, the researchers also emphasized a scientific way of approaching a society without pesticides, whereby they envisioned change in society as the result of the transfer of research outputs. These visions concerning the researchers' contributions to the eradication of pesticides are characterized as follows:

1. **New and more ambitious scientific questions** compared to previous projects without a societal mission in which PPR-CPA researchers have been involved.
2. **Contribution to the envisaged mission through a scientific knowledge mode**, reflecting the vision of the researchers' contribution to the mission through a scientific approach to how a pesticide-free society should be constituted and act.
3. **Interest in, adoption and straightforward use of alternative solutions in society**, for which it is the responsibility of research to provide scientific evidence.

When they got involved in ASIRPA RT (T_1), the researchers showed a change from the 'transfer' of research results to interested stakeholders to 'translating' the alternative solutions within a network of stakeholders. This was revealed through three changed visions of the researchers:

1. **Eradicating pesticides:** A pesticides-free future is considered from a scientific perspective (T0), versus a co-production between researchers and stakeholders (T1)
2. **Impacting society:** A scientific analysis of the performance of alternative solutions (T0), versus anticipating the role of other stakeholders in eradicating pesticides with the alternative solutions (T1)
3. **Favouring acceptability:** A scientific study of the acceptability and willingness of stakeholders to use alternative solutions (T0), versus the anticipation of raising interest and enrolling other stakeholders (building the network) (T1) that show how to enable or encourage stakeholders to continue developing and implementing alternative solutions.

To conclude, our research shows that for researchers to contribute in achieving a future without pesticides, guidance is needed. Through their involvement in ASIRPA RT, researchers realized that achieving the mission required the mobilization of a diverse set of actors, each of whom must take on specific responsibilities for realizing the eradication of pesticides. Hence, this reflects three main changes in the visions of researchers:

- For the researchers, contributing to a future without pesticides is no longer a question of envisioning the performance of alternative solutions from a purely scientific point of view, but of envisioning what such a future should look like and what other actors should be involved.
- For the researchers, contributing to a future without pesticides is no longer just the ambition of research projects that needs to change to achieve such a future, but also the other actors to enable the development and societal embedding of alternative solutions.
- For the researchers, contributing to a future without pesticides is no longer a linear process from research to society, but the research projects are envisioned within networks of other actors with whom they should/will interact.

This shows that excellent science can be directed towards societal goals. Achieving a desired future, such as a future without pesticides, is a collective process of researchers with other actors. The involvement of the other actors in the mission must be anticipated in order to facilitate the translation of results. In this process, collective visions are key of how such a future would look like and how it can be achieved. If research is expected to contribute to change in society, the researchers must change too: if society has to change, researchers' visions must change with it.

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Microbial and Organomineral Solutions as Effective Pillars in an Agro-ecological Practice

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Microbial and organomineral solutions represent an innovative mixture of microbial and mineral components which substantially increases the conversion rate and yield of a variety of crops in different types of soil, thus improving the overall output and sustainability of crop farming in general, including organic farming. The ultimate challenge we have recognized is formulating a set of environmentally friendly and healthcare-safe bio-based mixtures, highly efficient bio-fertilizers with pesticide characteristics, technologically not too complex to produce in scalable quantities, and consequently attainable at acceptable cost with solid market and commercialization potential. These components alone have a positive impact but combined they provide multiplied synergistic effects. And today's synergy is what we believe will yield a global impact on any local endeavour tomorrow. Improved management and recycling of plant residues for increased soil health, and reducing the discharge of nutrients (nitrogen, phosphorus, potassium) into the environment will be our priority, together with empowered interdisciplinary design processes to create soil improvers enhancing the functionality of the root-acting directly or indirectly with the crops, and to valorize plant by-products and beneficial microbes in sustainable agriculture. Circularity is a key component of the European Green Deal, especially the Circular Economy Action Plan, the Farm to Fork and the Bio-economy strategies, and the supporting FOOD-2030 research and innovation policy. Taking into account current EU and Serbian regulatory legislation, setting up an evaluation framework for the design, implementation, and monitoring of the performance of strategies to support circular bio-economy and initiatives that boost nutrient use for soil health will be imperative. An untapped opportunity lies in the valorization of new eco-friendly products containing mineral nutrients, organic matter, and microbes that can contribute to soil fertility and amelioration while considering the plant residues hierarchy focused on prevention actions and followed by reuse and recycling pathways (those residues cannot be used for other higher value uses). We strongly believe that this smart platform product [smart compost system for targeted crops - enabling plant disease control and efficient fertilization, eliminating adverse effects of pests growing resistance, pollution, toxicity, quality products (functional food for humans and animals) for better health of humans, and soil quality degradation caused by the usage of common chemically based fertilizers and pesticides] will have bright future.

Introduction

Food security and crop protection are of the greatest public interest, as the world population will grow to 9.7 billion people by 2050 and global food production will have to increase by 40% to meet the growing demand (FAO 2017). Pathogenic bacteria and fungi cause losses of around 10% of global production of various crops, leading to major economic losses (Arora et al. 2012). Although current EU legislation aims to reduce the use of chemical fertilizers and pesticides by up to 50% by 2030, agricultural practice still relies heavily on their use. Due to the negative effects of chemical pesticides on human health and the environment, as well as the emergence of resistant strains, there is a global need and intention to find alternative and safe ways to protect crops (Raio et al. 2017). The microbiological and chemical degradation of pesticides in soil is extremely slow, and their excessive use has led to permanent pollution of soil and groundwater, as well as their uptake by plants and entry into the food chain (Sánchez-Bayo and Tennekes 2015). In addition, agricultural intensification, including intensive tillage, monocultures, incorrect and excessive use of artificial nutrients, has contributed significantly to soil degradation, i.e. loss of soil organic matter, soil erosion and CO_2 release, making soil health management one of the most important steps in food production and sustainable agricultural practices (Lehmann et al. 2020).

Plants host diverse microbial communities that colonize every accessible tissue and play an important role in plant productivity, health and stress tolerance (Dastogeer et al. 2020). In a complex plant-pathogen-antagonist network, beneficial microorganisms interact with phytopathogens through antibiosis, competition for nutrients and space, production of antimicrobial compounds, parasitism and induction of systemic resistance, all of which suppress symptom development in plants (Lahlali et al. 2022). In addition, microbiota enables biotic and abiotic stress tolerance and has a positive effect on crop quality through plant growth-promoting mechanisms. Thus, maintaining the structure of the microbiome in a state of homeostasis is an ongoing process that is critical for healthy plants (Dastogeer et al. 2020, Dimkić et al. 2024). Based on naturally occurring interactions, research on alternative crop protection solutions has focused more on plant growth-promoting and antagonistic microorganisms, *i.e.* biocontrol agents. Beneficial microorganisms used as microbial inoculants are sustainable and environmentally friendly products that contain living or latent cells of efficient bacteria, fungi or algae. When applied to the soil, seeds or plants/seedlings, they improve plant biomass by 10 to 40 % (Montoya-Martínez et al. 2022). Moreover, the application of microbial solutions in agroecosystems is considered a promising tool to improve carbon sequestration, which is one of the key components of soil health. As part of management strategies for sustainable food production, the use of organic amendments such as compost and biochar is also recommended to increase the activity and survival of beneficial microorganisms in the soil (Lehmann et al. 2020, Malik et al. 2022).The main approach in designing microbial solutions for plant protection is presented in Figure 1.

Metabolites against plant pathogens

Beneficial *Bacillus*- and *Pseudomonas*-based formulations are the most widely studied agents for the control of many economically important plant diseases. They are ubiquitous in soil and colonize plants, including the rhizosphere, phyllosphere and endosphere, and exhibit almost all biocontrol and biostimulatory mechanisms that have a positive effect on crop quality and yield, such as higher biomass and nutrient quality, improved nutrient uptake, increased tolerance to biotic and abiotic stress. In addition to producing active compounds, they are also successful colonizers due to their low nutritional requirements and rapid reproduction, which is extremely important for the maintenance of biocontrol agents after application in the field. Their use has no or minimal negative impact on the environment and is therefore an environmentally friendly solution to reduce the need for chemical fertilizers (Dimkić et al., 2022).

Endospore-forming *Bacillus* species directly suppress and inhibit plant pathogens by producing various antimicrobial compounds such as volatiles, bacteriocins and lipopeptides, i.e., iturins, surfactins, fengycins and kurstakins. Complex biosynthetic systems provide the *Bacillus* species with lipopeptides of exceptional heterogeneity of type and sequence of amino acid residues, the nature of the peptide cyclization, and the nature, length, and branching of the fatty acid chain. They are also indirectly involved in plant protection through production of phytostimulatory compounds e.g. auxins, gibberellins, cytokinins and abscisic acid. Induction of systemic resistance in the host enable by activating jasmonic acid (JA), salicylic acid (SA) or ethylene (ET) signaling pathways. In addition, *Bacillus* strains and their volatiles silence quorum sensing mechanism in competing bacteria and down-regulate the expression of genes involved in the virulence of fungal pathogens. Suppression of fungal diseases is mediated by enzymes such as chitinases, glucanases and proteases (Cawoy et al. 2011, Fira et al. 2018, Dimkić et al. 2022).

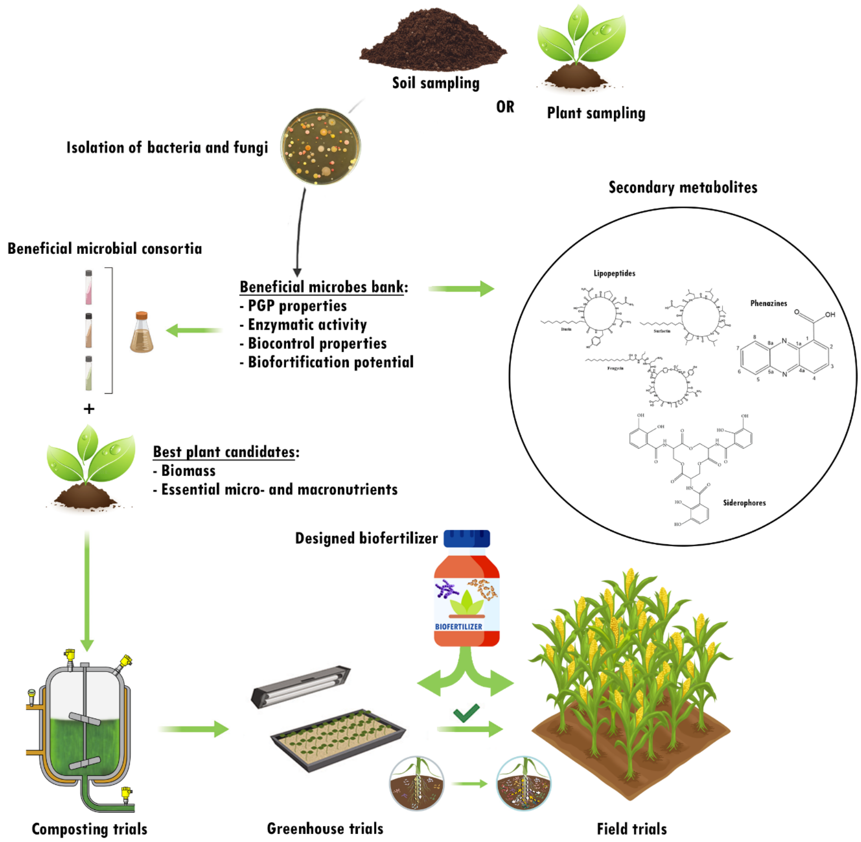

Fig 1: Main aspects of manipulating the microbiome of plants and soils for the development of biofertilizers: inoculation strategies, delivery methods and testing (Tosi et al. 2020)

The genus *Pseudomonas* comprises a large number of species that have both direct and indirect positive effects on plant health. The most common molecules involved in this mechanism are phenazine-1-carboxylic acid, phenazine-1-carboxamide, pyrrolnitrin, pyoluteorin and 2,4-diacetylphloroglucinol, cyclic lipopeptides and volatile organic compounds. Cyclic lipopeptides have been extensively studied as agents for biocontrol and biostimulation in agriculture, with nunamycin, nunapeptin, brasmycin, and braspeptin identified as essential for antifungal activity as well as sessilins and orfamides shown to have additive roles in the suppression of some fungal diseases. The enzymes chitinases, glucanases and proteases are also involved in the control of fungal pathogens. Competition for iron is based on siderophores such as pyoverdine and pyochelin, while the promotion of plant growth is stimulated by 1-aminocyclopropane-1-carboxylate deaminase, indoleacetic acid, abscisic acid, gibberellic acid, cytokinins, niacin, pantothenic acid, thiamine, riboflavin, and biotin (Mishra and Arora 2018, Dimkić et al. 2022).

Arbuscular mycorrhizal fungi- Soil improvers

There is increasing interest in the use of arbuscular mycorrhizal fungi (AMF) as commercial bioinoculants. AMFs are an important part of the soil microbiome, forming a functional mycorrhizal symbiosis with 80% of terrestrial plants, which benefits from improved nutrient uptake. By stimulating the production of secondary metabolites and phytohormones, they also improve plant productivity, plant quality and tolerance to biotic and abiotic stress. AMFs influence carbon sequestration and accumulation in the soil, which leads to a stabilization of long-term carbon storage in the soil. Commercial AMF-based inoculants are mostly based on *Rhizophagus*, *Funneliformis*, and *Claroideoglomus* strains (Basiru and Hirji 2022).

Biochar-Soil amendment for sustainable agroecological practice

Recently, soil amendments such as biochar and compost have become more prominent in sustainable agroecological practices, where they are used to promote crop growth, quality and yield as well as improve soil fertility. Biochar, produced by pyrolysis of organic material at low oxygen levels, has a carbon content of 70–80% and significant carbon sequestration potential. It has been proposed as a carrier for biofertilizers and nutrients in crop production, as it has a high resistance to decomposition and provides a larger surface area for microbial inoculants, improving their colonization and survival in the soil. When applied together with plant growth promoting bacteria (PGPB), it has a positive effect on nutrient cycling in the soil. As biochar alone reduces nitrogen accessibility to plants, the combination with PGPB reduces this side effect in the agroecosystem (Malik et al. 2022, Ahmad et al. 2023). The high compatibility of biochar and beneficial microorganisms makes it an excellent basis for the development of biofertilizers that can be used in soil and plant protection management.

Future perspectives

Global demand for environmentally friendly technologies and organically grown food is constantly increasing as urbanization and modernization influence agricultural practices. The accumulation of pesticides and pollutants, as well as the emergence of resistant pests, has led to a lack of soil fertility, a depletion of nutrients and a low number of heterotrophic microbial consortia. With the aim of reducing the use of chemical fertilizers and pesticides by up to 50%, the negative effects of pest resistance, pollution, contamination, toxicity and other negative impacts on the environment can be reduced. Biopesticides and biofertilizers are suitable solutions, especially in developing countries, to meet the demands of farmers and consumers to reduce chemical residues in final products. Furthermore, the use of biological plant protection products is not only an alternative to chemical pesticides, but also enables the control of diseases that cannot be controlled with other control strategies, such as crown gall disease. With the development of new technologies, the formulation of reliable and efficient microbial and organomineral solutions is seen as key to a holistic and integrated approach to agroecological practice.

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Participatory Research, Living Labs and Transformative Public Policies in France

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Introduction

Grassroots initiatives involve third sector organizations (TSOs) and other stakeholders engaged in transformation for sustainability. The third sector concept roots in the idea that society is divided in three sectors : the state, the market, and the third sector (Alcock 2010). Third sector includes non-governmental and non-profit-making organizations or associations, including charities, voluntary and community groups, cooperatives, etc. Over the past 80 years, TSOs have be excluded from the research and innovation system which is framed as a triple helix formed by State, universities and large firms (Etzkowitz, et al. 1995). Analysts hypothesized that Sustainable innovation depends on the transformation of this triple helix into a quadruple helix including TSOs because: 1. Sustainability research and innovation should be conducted in a way that is responsive to the needs and interests of society; 2. TSOs are associated with values and principles which may balance those of the state and the market. Inclusion of these new stakeholders implies a transformation of the whole Research and innovation system to include stakeholders such as smallholder farmers and local experts, as well as consumers and environment activists. This potentially transformative system needs adapted research policies. It also needs its own places, actors, culture, rules, and methodological tools for participatory action-research.

The article is divided into three parts including, i) Experimental public policy to support TSOs, ii) Research-action project that aims to may contribute to the reconfiguration, and iii) The institutionalization of community living labs in France.

Experimental public policy to Support TSOs

As a first example of transformative policy, I will present how grassroots initiative leaded to an Experimental Public Policy to Support TSOs in research and innovation. Although this policy was not specifically dedicated to Food and agriculture, I will situate the story in this context. During the first half of the XXth century, smallholder farmers were struggling to make a living out of their production. Research in agronomy was performed in few laboratories depending on engineer schools. After the Second World War, the Government created a national research institute for agronomy (INRA) to allow agriculture to feed the growing city areas. For 20 years, INRA grew, structured an agro-food sector and succeeded in transforming French agriculture into a flourishing agro-industry complex. At the beginning of the XXIth century, INRAE is a unique national research institute dedicated to research agronomy, a partner of the international agro-food industries he contributed to create, and under the umbrella of two ministries: Agriculture and Research/High Education.

Nevertheless, some scientists from INRAE have continuously been working with local farmers since the 70', including members of our own laboratory LISIS. They helped frame alternative modes of agriculture such as agro ecology. INRA also had to contribute to the transformation of the Rand I system into a quadruple helix. Since 2013, we have been contributing to the structuring of a network of public research institutes and TSOs. Over 5 years, this network has involved almost 100 organizations in the collective writing of a white paper entitled "Taking the knowledge society seriously" (Akrich et al. 2017). This white paper highlights the diversity of participatory approaches in research and innovation, identifies TSOs as strategic actors in the quadruple helix, and makes recommendations for structuring partnerships through appropriate public policies.

This white paper pointed the need to fund research and innovation in TSOs. It led to the experimentation of a policy instrument to finance the employment of a qualified employee (a master degree or a PhD) for 3 years, renewable twice. This instrument was expected to bring stability in the research activities of TSOs. I contributed to the experimentation from 2019 to 2021 (Lhoste and Sardin 2024). Over 10 of the 35 funded TSOs were intermediaries in research networks. They steered community living labs dedicated to research, networks leaders or systemic intermediaries as described by (Van Lente *et al.* 2003). Among them, seven were involved in transformative research in agro ecology or organic food production. They created (or develop pre existing) research projects, hybrid networks with scientists and professionals through seminars and working groups. They also contributed to scaling up through observatories, training programs, and living labs.

Although impaired by the Covid-19 pandemia, this experimentation demonstrated that funding TSOs' research activities through this experimental policy allowed time and legitimacy and fostered social learning in organizations. Although the experiments lasted only for 3 years, we also observed that it contributed to scaling up grassroots innovations (engaging more participants in a same project), to replicating an experiment in a different situation, or to translating a research project in a different domain through the community of practice (Seyfang and Longhurst 2016). We also observed a few changes in governance and work approaches. The subsidies facilitated the implementation of reflective and experimental approaches within the organization. It has also proved to be a lever for other sources of funding since it prompted decision-makers such as local and national authorities, to acknowledge TSOs as credible and legitimate players in research and innovation. Indeed, grant winners asserted that being paid for research/innovation activities conferred TSOs not only time, but also legitimacy towards their organization and universities. TSOs also contributed to changing the cultures, rules and norms of cooperation between the TSOs and universities. These are premises of transformation.

Action-research project to steer tools for transformative research and innovation

Another direct consequence of the work of the think tank is an action-research project aimed at providing methodological tools for transformative participatory research involving TSOs. Participatory research is necessary for Socio-Economic Transformation, Sustainability and Natural Resource Management. It may contribute to the democratization of our society and strengthen endogenous territorial development. I coordinate this action-research project called EQUIPACT. The EQUIPACT consortium is representative of the diversity of organizations involved in participatory research processes. It includes eight NGOs, two public laboratories, two national research infrastructures, and a museum. It is connected to various networks that are expected to contribute to the dissemination of action knowledge developed. EQUIPACT should produce methodological tools and recommendations for participatory research. We are currently experimenting formative evaluation (Matt et al. 2023). Formative Evaluation is based on the assumption that action research will only be transformative if a series of systemic changes are introduced simultaneously. Formative evaluation is a process that involves members of a collective who co-construct a common future and identify the path to follow. In doing so, they consider concrete achievements to access it. Successive revisions of the impact path allow them to check their progress towards their goal. They move forward together, continuously adjusting their actions and alliances in response to encountered problems and opportunities. In case of deviation, they can take corrective measures to return to the initially envisaged trajectory or establish a new trajectory better suited to the new situation. At the EQUIPACT project's launch in 2023, we proposed to our fellow participants to construct a prospective impact pathway of the research project. This impact pathway should serve as a basic tool for guiding our actions throughout the project. It reflects a collective vision of the desired social ideal (i.e., societal impacts[7]) and materializes the path to achieving it. The available resources, expected outputs, actors to involve, and anticipated changes are noted. It must be regularly and collectively revisited to identify encountered obstacles and levers, and to consider remedies and new actions. In 2024, we revised this impact pathway. We discussed our productions, the obstacles encountered and potential leverage points. This methodological tool helped catalyze social learning within the network.

The Institutionalization of grassroots living labs

Another instrument which is known to be necessary for participative innovation are living labs. I will briefly report how community living labs were institutionalized in France. These living labs should not be confused by those open by institutions such as INRAE. These living labs were first created by communities, often supported by public fundings. They provide people with a place to meet and experiment together solutions to local problems. They offer equipment and methods to organize participatory action-research in agriculture, environment, food, health, education, and more. In France, we call them third places. Since 2010, this movement met the participatory dynamics launched by public authorities. Public authorities first took an interest in fab labs. Fab labs are defined as "platforms for the rapid prototyping of physical objects... fitting into the movement of Third Places and the collaboration mechanisms at work on the internet". In the early 2010s, hacker spaces and fab labs began to emerge in France (Lhoste and Barbier 2018). Founders choose one name or the other depending on their connections with hacker ethics, counterculture, and academic institutions. They also claimed a lineage with low tech innovation, popular education, the social and solidarity economy, and the do-it-yourself movement. All of them advocate for openness, knowledge sharing, and learning by doing. The resulting sociability is both a means and a consequence of this desire for sharing. In 2013, the French Ministry of Industrial Renewal launched a dedicated call for projects with a budget of two million euros. This has not be reproduced, although Fablabs have been very active in mask making during the Covid lock down.

Simultaneously, pioneers open a place called Le Comptoir Numérique in Saint-Etienne, which brought together a co-working space, a digital public space, and a digital resources hub. Along with others, its founders were at the origin of the French-speaking community of Free and Open Source Third Places Developers / TiLiOS. In 2018, a report counted more than 1,500 co-working spaces and fab labs. In 2023, they were over 3000. This mushrooming has been made possible through public policies. The publication of the report was followed by the creation of a financing program under the auspices of the National Agency for Territorial Cohesion (ANCT), further transformed into "NGO France Tiers-Lieux" which was open to any organization which identified itself with the so called "third place movement". The Fablab network joined the movement. In late 2020, the State recovery plan promised to support local initiatives through 300 "Territory Factories" and 500 "Local Manufactures." Three calls for projects dedicated to third places followed,

[7] Impacts are qualified as "societal," meaning that the focus is on the effects on all potentially concerned people, not just the direct targets. The study of impacts on field professionals, who also belong to society, is, of course, particularly relevant for this analysis.

totaling 292.1 million euros. Beyond these national calls for projects, it is difficult to assess the investment of public authorities, who can also provide human, real estate, and financial resources through other mechanisms. Nevertheless, these public policies have helped structure local and national networks and create a national observatory.
The 2020 Covid lockdown and crisis highlighted the contribution of Third places to the resilience of territories. Their impressive multiplication across the French territory reflects the impact of public investment. Their number has tripled in five years, and there are now over 3000 living labs outside universities and cities, where these actors experiment with new ways of working together to address environmental and social challenges. Among these third places, some have agri-food ambitions. They are mostly located in rural areas and aim at agro ecology and organic production, local markets. They are open to both professionals and consumers. They support professionals in agricultural entrepreneurship (help with setting up, access to land, agroecological innovation, etc.). They also engage in mediation activities with residents/consumers, inviting them to actively contribute to transitions. Their research and innovation practices concern all levels of agroecological systems organization. They focus on socio-technical innovation and agricultural practices, on the organization and governance of businesses, and on the structuring of a local ecosystem. Like other third places, the COVID-19 crisis highlighted their contribution to the resilience of territories.

Conclusion

These three examples show how transformation of the research and innovation system needs both grassroots initiatives merging with public policies. First, the grassroots living labs movements is sustained by public policies. However, it is rather small since 3000 places skattered on a 66 billions square meter territory is anecdotic. Second, a policy instrument that financed researcher's positions in TSOs showed to be valuable for developing participatory research. But here again, the experimentation should be 10x expanded and last for a decade to fulfill changes. The formative evaluation is a methodological tool which may also contribute to social learnings.

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Agroecological based Farming System Approaches for Sustainable Food Systems and Climate Resilience

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Introduction

Agroecology addresses Sustainable Development Goals (SDGs). The Food and Agriculture Organization (FAO) highlights that agroecology can play a critical role in alleviating hunger (SDG 2) and poverty (SDG 1) while also contributing to other goals (Pimbert 2018) like good health and well-being (SDG 3), gender equality (SDG 5), climate action (SDG 13), life below water (SDG 14)and life on land (SDG 15). In the context of current and future climatic, energy, and economic challenges, agroecology is regarded as one of the most reliable approaches to achieving sustainable development (Streimikis and Baležentis 2020). Agroecology embodies a long-term vision and offers a pathway for successful transitions toward sustainable agriculture and food systems. The agroecology-based production system underpins the concept of food sovereignty due to its resilience, efficiency, biodiversity, and social acceptance. Practices such as crop diversification, intercropping, agroforestry, mixed crop-livestock systems, resource recycling, and reducing external inputs have demonstrated positive impacts on food security and nutrition (Kerr et al. 2021, Kumar et al. 2022).

Integrated Farming Systems (IFS), which incorporate these agroecological principles, focus on ecological intensification and minimizing the use of anthropogenic inputs while enhancing ecosystem functions like nutrient recycling, soil formation, and fertility improvement. Efficiently managed IFS are considered less risky, benefiting from synergies between enterprises, product diversity, and ecological stability (Kumar et al. 2023). Consequently, agroecological-based IFS, which integrate animal and crop enterprises, are gaining renewed interest among marginal, small and medium farmers who cultivate less than one hectare of land.

Approaches of IFS

The increasing demand for food coupled with a decreasing amount of arable land necessitates improvements in agricultural productivity. Many small and marginal Indian farmers struggle to secure their livelihoods due to the limited financial support available after covering input costs. Addressing the challenges faced by these resource-constrained farmers and enhancing their livelihood security has led to the development of the Integrated Farming System (IFS)—a comprehensive, resource-focused, and client-centered approach (Kumar et al. 2018).

Food and nutritional security

Securing both nutritional and food security necessitates a comprehensive strategy that considers not only the quantity of food produced but also its nutritional quality and accessibility for farm families. IFS incorporate various elements from different sectors of agriculture and related enterprises, creating a robust and sustainable food production system that also addresses the nutritional needs of the population (Bhagat et al. 2024). These systems are crucial for meeting the future food and nutrition demands of India's growing population. The IFS model implemented at Modipuram (0.7 ha) demonstrated its ability to meet the food and nutritional needs of farm families while providing sufficient green and dry fodder for livestock and fuelwood for household use. The potential of IFS in diversifying the food sources available to small and marginal farmers on limited land at different locations. Devendra and Thomas (2002) underscore the significance of IFS for poor small-scale farmers, as it helps meet protein requirements through livestock products like eggs, milk, and meat. Moreover, IFS can contribute to food and nutritional security by optimizing resource use and introducing legumes, vegetables, oilseed crops, and agroforestry systems.

Employment generation

The integrated farming system has significant potential to generate employment for farmers and rural youth by incorporating a variety of agricultural components such as crop cultivation, livestock rearing, agroforestry, aquaculture etc., all of which demand a larger workforce. The level of employment created depends on the specific combination of enterprises involved. For instance, integrating vegetables, field crops and livestock with tuber crops can result in a 31% increase in employment opportunities compared to solely cultivating tuber crops (Shankar et al. 2018). In contrast, specialized agricultural practices and monocropping tend to raise production costs, heighten the risk of crop failure, and result in lower market prices. These challenges often force small and marginal farmers to migrate to nearby cities in search of jobs and better livelihoods. In this context, the IFS approach can help to mitigate economic risks while boosting employment. The continuous labour demands of diverse crops and livestock systems also provide sustained employment and keep farm families actively engaged in their agricultural activities.

Profitability

Diversifying agricultural activities by linking farm-based enterprises with crop cultivation offers resource-poor farmers a way to increase their income and enhance overall system productivity (Kumar et al. 2018). The increased net income in IFS is largely due to reduced production costs achieved through recycling by-products and residues from different system components. By promoting resource flow and integrated pest and nutrient management, IFS helps to reduce input costs. Livestock components such as dairy, goat farming, poultry and pig farming serve as a form of insurance against crop failures. Systematically planned interventions that address constraints within various farming system components can significantly boost farmers' net income (Kumar et al. 2022).

Nutrient recycling

Nutrient recycling plays a crucial role in the integrated farming system, as it involves the efficient reuse and redistribution of nutrients within the farming system (Kumar et al. 2018). This practice entails utilizing organic waste, residues, and by-products from one component of the farm as inputs for another. By optimizing the use of farm resources, IFS makes farming more feasible and cost-effective through the recycling of by-products between different enterprises. The IFS approach aims to create synergy among various components, ensuring that the by-products of one enterprise serve as valuable inputs for another, thus promoting nutrient recycling and resource efficiency (Gill et al. 2009). Numerous studies have demonstrated the potential of IFS to enhance soil health by supplying essential macronutrients.

Soil quality enrichment

Integrated farming system is an effective strategy for resource management that minimizes reliance on external market inputs while enhancing soil health (Hu et al. 2016). Soil health is defined as the soil's overall capacity to sustain plant and animal productivity, maintain environmental quality, and support ecosystem stability (Lal 2016). The extent to which soil processes and nutrient flows are impacted depends on factors such as crop selection, nutrient management practices, and the integration of livestock. Incorporating livestock and fisheries with crops improves nutrient use efficiency, promotes nutrient recycling, boosts soil microbial activity, and reduces the need for external fertilizers, thereby emphasizing the critical role of IFS in sustainable nutrient management and soil health enhancement (Sujatha & Bhat 2015). Additionally, integrating agroforestry systems and green leaf manuring within IFS can enhance soil quality, conserve water, and increase carbon stocks.

Biodiversity conservation

Human activities have substantially disrupted natural habitats and biogeochemical cycles which lead to ecological imbalance. For example, the dominance of the rice-wheat cropping system in the Indo-Gangetic plain has displaced traditional crops, causing issues like groundwater depletion, soil health decline, yield stagnation, waterlogging, greenhouse gas emissions, pest and disease resurgence, and decreased productivity (Chaudhary et al. 2017). IFS advocate for practices such as polyculture, agroforestry, wildlife corridors, integration of native livestock, reduced use of synthetic inputs, and promotion of beneficial insects (Bhagat et al. 2024), offer a viable solution for biodiversity conservation.IFS has the potential to restore ecological functions and enhance both economic and agronomic productivity across the system. By promoting the cultivation of multiple crops—whether as intercrops, mixed crops, or sequential crops—IFS delivers essential ecosystem services from agriculture. This approach fosters polycultures, integrates livestock or fish with crops, and incorporates practices like cover cropping, fodder production, and rotational grazing, leading to diverse and complementary agricultural landscapes (Perfecto et al. 2005). Moreover, incorporating trees into farming systems not only provides income and nutritional security but also attracts pollinators, increases biodiversity, acts as a windbreak, and enhances the farm's aesthetic value. Therefore, IFS supports biodiversity conservation, supplies feed, fodder, and fuel, and mitigates the risks associated with crop failure.

Climate Resilience

Integrated farming systems represent a sustainable approach to boosting agricultural production while reducing GHG emissions. By fostering a synergistic relationship among various farm components, IFS reduces dependence on synthetic inputs and lessens the need for energy-intensive practices, thereby significantly cutting down GHG emissions and serving as an effective strategy for combating climate change (Meera et al. 2019). The AICRP-IFS models from Raipur (-7713), Kalyani (-4517), Telangana (-27036), Palampur (-1787), and Johrat (-3175) reported net negative GHG emissions (kg CO_2-e ha^{-1}) due to increased carbon sequestration. These models incorporated boundary plantations with perennial trees or horticultural component, which enhanced residue recycling and allowed tree components to mitigate climate change effects by sequestering more carbon in the soil and above-ground biomass (Ravisankar et al. 2019). The agroforestry components of IFS, along with the integration of biomass and manure into the soil, functioned as carbon sinks, aiding in GHG emission reduction (Meera et al. 2019). The impact of IFS on methane (CH_4) absorption may be linked to improved nutrient recycling through organic farming practices, which potentially increased the activity of methanotrophs (Zhou et al. 2008) and altered air diffusion, possibly limiting CH_4 diffusion (Chen et al. 2011). Management practices within IFS, such as nutrient management through composting and crop residues, the use of legumes for nitrogen fixation, and adjustments in cultivation methods like direct-seeded rice, can enhance crop resilience to climate change while reducing GHG emissions. Therefore, IFS offers a practical strategy for lowering GHG emissions and minimizing nutrient loss by improving nutrient recycling and utilizing crop residues as animal feed (Barbosa et al. 2015).

Constraints

Market access: Farmers encounter difficulties in identifying suitable markets for the diverse, small-scale outputs produced by different components of an IFS, which can hinder the profitability and sustainability of the system.

Resource limitations: Key barriers include the lack of access to improved livestock breeds, timely availability of fish seed and feed, comprehensive information on government programs, and sufficient credit facilities from financial institutions.

High initial investment: Establishment of an IFS model is capital-intensive, requiring significant start-up investments. Resource-poor farmers often lack adequate funds for the initial investment, limiting their ability to adopt IFS and benefit from resource integration.

Lack of awareness: The low rate of IFS adoption among farmers can also be attributed to a lack of understanding regarding the harmful effects of excessive agricultural chemical use (such as fertilizers and pesticides) on soil health and human well-being.

Transition challenges: Implementing an IFS model requires a transition period of 3-10 years. During this time, farmers may experience declines in food production and income generation, which they often cannot afford.

Input and service accessibility: Other challenges include the unavailability of high-quality inputs necessary for setting up the farm, inadequate knowledge about incorporating new crops such as fodder, and a scarcity of veterinary services.

Research Gap

- *Land holding size and livelihoods:* IFS boosts yields, but the marketable produce may not sustain long-term livelihoods, particularly for small and marginal farmers. Research should explore the link between land size, productivity, and income sources, including value addition strategies for sustainable livelihoods.
- *Environmental impact of production types:* Research on the environmental effects of various IFS production methods is limited. Future studies should assess how different farm sizes, enterprise types, and recycling methods impact environmental sustainability and ecological health.
- *Ecosystem services in IFS*: There is a lack of comprehensive research on the ecosystem services provided by IFS models like homestead farming, agroforestry, and livestock systems. Future research should investigate their roles in biodiversity, soil health, and climate regulation.
- *Social and well-being outcomes:* More research is needed on the well-being of labourers, farmers and consumers, and how these factors interact with farm size, social dynamics, and environmental impacts. A holistic approach will better reveal the social and economic benefits of IFS.

Future thrust

- Research modules tailored to specific locations, considering various farm sizes, agro-climatic conditions and socio-economic factors should be developed.
- Policy initiatives should be developed to encourage the widespread adoption of IFS, with a focus on offering minimal financial assistance through short-term, medium-term, or long-term loans to support initial start-up efforts.
- Implementing IoT technology in IFS to enhance automation on farms, optimizing resource utilization, and to improve predictive analysis.
- Developing farm typology frameworks to categorize and comprehend various farming systems, facilitating targeted interventions and customized IFS models that address the unique conditions, needs, and constraints of specific regions.

Conclusion

Indian agricultural sector, dominated by small and marginal farmers, faces challenges of land fragmentation, climate vulnerability, and economic insecurity. IFS apply agroecological principles, offer a sustainable solution to these challenges by enhancing food and nutritional security, employment, profitability, and resource recycling. IFS promotes diversification, reduces input costs, and increases resilience against climate change while improving soil health and biodiversity conservation. By fostering synergies among crops, livestock, and agroforestry, IFS enhances productivity, reduces greenhouse gas emissions, and supports long-term sustainability. Therefore, adopting IFS approaches is vital for ensuring the livelihoods of India's small farmers, achieving food security, and meeting sustainable development goals.

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National Mission on Ensuring Sustainable Food Systems through Natural Farming

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Introduction
India is going to be the most populous country in the world, earlier than the expectation of general masses. To feed such a large population had also been a challenge in the past when we take the acute food scarcity of 1950's and 1960's into consideration. Indian Green Revolution was one of the globally remarkable developments in agriculture. Today, we are not only self-sufficient in food production, but we are a significant exporter of food commodities. However, this glaring achievement was not without any price. India as a country, paid high price for the Green Revolution achievements in terms of depletion/pollution of soil, water and air. Now, the society and the policy makers have clearly understood that such farming is not sustainable and beneficial for human/animal/environmental health. Therefore, very high emphasis has been put on producing safe food with environmentally restorable practices during recent past. Following text elaborates upon the negative aspects of green revolution.

Important Undesirable Outcomes of the Green Revolution
Chemical-based modern agriculture, which is the true form or a close variant of Green Revolution has some very important environmental and socio-economic undesirable outcomes (Singh et al. 2022). The details of these undesirable developments have been given below:

- *Environmental Degradation:* With the overuse of chemical fertilizers and pesticides the soils degraded and water bodies polluted significantly. Further, Excessive use of water for irrigation caused a decline in groundwater levels.
- *Economic Inequality:* As a result of green revolution, the wealthier farmers benefited more due to higher ability to access resources, while small and marginal farmers struggled to do that. As a result of increased regional disparities, Punjab, Haryana, and Western Uttar Pradesh derived more benefits from green revolution compared to other states.
- *Health Issues:* Exposure to pesticides led to health problems not only among farmers but among the other rural population also. Further, consumption of pesticide-contaminated food affected public health at large scale.
- *Loss of Biodiversity*: Excessive focus on high-yield variety (HYV) crops reduced are under traditional crops negatively affecting crops diversity. Moreover, the loss of genetic diversity made crops more vulnerable to pests and diseases.
- *Social Impact*: Increased mechanization as an essential component of green revolution, led to significant reduction of jobs under agricultural sector, contributing directly to the rural unemployment. The commercialization of agriculture exposed farmers to several imprudent personal and business expenses by the farmers leading them to debt traps and consequent financial distress.

Natural Farming- A Welcome Initiative
Natural farming represents several desirable attributes that make it a sustainable and holistic approach to agriculture. By advancing towards sustainability, it promotes practices that are

environmentally sound and resource-efficient, ensuring that farming can be sustained over the long term without depleting natural resources. Food safety is enhanced as natural farming avoids the use of synthetic chemicals, leading to healthier and safer produce. This method emphasizes farming in harmony with nature, relying on natural processes and biodiversity to maintain soil health and ecosystem balance. Additionally, it enables agriculture without external inputs, reducing farmers' financial distress by eliminating the need for costly chemical fertilizers and pesticides. In addition, this approach enriches organic carbon content in the soil, fostering chemical-free farming and enhancing soil fertility, which is crucial for long-term agricultural productivity and ecological health. Consumers and farmers are now gradually shifting back to organic farming in India in order to produce chemical free food and to restore ecological balance.

Natural Farming vis-à-vis Organic Farming

From consumer point of view the output of organic as well as natural farming doesn't carry any difference; however, from production point of view these two approaches do have important differences in the production approach. Organic farming has dependence on external organic inputs and is quite expensive vis-à-vis the natural farming. Similarly organic farming doesn't follow the principles of minimum or no tillage. As a result of heavy tillage, the soil organic carbon augmentation is very slow compared to natural farming (Singh et al. 2022). Organic farming is still expensive due to requirement of large quantity of organic manures from external sources. "Low Budget Natural Farming" has recently got favour of policy makers in order to overcome all these problems.

Low Budget Natural Farming

The fundamental concept of natural farming is that it is not the farming of crops rather it is farming of microbes and microbes do the farming for the farmer. Following points elaborately explains these farming practices.

- *Jeevamrit/Ghanjeevamrit, Beejamrit, Acchadan* (Mulching) and *Whapasa* are the four basic pillars of Natural Farming.
- Prescribed crop combinations (intercropping with legumes) and crop rotations are the important facilitating practices.
- Includes efficient crop spacing, conserving water, mulching, crop rotation.
- Uses cow dung, urine, crop residues and locally made bio-formulations.
- Decomposition of residues by microbes restores fertility and augments soil organic carbon.
- Holistic practice that reduces market dependency of farmers for inputs.
- Uptake and utilization of available nutrients is improved tremendously once the volume and ideal composition of microbes is restored.

Benefits of Natural Farming

Natural farming practice significantly improves soil health by increasing organic carbon levels and stimulating biological activity, leading to more resilient and productive soils. The conservation of energy, water, and nutrients is another key advantage, as natural farming techniques optimize resource use, reducing wastage and environmental impact. One of the most tangible benefits for farmers is the reduced cost of cultivation, as the reliance on costly chemical inputs is minimized. Additionally, natural farming decreases disease incidence in crops by bolstering plant immunity through natural processes, leading to healthier and more resilient plants. The quality and safety of food produced under natural farming practices are also superior, as the absence of synthetic chemicals results in cleaner, more nutritious produce (Rana and Singh 2018). Ultimately, this approach helps keep farmers free from financial distress by lowering input costs and fostering a more sustainable and profitable farming system (Rana and Singh 2018). Jee*vamrit/Ghanjeevamrit, Beejamrit, Acchadan* and *Whapasa* are the four pillars of Natural Farming (Rana et al. 2023).

Out-scaling Natural Farming through KVKs

Indian Council of Agricultural Research (ICAR) has initiated an ambitious project on out-scaling of natural farming through 425 Krishi Vigyan Kendras (KVK) in India. In Zone-1 states/ UTs of India, the ICAR ATARI Ludhiana is implementing this project in 42 KVKs of Himachal Pradesh, J&K, Ladakh, Punjab and Uttarakhand right from 2022. Capacity building of farmers to adopt natural farming efficiently, establishing demonstration units or working natural farming units at KVK as well as farmers' fields, and organising awareness programs across the farmers on natural farming principles are the three basic components of this out-scaling program. ICAR ATARI Ludhiana have made special efforts to ensure uniform out-scaling of natural farming through adopting same technical program during capacity building programs.

National Mission on Natural Farming (NMNF)

Objectives

- To promote nature based sustainable systems, freedom from external inputs, improved soil health, and cost reduction and thereby to increase net income.
- To popularize livestock integrated farming models
- To strengthen on-farm agro-ecological research and extension capacities of public institutions
- To bring together scientific expertise and on-field experience of farmers for improved knowledge
- To improvise location specific NF package of practices for increasing adoption and promotion of chemical-free agriculture.
- To build Institutional and human capacities for scaling up of natural farming
- To establish scientific standards and certification procedures
- To create and promote a single national brand for such produce

Implementation

Intensive Seeding (Phase-I): The first phase of NMNF involves awareness generation, orientation and capacity building of components on benefits, potential and methodology of natural farming. Under this phase, the implementation will be done at 15000 clusters (6% of Gram Panchayats) where one cluster is a unit of one Gram Panchayat. The progress of the mission will be assessed to know its overall impact. Identification of policy support to generate large coverage area expansion under natural farming will also be explored.

Expansion and Saturation (Phase-II): Under the second phase of NMNF implementation, outputs of Phase-I shall be used to expand natural farming up to 20% of Gram Panchayats. Saturation of blocks of the seeded clusters will be on the target of this mission.

As, adoption of natural farming is a part of behavioral change of the farmers which takes considerable time and effort, it needs to be led by the extension agencies like State Agricultural University (SAU), KVKs and Agricultural Technology Management Agency (ATMA) etc. ICAR, SAUs and KVKs along with the practicing natural farmers will be engaged for carrying out on-farm research on natural farming under this mission. The guidelines of the mission suggest closely working of implementing agencies with the natural farming communities, Farmers Producer Organization (FPO), agriculture para-extension workers (Krishi Sakhis) and Primary Agricultural Cooperatives (PACs). The whole program will be implemented in clusters of priority regions (given below). Establishing scientific standards and certification procedures is one of the important focuses of this mission.

Similarly, development of common national brand for natural produce is important consideration under this mission for building a trust among consumers for achieving wider consumption for the natural products.

Administrative Structure (National level)
National Steering Committee (NSC) chaired by the Hon'ble Agriculture Minister is the apex body following by National Executive Committee (NEC) chaired by the Additional Secretary, Integrated Nutrient Management (INM), and Natural Farming Wing at Department of Agriculture and Farmers Welfare (DA&FW), comprise of the main administrative structure at national level.
National Advisory Committee (NAC), again chaired by the Additional Secretary INM and Natural Farming Project Monitoring Unit (PMU) at DA&FW provide support and assistance to the main administrative body of the NF Mission.
Krishi Vigyan Kendras (KVKs) of ICAR and State Agricultural Universities (SAUs) are the key centres for taking care of Training, Research and Extension Needs on NMNF. The practicing natural farmers hare the important leaning sites in this mission. National Institute of Agricultural Extension Management (MANAGE), Hyderabad, will act as key knowledge partner in this mission while National Centre on Organic and Natural Farming (NCONF), Ghaziabad, will also take care of capacity building process under the NMNF. National Rural Livelihood Mission (NRLM), State Rural Livelihood Mission (SRLM), Primary Agricultural Cooperatives (PACs) and Farmer Producer Organizations (FPOs) will shoulder the responsibility of creating awareness about natural farming and the mission along with the crucial role of community mobilization.

Administrative Structure (State level)
On the lines of administrative structure at national level, a similar structure exists at the state level. State Level Steering Committee (SLSC) chaired by the Chief Secretary of the state is the apex body following by State Level Executive Committee (SLEC) chaired by the Agriculture Production Commissioner/ Principal Secretary, and State Natural Farming Wing, comprise of the main administrative structure at state level. However, State Level Monitoring Committee, District Level Monitoring Committee and Block Level Implementing Agency are the key agencies that help in implementation of NMNF at state level.

Integrated approach for capacity building
An integrated approach will be adopted for capacity building on natural farming under the NMNF. The selected 425 KVKs of the ICAR will be training 2,12,500 persons on Natural Farming. Similarly, the selected 40 SAUs (training 4800 persons), MANAGE (training 7500 persons), NCONF (training 625 persons), selected 150 practicing natural farmers (training 27000 persons), 15000 community resource persons (training 18,75,000 farmers) and trained 18,75,000 natural farmers will further train 1,12,50,000 farmers through farmer-to-farmer extension on natural farming under the NMNF.

Implementation through Community Based Organizations
Community Based Organizations (CBOs) have to play an important role under NMNF. The mission intends to work in 15000 clusters where KVKs with active support from Agricultural Technology Management Agency (ATMA) and CRPs will implement NF in *Gram Panchayats* for large area coverage with their primary role as providers of trainings, demonstrations, and continuous hand holding. Further, KVKs with ATMA/ CRPs shall regularly monitor farm level progress indicators of the natural farming adopting farmers. At

least 80% of farmers (or 125 farmers and minimum 50 ha area) will constitute one cluster, (however, in hilly areas the concerned states will decide size of natural farming plots) with the active support from Self-Help Groups (SHGs), FPOs and PACs. Enrolled farmers under NMNF will also be eligible for performance-based incentives for bring 6 additional farmers under natural farming practices.

Bhartiya Prakaritik Kheti Bio-input Resource Centers

Bio-input Resource Centers (BRCs) shall be very important inputs resource centres under the NMNF. These centers aim to provide livestock and plant extract-based natural farming inputs to the farmers to be brought under this mission. The mission aims to establish 10,000 need-based BRCs for production and supply various bio-formulations used under natural farming in order to support farmers willing to adopt natural farming. These centres can be operated by farmers themselves, cooperatives, Gaushalas and any other agency identified by the state. However, detailed guidelines for establishment and operational modalities of these input centers are awaited.

Online Digital Monitoring Mechanism

NMNF will have a strong onlinedigital monitoring and evaluation mechanism for assessing the progress of the mission. A digital portal (such as Kisan Sarathi) with geospatial data system for tracking progress will collect data for effective monitoring of the mission. Under this initiative, baseline data will be tracked on GIS mobile integrated system and help of Krishi Sakhis will be taken under the direct control of NRLM. The portal will compile various databases related to different aspects of natural farming.The portal will also capture and track field data in the clusters. Further, the IT portal for natural farming will also undertake Participatory Guarantee System (PGS) certification of the registered natural farmers.

Conclusions

Natural farming is an environment friendly way of doing farming that also saves the cost of cultivation for farmers. Soil properties and productivity is well known to increase on account of microbial activity in the soil. In addition to its ecological benefits, this method of farming focuses highly on mitigating financial distress of the farmers. Implementation of natural farming project and popularisation of this method of farming is at very high priority of Government of India (GOI). The commitment of the GOI on making natural farming a commonly adopted method of agriculture in India is evident from their ambitious programs like 'Out-scaling Natural Farming through KVK; 2022 onward' and subsequently up-gradation of the program under mission mode under National Mission on Natural Farming (2024 onward).

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Pathway to Socio-Economic Transformation through Natural Farming Solutions

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Keywords: Transformation, Ecological balance, Sustainability

Introduction

Indian version of Natural farming was mainly developed by Shri Subhash Palekar largely based on the ancient Indian knowledge described in *Vrikshayurvedas* (Nene 2012). This concept describes an agricultural method that relies on locally prepared natural inputs and processes to cultivate crops. This approach stands in clear contrast to conventional farming, which depends heavily on chemical fertilizers, pesticides, and intensive irrigation. The philosophy behind natural farming is to create a self-sustaining ecosystem that minimizes human intervention and maximizes the natural productivity of the soil (Singh et al. 2022). As a result, natural farming not only takes care of environmental sustainability but also serves as a powerful tool for socio-economic transformation, particularly in rural communities (Rana and Singh 2018)

Principles of Natural Farming

Natural farming includes fermented liquid as well as solid organic manures in the form of *Jeevamrit*/ *Ghanjeevamrit* and a range of bio-formulations made from plant extracts for plant protection. Further, natural farming discourages ploughing or tilling the soil, which can disrupt the natural structure and biodiversity of the soil. Instead, the soil is left undisturbed, allowing microorganisms and earthworms to thrive.

Mycorrhiza is believed to be the greatest facilitator or plant nutrition and healthcare under natural farming. For developing and maintaining good population of mycorrhiza the principal of minimum or no tillage is at most important. Using dung and urine of desi (local breed) cow has been termed bio-nationalism (Fitzpatrick et al. 2022), however, this principle is based on scientific considerations. As dung and urine are used for preparing *Jeevamrit/ Ghanjeevamrit*, which are the basic source of microbial culture added to the soils for maintaining desirable volume and diversity of microbes, the selection of animal for this purpose is made on the basis of healthy gut flora. Health of gut flora depends upon genetics, exercise, diversity of food intake (as every type of feed and fodder act as prebiotic for the gut microbes) and stress-free living. Local cows in India evolved in grazing process where they used to eat self-selected and highly diverse sources of fodder. The left-over food in the families was also fed to them creating a source of further diversity of flora in their gut. Being low yielders, such cows were relatively free from lactating stress vis-à-vis the stall fed exotic cows. The gut-flora of local cows has been found much diverse and healthy in various microbial studies.

Socio-Economic Benefits

Adoption of natural farming practices can lead to significant socio-economic benefits, particularly in rural areas where agriculture is a primary livelihood.

- Cost Reduction and Economic Independence
- Enhanced Livelihoods and Rural Development
- Food Security and Nutrition
- Empowerment of Marginalized Groups
- Complete independence from international uncertainties
- Great potential of enhancing income under rainfed agriculture

- Resilience to Climate Change

Ecological Benefits

- Improved Soil Health and Long-Term Productivity
- Environmental Sustainability

Policy support

PKVY: Government of India realised the imperativeness of sustainable agriculture based on locally produced inputs and launched Paramparagat Krishi Vikas Yojna (PKVY) in 2015.

BPKP: Later on, GOI promulgated Bhartiya Prakriti Krishi Paddhati (BPKP) in 2019 in order to promote and propagate natural farming in India. Prime Minister of India specially emphasized on mass promotion of Natural Farming on 10 July 2022 and an ambitious project "Out-scaling of Natural Farming through KVKs" was launched involving 425 KVKs across the country with the theme 'Food security alongwith harmony with nature'. Under this initiative Natural farming was intensively promoted in 5 km wide corridors along the river Ganga. Rigours awareness spreading programs, intensive training programs of trainers and farmers along with natural farming demonstrations on farmers' fields were undertaken under this program during 2022 and 2023.

NMNF: During early 2023 the idea of pursuing natural farming under mission mode emerges and draft guidelines on National Mission on Natural Farming (NMNF) were formulated in December 2023. Now the GOI has taken a decision to implement natural farming project under mission mode.

CASE STUDY-1

Natural Farming or Spiritual Farming-Benevolence First

Name of Farmer: Mr. Anirudh Vashisht

Address: 135, Ward No. 16, Mohalla Bhai Ka, Sunam, Sangrur- 148001, Punjab

Contact: anirudh_vashisht2002@yahoo.com

An in-depth analysis of a dedicated natural farmer who initiated natural farming in 2013 on a farm of 20 acres in Southeastern was carried in order to understand ground realities associated with this type of farming in one of the best productive and intensively cultivated area in India. As a period of five years is considered sufficient for the transition from conventional to natural farming the study was carried out during 2018. Mr. Anirudh Vashisht a 53 years old graduate is a simple, honest, contented and considerate person fully devoted to the cause of social service with his farm profitability as secondary consideration. He has very strong determination for doing 100 per cent non-chemical farming, based on the principles of zero/ low budget natural farming promoted by Sh. Subhash Palekar, in the best interest of his family, his friends and the general people not even known to him. He was mentored by the Kheti Virasat Mission (KVM), Jaitu, Faridkot, Punjab.

After initial difficulties in marketing the premium product from his farm he started selling his produce at premium price at Kudrati Kisan Haats located at different locations in Punjab. Simultaneously, he started selling his produce through direct marketing to his known people who have trust on the quality of his produce. Although the farmer is currently facing yield depression due to shift from high fertilizer response commercial varieties used under conventional to the low fertilizer responsive crop varieties used under natural farming, yet due to premium prices received for his products and sizeable cost advantage he was getting slightly better profits compared to the conventional agriculture. His successful natural farming experience has also motivated other farmers in the locality to follow natural farming. Most of his follower farmers are young and are guided by the force of feeding their families and friends with healthy food.

Although he is growing rice and wheat on more than half of his land under natural farming yet he is cultivating a large number of other crops including the perennial fruit plants in order to make best conditions for carbon sequestration (Keprate et al. 2024). He started feeling the positive effects of natural farming at his farm after third year of practice when the activity of earthworms was visible. The disadvantage of low yielding varieties used under natural farming (of course with distinctly greater quality attributes in terms of nutrition and flavour) was outweighed by the significant saving on cost of cultivation and premium price received for his premium produce, making his farming slightly more profitable than the crops grown under conventional agricultural practices. On the other hand, productivity of his dairy animals is better than those reared from the output of conventional farming.

Of course, natural farming needs a considerable human labour, farmer has sufficient number of helping hands with him. The economic analysis of this farm was satisfactory as the farmer earned net income of ₹ 12.90 lakh through natural farming while under similar management practices in conventional farming; he was estimated to earn ₹ 12.14 lakh per annum (Table 1).

CASE STUDY-2

Pursuing Natural Farming to Pursue the Path to Righteousness

Name of Farmer: Mr. Munish Kumar;

Address: Village Samrala, Block Didwin, District Hamirpur, Himachal Pradesh

Sh. Munish Kumar used to cultivate vegetables on a small holding of 7 Kanal area (less than 1 acre) when he came under the intervention of KVK Hamirpur at Bara during 2016-17. His village is about 12 km from the district headquarters of Hamirpur and about 45 km from the KVK. For earning livelihood his family used to cultivation until 2015-16. With the advice of the KVK he constructed two polyhouses, each having a covered area of 105 m^2 and started cultivation of vegetables under protected conditions in 2016-17.

He was trained at KVK Hamirpur at Bada in 2016 to upscale his farm business and the concerned scientist advised him to adopt protected cultivation of vegetables under natural farming with financial support to make his polyhouse fully functional. After renovation of both his non-functional poly-houses, he started growing high value vegetables under protected conditions. Capsicum, Cucumber, Brinjal, Coriander, Onion, Palak, Tomato, Summer Squash, Methi, Cauliflower and Radish etc., were the important crops grown by him. Growing and selling nursery seedling of vegetable crops proved to be another critical component for enhancing his net-income. He never had to visit the conventional markets for selling his premium produce. Further, he started selling high-quality seedlings of vegetables (mainly the cucurbits) grown under polyhouses, for earning additional income from January to March months of the year. While COVID-19 destroyed business opportunities for majority of the vegetable growing farmers, Munish converted it into a rewarding opportunity for him. Strong demand for his high-quality seedlings of vegetable crops encouraged him to enhance his area under vegetable nursery, just before COVID-19 lockdown, in January 2020 by reducing main crop cultivation and shifting his polyhouse space to the production of vegetable seedlings. During COVID-19 lockdown buyers approached him to purchase nursery seedlings. As a result, his farm profitability improved by 60% in the COVID-19 affected year 2020.

Table 1: Comparative economic analysis of natural versus conventional farming of Anirudh Vashisht's farm

Crops	Area (Acre)	Yield (q/Acre)		Price (₹/q)		Cultivation Cost (₹/acre)		Gross Income (₹/acre)		Net Income (₹/acre)		Net Farm Income (₹)	
		Org.	Con.	Org.	Con.	Org.	Con.	Org.	Con.	Org.	Con.	Org.	Con.
Potato	1	60	150	1000	500	22000	38000	60000	75000	38000	37000	38000	37000
Wheat	14	13.5	20	2250	1735	6000	10000	30375	34700	24375	24700	341250	345800
Linseed	0.5	2	3.5	7500	4200	3000	5000	15000	14700	12000	9700	6000	4850
Chickpea	1	2.5	4	6500	4400	3800	6000	16250	17600	12450	11600	12450	11600
Chickpea white	0.5	2.5	4	7000	4400	3800	6000	17500	17600	13700	11600	6850	5800
Veg. Rabi	1	70	120	1100	700	20000	35000	77000	84000	57000	49000	57000	49000
Sugarcane$	0.5	210	350	Gur	255	11000	15000	210000	89250	180000	74250	90000	37125
Mustard	0.5	3.5	5	5500	4000	4500	7000	19250	20000	14750	13000	7375	6500
Lentil	0.5	1.7	2.5	6000	4400	4000	6000	10200	11000	6200	5000	3100	2500
Barley	0.5	8.5	13	1800	1410	5200	8000	15300	18330	10100	10330	5050	5165
Cotton	1	4.1	6	5400	4020	12000	18000	22140	24120	10140	6120	10140	6120
Paddy	11	14	25	4250	2590	8500	13000	59500	64750	51000	51750	561000	569250
Chillies	1	40	60	2000	1550	24000	38000	80000	93000	56000	55000	56000	55000
Moong	1	4	6	8500	5575	3500	4800	34000	33450	30500	28650	30500	28650
Mash	0.5	3	5	7500	5400	3500	4800	22500	27000	19000	22200	9500	11100
Veg. Kharif	1	70	95	1050	700	18000	28000	73500	66500	55500	38500	55500	38500
Fodder Rabi	0.5	200	300	-	-	4200	5500						
Fodder Kharif	2	250	300	-	-	4000	5000						
Total	38											1289715	1213960

Org.=Organic, Con.=Conventional, Veg.=Vegetables; $=Sold as organic Gur (jiggery), @=used at home for dairy farming (Rana and Singh, 2018)

During the second attack of COVID-19 during 2021 his farm-profitability further increased nearly 47% compared to the previous year's (2020) farm profit of ₹ 4.57 lakh. This hard-working farm-entrepreneur started earning supplementary earnings by being the master trainer on various trainings such as scientific mushroom cultivation and adopting correct natural farming practices. All his hard work and genuine advices from the KVK scientist enabled him to enhance his annual net income from his natural farming and consultancy services to ₹ 8.47 lakh during 2022

Data presented in Table 2 revealed the impact of KVK interventions on the net-income enhancement of this entrepreneur in terms of his conventional net income versus his net income after the interventions. The proportion of his net income accruing out of KVK suggested strategies in his total net income increased from meager 35% (2016) to 72% (2017) and 92.5% (2022). The factor of income enhancement of Munish Kumar due to KVK interventions increased from 1.5 times (2016) to 13.5 times (2022). This success story is a strong source of motivation and guidelines worth emulation for several youth from his locality as well as from other parts of the state and country who aspire to earn well while delivering health, positivity and righteousness.

Table 2: Proportion and enhancement of net-income due to KVK intervention

Particulars	2016	2018	2020	2022
Proportion (%) of income due to KVK intervention	35.11	75.93	86.23	92.56
Income enhancement due to KVK (multiple times)	1.54	4.16	7.26	13.44

CASE STUDY-3

Natural Farming Ensured Economic and Ecological Sustainability Combating Inadequate Irrigation

Name of Farmer: Mr. Jatinder Singh
Address: S/O Sh. Chamail Singh, Village Bhabber, District Reasi, Jammu & Kashmir

Mr. Jatinder Singh a retired person from Indian army is a very hard working agri-entrepreneur. He used to grow maize, wheat, pulses and spices along with an orchard on his farm of 2.5 ha having limited irrigation facilities. He was following organic farming until 2021-22 earning an annual net farm income of ₹ 3.28 lakh. He was finding organic farming expensive and difficult to manage due to dependence on external supply of inputs in addition to inadequate availability of canal irrigation water, especially during critical stages of the crop. As, he was not satisfied with yield and farm profitability, he approached KVK Reasi to explore the possibilities of higher income during 2022.

KVK Reasi advised him to convert his farming from organic to natural for mitigating the impact of limited and un-assured availability of canal irrigation water for significantly enhancing his farm productivity and profitability. Mr. Jatinder agreed to this proposed change and urged the need of guidance and technical support from KVK Reasi. The KVK enrolled him for a comprehensive training on natural farming under the ongoing project 'Out-scaling Natural Farming through KVKs' being implemented at KVK Reasi. The farmer underwent the training for leaning detailed concept of natural farming and methods & procedures of preparing various bio-formulations such as *Jeevamrit, Ghanjeevamrit, Beejaamrit, Agniastra* and *Brahamastra* etc., for enabling him to reduce his cost of cultivation. The farmer kept on participating in various awareness programs, Kisan Melas and other programs organized by the KVK and other related agencies in order to enrich his knowledge base on the subject.

In this process he started earning higher net income which increased to ₹ 5.52 lakh during 2022-23 from ₹ 3.28 lakh in 2021-22. In the journey of this higher income a significant role was played by reduction in cost of cultivation from ₹ 0.81 lakh (2021-22) to ₹ 0.21 lakh (2022-23). It is worth specifying that the cost of cultivation has been estimated without accounting for labour cost as majority proportion of the labour is contributed by him and his family only. As he is dedicated to the cause of service to others hence, the cost of his and his family's time reflects only in his net annual farm income. This change motivated the farmer and he could further enhance his farm profitability to ₹ 5.86 during 2023-24. The farmer is now exploring the possibility of making turmeric powder and selling under his own brand name for earning higher profit in the market.

Mr. Jatinder Singh has now been established as a credible resource person on natural farming and his efforts have been widely appreciated by various visitors including scientists and development officers. Now, he has become a source of motivation to the rural youth, of unirrigated/ partially irrigated areas, for adopting natural farming not only to enhance their farm income but to serve the cause of ecological restoration too.

Challenges and the Way Forward

The transition from conventional to natural farming is not very easy due to the long-term capacity building of farmers in chemical-based farming. Inadequate, institutional support, missing marketing channels for natural products, and lack of complete awareness on natural farming methods is hindering its widespread adoption. To overcome these challenges, the government of India have put following multipronged concerted efforts:

Capacity building: Farmers rigorous capacity building in natural farming techniques and the science behind them has been followed under the initiative of Out-scaling Natural Farming through KVKs. ICAR-ATARI Ludhiana has put special efforts to ensure uniform capacity building under this initiative (Rana et al. 2023)

Market Access: Creating markets for organic and naturally farmed products can help farmers earn premium prices, making natural farming economically viable. GOI is very serious on this aspect and is promoting collective marketing strategies through Self Help Groups, direct marketing, FPOs and online trading platforms (Rana et al. 2022; Singh et al. 2022a; 2022b).

Research and Innovation: Ongoing research into natural farming methods and their long-term impacts can help refine practices and make them more effective in order to adjust to the present-day realities vis-à-vis the time when the concept of natural farming was developed.

Conclusion

Natural farming presents a viable solution for achieving socio-economic transformation in rural areas. It offers small and marginal farmers a sustainable and economically viable alternative to conventional farming. By reducing dependence on costly chemical inputs, enhancing soil health, and promoting sustainable practices, natural farming can lead to improved livelihoods, food security, and environmental sustainability. With the right support and encouragement, it has the potential to transform agriculture into a tool for socio-economic development, benefitting not only farmers but society as a whole. The concerted efforts of the Government of India (GOI) to popularise and promote natural farming during recent past is praiseworthy. The decision of the GOI to implement natural farming in India under mission mode and proposed National Mission on Natural Farming present very optimistic picture about the future of natural farming in India.

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Empowering Farmer Producer Companies: The Transformative Role of Extension Institutes as POPIs

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Keywords: POPI, FPO/FPC, Monitoring

Introduction

Agriculture is essential for global food security, economic advancement, and rural livelihoods, especially since the globe faces considerable hurdles in meeting the food security demands of an expanding population. Projections suggest that the global population will attain 9.7 billion by 2050, necessitating a 50% increase in food production to satisfy this escalating need (FAO et al. 2022). This situation is becoming urgent since roughly 828 million individuals globally are currently experiencing hunger, highlighting ongoing food security concerns (FAO et al. 2022). The worldwide agricultural landscape is experiencing a significant transition, influenced by various interconnected concerns. Climate change represents a critical concern, evidenced by worldwide yield reductions of 3.1-7.4% per degree Celsius of warming for primary crops (Zhao et al. 2017). These losses are further intensified by increasingly frequent and severe weather events, jeopardising agricultural stability (IPCC 2022). Exacerbating these difficulties is resource scarcity, as arable land per capita has diminished by 50% since 1960, and water constraint impacts 40% of the global population (World Bank 2022). Soil degradation, affecting 33% of the earth's terrestrial area, jeopardises agricultural productivity. Moreover, agriculture substantially impacts environmental concerns, representing 24% of global greenhouse gas emissions and 70% of freshwater consumption (IPCC 2022).

Agriculture in India is mostly production-oriented, limited to tiny and fragmented landholdings, yet it remains a fundamental component of the nation's economy. The industry accounts for around 18.2% of India's GDP and sustains around 42.3% of the population (Economic Survey 2023-24). Despite the sector's resiliency, evidenced by an average annual growth rate of 4.18% over the past five years, ongoing constraints like as low productivity, significant post-harvest losses, and insufficient infrastructure constrain farmers' potential. The Government of India has facilitated the establishment of Farmer Producer Organisations (FPOs) to enhance the livelihoods of small and marginal farmers through collective action, improved market access, and reduced input costs. In this setting, Farmer Producer Companies (FPCs) have arisen as a strategic method to enhance the socio-economic status of small and marginal farmers. Farmers, frequently hindered by restricted access to resources, markets, and technology, increasingly depend on collective farming initiatives to surmount these obstacles. FPCs offer a framework for farmers to consolidate their resources, so augmenting their collective bargaining strength, promoting market accessibility, and increasing their income prospects. The success of FPCs mostly depends on the support structures that facilitate their establishment and development. The Producer Organisation Promoting Institutions (POPIs) are essential support mechanisms that facilitate the development and operation of FPCs.

Extension institutes, functioning as POPIs, are essential to the creation, sustainability, and efficacy of FPCs. These institutes, frequently associated with agricultural universities or governmental organisations, offer crucial information, training, and assistance to FPCs. Their function is essential for ensuring that these organisations not only endure but also prosper in a competitive and dynamic agricultural landscape. This study seeks to evaluate the efficacy of extension institutes operating as POPIs, concentrating on a strategy framework founded on four principal pillars: Monitoring, Reporting and Compliance, Training, and Marketing. These pillars are essential for improving the operational efficiency and market competitiveness of FPCs, guaranteeing their sustained success and fostering the socio-economic welfare of farmers.

FPOs in India

Approximately 5,000 FPOs are registered in India, with over 3,200 functioning as producer firms. Each FPO comprises an average of 100 to 1000 farmer members collaborating jointly. Approximately 5 million farmers are benefiting from FPOs. The data indicates that FPOs have emerged as an efficient mechanism for organising farmers and facilitating lucrative market possibilities. FPOs empower farmers to collaboratively compete in the marketplace and secure superior prices for their products (SFAC 2023).

The geographical distribution of FPOs in India is unequal. North India accounts for the largest proportion of FPOs, constituting 32%, South India (28%), Central India (22%), and East India (18%) of all registered FPOs. This geographical divide indicates that FPOs are expanding at varying rates based on regional agricultural activity and market demand. The elevated quantity of FPOs in North and South India may be attributed to the prevalence of agriculture and convenient market access in these areas (NABARD Regional Report, 2023).

FPOs/FPCs in Himachal Pradesh

Himachal Pradesh (HP), distinguished for its horticulture-driven economy, has experienced the emergence of numerous successful FPOs and FPCs. These organisations mostly concentrate on horticultural crops, including apples, stone fruits, and high-altitude vegetables. FPOs and FPCs in HP have emerged as pivotal entities assisting small and marginal farmers in addressing issues concerning market access, resource mobilisation, and economic sustainability.

The state's topography, marked by rugged terrain and varied agro-climatic conditions, offers distinctive potential for horticulture. Nonetheless, this also poses considerable logistical difficulties, especially with the marketing and delivery of produce. FPOs and FPCs seek to resolve these challenges by uniting farmers, so augmenting their negotiating strength and facilitating their access to resources and markets.

As of December 31, 2023, HP has 174 registered FPOs under the Central Sector Scheme for the Formation and Promotion of 10,000 FPOs by the Small Farmers’ Agribusiness Consortium (SFAC). These organisations are distributed over multiple districts of the state, primarily concentrating on horticulture products. This emphasis corresponds with the state's dependence on fruits such apples, plums, peaches, and pears, and vegetables such as peas and beans.

The primary focus of FPOs in HP is on horticultural crops, which form the backbone of the state’s agricultural economy. The most prominent crops cultivated by these FPOs include:

- ***Apples and stone fruits***: HP is renowned for its apple orchards, particularly in districts like Shimla, Kullu, Lahaul-Spiti, Kinnaur, and Mandi. FPOs in these areas focus on collective marketing and transportation of apples. They are also involved in the processing of value-added products such as apple juice, cider, and dried apples.
- ***Vegetables***: Numerous FPOs concentrate on vegetables such as peas, tomatoes, ginger, garlic, beans, and capsicum. These crops are grown extensively in districts like Solan, Sirmaur, Mandi, Bilaspur, and parts of Kullu. FPOs in these regions facilitate the sale of fresh produce and are also involved in value addition to increase market appeal and profitability.

Role of Dr YS Parmar University of Horticulture and Forestry (UHF) as POPI:
UHF has been recognized as POPI by NABARD and Department of Agriculture, Govt. of HP. A structured approach has been developed based on four pillars by UHF. The impact of these interventions was evaluated using both qualitative and quantitative methods, including surveys, interviews, and financial analysis. The four pillars and their outcomes are presented below.

Table 1. Pillars and outcome designed by UHF as POPI

Pillar	Key Outcomes
Monitoring	Improved operational efficiency; early issue detection
Reporting & Compliance	Enhanced transparency; increased access to schemes
Training	Better decision-making; skill development
Marketing	Increased market access; better price realization

The structured approach adopted by institutes in acting as POPIs has had a significant positive impact on the performance of FPCs. Each of the four pillars contributed in distinct ways to the overall effectiveness of the FPCs, enhancing their operational efficiency, compliance, skill set, and market reach. The key outcomes associated with each pillar are outlined below:

Monitoring: The monitoring of FPC activities led to improved operational efficiency, we were able to identify and address issues early in the process. Regular field visits allowed for real-time feedback and immediate corrective actions, ensuring that FPCs stayed on track to meet their goals. Additionally, monitoring helped in identifying any gaps in the operational processes of FPCs, such as inadequate resource utilization or poor management practices, enabling targeted interventions.

Reporting and compliance: The introduction of standardized reporting formats and training on regulatory compliance resulted in enhanced transparency within FPCs. Members and stakeholders could easily track the progress of their organizations, fostering greater trust and accountability. Furthermore, increased awareness of regulatory requirements ensured that FPCs complied with necessary laws, which, in turn, improved their access to government schemes and financial support.

Training: The training programs significantly improved the decision-making capabilities of FPC members, as they gained the knowledge and skills required to manage their organizations effectively. Leadership training helped build confidence and fostered a sense of ownership among FPC members. Additionally, the skill development programs, particularly those focused on financial management and business planning, improved the financial sustainability of FPCs. This allowed them to make better investment decisions, manage costs, and plan for long-term growth.

Marketing: The marketing support provided by the institutes led to increased market access and better price realization for FPCs. By facilitating market linkages, extension institutes helped FPCs access new buyers and consumers, thereby diversifying their revenue streams. Moreover, branding and value-added products helped FPCs differentiate themselves from competitors, resulting in higher prices for their products. This not only improved their financial performance but also boosted their competitiveness in the market.

Conclusion
The study underscores the critical role of extension institutes as POPI in ensuring the success and sustainability of FPCs. Through a structured focus on monitoring, reporting and

compliance, training, and marketing, these institutes enhance FPCs' operational efficiency, transparency, and market competitiveness. This holistic approach strengthens the socio-economic well-being of small and marginal farmers. By fostering skills, market access, and adherence to regulations, extension institutes enable FPCs to navigate challenges and seize opportunities. Their support ensures sustainable growth for FPCs, improving rural livelihoods and bolstering agriculture as a pillar of economic development.

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From ex post evaluation to real time evaluation of societal impact: the ASIRPA method

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Introduction

Classical methods for research impact evaluation in agriculture (Alston 2017) aim to analyze the links between research and economic growth, based on the assumption that science has a direct effect on the economy and thus on society. Today's SDGs are not only about solving economic growth issues, but are broader in nature and require collective efforts for long run transformations. The solutions that will need to be developed will require the involvement of numerous stakeholders, complex evolving networks, public–private interactions, and contributions from end-users.

SDGs are about systems transformations: to transform current unsustainable systems (conventional agriculture) to sustainable systems (sustainable agro-food systems). This involves changes of production and consumption modes, regulations, policies social interactions, infrastructures (Schot & Steinmuller 2018). These new societal objectives induce changes in the focus of research impact assessment (RIA). New methods (quantitative, qualitative, mixed methods) should include a wider range of non-economic impacts (Bornmann 2013), based on the expectation that science is important for society as a whole (Joly and Matt 2017).

RIA objectives are not only related to accountability, economic justification and allocation of resources; they also involve advocacy, and learning. Thus, a major issue is to better link evaluation approaches and strategies to learning and continuous improvement of research and innovation strategies and public policies. RIA involves collective learning and can be considered a tool to understand and guide complex transformation dynamics. Evaluation should provide an understanding of the complex and uncertain processes that produce various values. Hence, there is a strong need to develop new RIA approaches that go beyond traditional methods and are suited to the current interactions between research, innovation, and society.

In this paper, we will present the ASIRPA (Assessment of socio-economic impact of public agricultural research) method that was developed first to evaluate the societal impacts of past research (ex-post) and more recently to help project and program managers to guide their activities and navigate towards expected societal goals (an agriculture without chemicals; natural farming).

What is an impact and how is it generated?

In ASIRPA, societal impact is a non-linear process represented by an impacts pathway that underlines the different steps between research, knowledge produced, new solutions, their adoption, diffusion and impact generated (Fig. 1). It highlights (i) the contributions of various actors, their roles, skills, and infrastructures needed to generate impacts; (ii) the role of the context; (iii) the critical steps that enables success (or failure); (iv) the evolution of the networks of actors that contributed to the generation of societal impacts

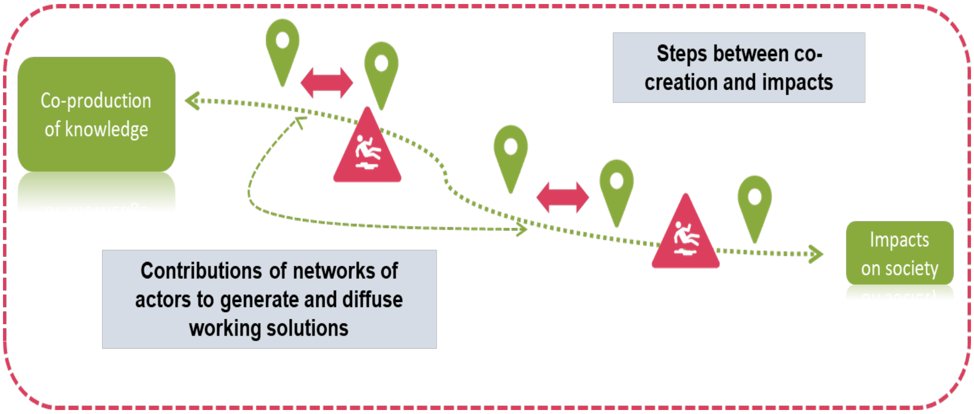

Fig 1: Non-linear impact pathway

We consider five dimensions of impacts: economic, environmental, political, social and health. A societal impact is observable at a given time, affects actors of society (political sphere, firms, farmers, NGOs, citizens, universities) and is intentional or non-intentional, positive or negative. Impact is not the direct result of research (prototype, patents, plant variety, model, software), but it is generated by the transformation and use in society of these research results. The co-creation project and other actors will contribute to these transformations.

Examples of ideal-typical ex-post impact pathways

In what follows, we discuss the results of ASIRPA ex-post. Based on 32 case studies, we have developed a typology of four impact pathways that highlight how agricultural research conducted by INRAE contribute to generating societal impact and transform existing systems into more sustainable ones. We underline the main beneficiaries of the broader returns generated by the innovation (Matt et al. 2017). We will highlight the two most transformative cases.

Intensive transformations drawing on existing networks

These cases deal with systemic changes. Research outputs and societal impacts are generated based on longstanding, important, and stable partnerships between INRAE and external academic and socio-economic actors (Vignette 1). The research/co-production networks involve numerous academic and non-academic actors, who help to structure multidisciplinary research activities. The non-academic partners are highly committed to the activity, and co-produce the knowledge with INRAE researchers and provide resources. Early involvement, co-production of knowledge, and strong engagement of socio-economic partners with high absorptive capacity are key to the success of these cases. Actors and material resources are mobilized and aligned to common goals and interests. The heavy involvement of the actors reduces the time required to achieve outputs. In the implementation phase, the network of actors enlarges and other stakeholders collaborate with INRAE to remove obstacles related to technologies, regulation, market creation and access, and to transform and structure the user side.

These cases are linked to deep transformation of the system (regulatory and market changes, restructuring of value chains, reconfiguration of the sectoral system, etc.) leading to high economic, political, environmental, and social impacts, and high returns to INRAE (royalties, R&D contracts, reputation, scientific credibility). Coordination of stakeholders and final users, granting of non-exclusive intellectual property rights, enrolment of relevant first/lead users, influence over the regulatory sphere, and involvement of INRAE in training activities are the crucial elements driving these transformations. Despite the obstacles to diffusion due to the required system transformations, societal impacts emerge soon after the production of outputs.

These cases identify two specific roles of INRAE. The first is provision of the knowledge infrastructure and ability to coordinate complex research projects involving major scientific challenges. The second is the contribution to structuring the adoption process (market access, structure of the agricultural sector, and influence over regulation) needed for intensive system transformations. This important orchestrating role played by INRAE in the adoption phase is rarely considered by the literature and by INRAE managers themselves.

Vignette 1. Intensive transformations drawing on existing networks

Genomic bovine selection

In the space of a very few years, genomic selection has substituted for traditional methods of animal breeding. Genetic tests performed on microarrays allow assessment of the genetic value of bulls. The speed of genetic progress has increased by between 50% and 100% resulting in and estimated €1billion to €2 billion gains in France between 2009 and 2022 for dairy cows alone. These changes are related to general progress in the world knowledge pool.

INRAE contributed to the rapid rate of diffusion, the strategic autonomy of French and European breeders, application of genomic selection to local breeds, and a range of other objectives. Various critical elements enabled this progress e.g. capacity to produce original knowledge in high throughput biology, ability to manage huge databases on genetic and phenotypic characterizations of French dairy cows, and an enduring and intensive partnership with the French Animal Breeding Institute and artificial insemination cooperatives. The mutualization of data and genotyping facilities in this consortium, and the co-production of knowledge with European academic partners enabled the production of a composite tool for genomic selection based on a robust assessment method, large reference populations and a range of microarrays. This highly structured network was instrumental in a set of major transformations (new regulation, creation of market for genomic goods and services, restructuring of the animal breeding and selection sector), critical for the wide diffusion of the new technology.

Public research as key initiator of intensive transformations

These cases are considered as the development of a protected space that provides an environment sheltered from the pressures of the current regime to allow the nurturing and further development of path-breaking innovations (Smith & Raven 2012). In these cases, research aims at important systems' transformations to support the transitions towards sustainable systems by opening up new technological trajectories (e.g. new seed technologies to reduce the use of chemical pesticides; natural farming practices) or influencing regulatory decisions, which affect markets and/or practices. A new trajectory or niche cannot exploit existing networks (cf. 3.1) and must compete with incumbent networks and incumbent interests (cf. the plant protection companies in Vignette 2.).

The research network includes a high proportion of academic partners and technical centers, and very few firms. The research generates high impact publications, and research outputs result from strong involvement of INRAE (production of original knowledge, scientific advice capabilities and coordination of actors). The non-academic partners are much less engaged in the co-production of knowledge and provision of resources, and participate only in later stages of the research.

INRAE is deeply involved in the diffusion phase and in activities such as coordination, technical expertise, training, and contribution to regulation. It remains involved in the long run diffusion phase. INRAE continues to test (crops in experimental field trials or fields owned by the networks of farmers), to experiment to demonstrate the local adaptation of technical itineraries, and to update data. Stakeholders are mainly technical centers and public institutions, which contribute to the regulation and coordination of actors. So far, the highest societal impacts accrue to the political dimension. Outputs contribute to public debate, policymaking, and percolation of new ideas in the political sphere. These political impacts can have potentially high impacts in other dimensions. The economic impact is generally low because the reconfiguration of networks is too weak to change existing practices and technological trajectories. Low levels of use are due to a combination of economic (high prices), structural (adaptation of users to new practices, resistance to change), and regulatory (absence of regulation) factors.

Vignette 2. Public Research as key initiator of intensive transformations

Bee protection policies

INRAE's research is performed on a technological and scientific platform involving technical institutes and professional associations, which allows the sharing of competences, experimentation, coordination of actors, and structuring of the beekeeping sector. The aim of this research is to understand better the role of pesticides on bee decay. Proof of the effects of low-doses of insecticides on bees has led to high impact publications.

INRAE has developed a bee counter software and has transferred the know-how and software to a startup through a non-exclusive license. INRAE informs the relevant French ministries on the dangers threatening bees. This led the Ministry of Agriculture to develop an action plan for sustainable apiculture and to create a Technical Bee Protection Institute. It led also to a European level ban on some previously approved molecules such as Fipronil. A bee larva test was developed as a 'best practice lab' and was approved by OECD for use in the homologation procedure for insecticides. Private service companies in Europe conduct these tests and help plant protection producers to certify their products.

INRAE has conducted diffusion activities to accompany use of its outputs, which have led to some initial transformations: creation of several organizations (platform, technical institute, start-up, service companies) and the banning of some molecules at the European level. However, plant protection firms are unwilling to change their products and practices, and regulation and market changes will be required to ensure the protection of bees.

In these two cases, the contribution of research consists of the production of basic knowledge and interventions in downstream phases of the impact pathway (regulation related to new technologies, coordination of actors involved, and construction of new markets). The difference between the cases lies in the degree of coproduction of actionable knowledge, which is very high in the case of "intensive transformation drawing on existing networks" and much lower in the case of "public research [as] a key initiator of intensive transformation". In the latter case, research aims at important transformations, needed to unlock the current system. Innovation requires new networks (natural farming system) that often compete with incumbent networks and interests (conventional farming system). The analysis shows that in these cases, the societal impacts created may be first limited and will take time to generate.

ASIRPA Real Time: what is new?

The experience in carrying out ex post evaluations, contributed to our ambition to design a framework and tools to support researchers and program managers to steer R&I towards desired societal transformations-to go from a backward-looking to a forward-looking approach. This ambition was induced by an increasing demand for R&I and by the implementation of new types of innovation policies (Schot and Steinmueller 2018) capable to address SDGs or grand societal challenges.

To take into account complexity and uncertainty, our approach is inspired by adaptive management. It is anticipatory and iterative: creating a vision of the future is not made ex ante (before the co-production starts) once for all, it is made real time i.e. on a regular basis (for instance each 18–24 months) as intermediate results may lead to reconsider the initial vision. We use impact pathways (Fig 2) to conduct the anticipatory and iterative approach and as a way of probing the future (Matt et al. 2023).

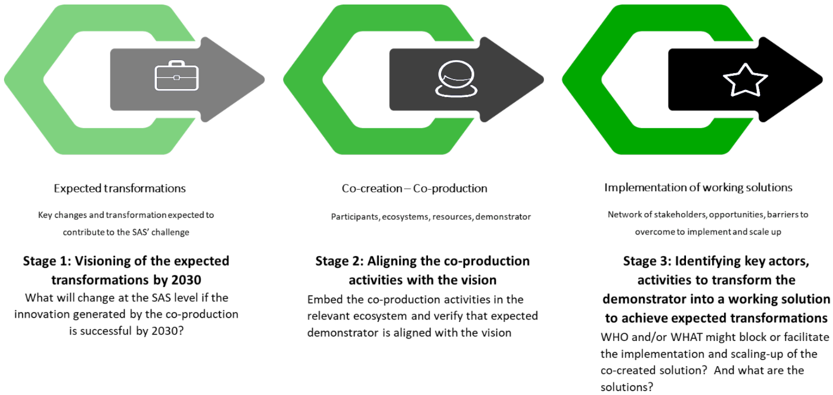

Fig 2: Anticipatory impact pathway (IP)

In the case of sustainable agroecological systems (ex: Gram Disha Trust SAS or Chaupal NFPC SAS), the anticipatory IP helps the community (actors of the SAS) to anticipate how of their activities will contribute to achieve the expected societal transformations linked to 100% Natural Farming in the district by 2030. It helps to steer co-production activities towards these expected changes. In ASIRPA Real Time, the IP (cf. Figure 2) accompanied with a narrative is constructed in the following three steps:

Step-1, the actors of the SAS start by identifying the targeted transformations expected by a certain time horizon. The identification of the targets requires describing a future world in which their activities have succeeded and contributed significantly to the achieved transformations. To elicit their vision about the future, we provide a list of guiding questions: what will have changed significantly in 2030? To which transformations are you expected contribute?

Step-2 helps in designing the co-production activities, the expected demonstrators and in defining the group of actors of ecosystem to involve. These co-production activities should be aligned with the targeted transformations. Example of guiding questions: what are the current knowledge gaps? Are the scientific and technical knowledge and the expected results in line with the targeted transformations? What is the timing of the various results? What is the level of uncertainty/risk? Which actors should be involved in the co-production?

Step-3 consists in sketching and anticipating contributions of other stakeholders and the interactions of co-production group with various spheres of influence and spheres of concern. This step involves the identification of the critical points, tipping points, obstacles and intermediate targets important to achieve to ensure that the process is on the right trajectory. Example of guiding questions: who are the main beneficiaries of the results? What benefits can they gain? Who are the actors needed to facilitate the transformation of co-production into working solutions? What is the blocking and facilitating actions? What activities are needed to achieve the transformations and check whether actors are missing?

These steps will be revisited at each iteration. After each iteration, the actors of the SAS will set up a strategy and an action plan that will enable them to assess the progress, learn and reorient activities.

Lessons learned

We have used this method in a number on contexts: French Priority Research Program 'towards zero chemical pesticide agriculture'; Technology Transfer Office of INRAE; Mission-oriented Science with and for society to Advance Innovation through Co-creation in Cities; Participatory research project on sustainable transitions of French agricultural ecosystems; a Living Lab on digital agroecology. These experiences show that using ASIRPA TR brings three improvements: (i) a better definition of the societal transformations targeted, which can be used to research and innovation activities in the desired directions. Without ASIRPA, the project partners formulate the desired futures in terms of new technical solutions or research questions.

With ASIRPA, the R&I players envisage transformative modes of production and consumption, new markets, new institutions and changes in the academic sphere, (ii) a reassessment of the partnerships and network of actors needed to ensure that the alternative solutions developed in the co-production phases are aligned with the targeted transformations, (iii) networks of stakeholders to be built up over time in order to contribute to the targeted transformations. With ASIRPA RT, the partners are considering the role and responsibilities of other stakeholders (not involved in the initial creation of the solution) in overcoming obstacles and implementing alternative solutions. They anticipate how to interest and involve these stakeholders in the network so that the alternative solution is used. This network of stakeholders will evolve over time, and (iv) a more proactive attitude integrated into a strategy and an action plan. The aim of the action plan is to define actions to improve the dynamic of knowledge co-creation, and to determine actions to be carried out with stakeholders in order to implement the necessary changes (new practices, new labels, training, new regulations, new markets, etc.) to contribute to the targeted transformations. Without ASIRPA, the projects carry out conventional project management using conventional tools.

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Insect-Pests Management under Natural Farming

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Keywords: Natural Farming, Pest surveillance, Natural enemy

Introduction

Modern agricultural practices have adversely affected the agro-ecosystem due to indiscriminate use of agrochemicals. Even the cost of inputs has increased manifold and in spite of their regular use the production level is static. Therefore, development of effective management strategies is essential for sustaining productivity and maintaining long-term profitability. An ever-increasing problem in containing pests in recent years is probably the result of dependence on single control tactics employing chemical controls. Rachel Carson in 1962 in her book Silent Spring attracted the attention of mankind on the adverse effects of chemicals in the environment. Thereafter, several researchers have reported the ill effects of pesticides on the environment as well as on living organisms This indicated that chemical controls alone will not provide long-term control of pests (Cuperus et al. 1990). The use of synthetic chemicals has resulted in environmental pollution, pesticides residues, resistance in insect-pests and killing of natural enemies, thereby affecting the sustainability (Vega et al. 2009). It is therefore, necessary to devise a pest management system which is based on ecological principles resulting in sustainable agricultural production without disturbing the balance of nature (Kennedy and Sutton 2000). The use of pesticides in controlling the pests is eliminated through Subhash Palekar Natural Farming (SPNF) practices. The SPNF is an agroecological farming approach that promotes growing crops in harmony with nature. This farming system, is about improving soil fertility through a number of agro-ecological approaches, including diversification, nutrient recycling and increasing beneficial biological interactions in the soil.

Even Integrated Pest Management programme could not reduce the use of pesticides consumption in India and it has reached to 62,192 MT during 2021. In an agroecosystem, the plant diversification prevents the pest infestation in crops. Natural farming as an agroecological practice provides basic ecological principles on how to study, design and manage agroecosystems that are productive, enduring and conserving natural resources. Instead of focussing on one particular component of the agro ecosystems, agroecology emphasises the interrelatedness of agroecosystem components and the complex dynamics of ecological processes such as nutrient cycling and pest regulation. Therefore, design a cropping system in such a way that the main and intercrops are unrelated to each other and one of the intercrops should be leguminous crop, use of dry grass/ crop refuse mulch/live mulch, maintenance of *whapasa* and it should also be antagonist s to pests. The aim of SPNF is shift from monocropping system to multilayer cropping system so that dependence on external input is excluded and locally available inputs can be used and there should not be use of agrochemicals. Thus, SPNF system is an option for sustaining productivity and maintaining the health of ecosystems (Kennedy and Sutton 2000). SPNF system not only manages the pests but also enhances the quality of soil, increase soil organic carbon, increase beneficial microbes and earthworm's population besides increasing natural enemies and pollinators population (Altieri 1994; Altieri and Nicholls 2003). Natural farming enhances the biodiversity in the farming system, which helps creating local barriers against insect-pests and diseases, enhance population of natural enemies beneficial microbes and using other indigenous low cost inputs like *darekaster, brahmaster, agniaster*, etc. as plant protectants (Palekar 2006).

Insect-Pests Control Solutions

Natural Farming practices provide immunity to plants. Seed treatment with *beejamrit*, application of *ghanjeevamrit, jeevamrit, achhadan* (mulch) and *whapasa*, all these help in increase in beneficial microorganisms, increase earthworms activity and increase soil organic carbon which cause resistance in crop plants. Therefore, menace of pests is reduced. However, when infestation occurs, the preparations of various decoctions viz. *agniaster, neemaster, drakaster, brahamaster* and *dashparni ark* from locally available plants in cow urine helps to control the pests (Palekar 2006).

Insect-pests and Natural enemy fauna

Multispecies cropping system is considered as the application of ecological principles based on biodiversity, plant interactions and other natural regulation mechanisms (Vandermeer 1989). Guava orchard intercropped with cowpea, the highest number of parasitoids and predators was recorded compared to that in the sole cropped field. Mealybug-specific parasitoids *viz., Anagyrus dactylopii* (Howard) and *Coccido xenoides* sp. were recorded in the guava orchard intercropped with cowpea. *Anagyrus dactylopii* (Howard) and *Coccidoxenoides perminutus* (Girault) as efficient native parasitoids of grapevine mealybug, *M. hirsutus*, were reported by Amala et al. (2013). Cabbage intercropped with fenugreek, pea and coriander and grown under SPNF system recorded higher number of cabbage aphids as compared to the Chemical Farming (CF) system (cabbage as sole crop). Similarly, tomato intercropped with brinjal and Frenchbean recorded higher numbers of serpentine leaf miner, fruit damage (19.12%) by fruit fly and 14.53 per cent fruit damage by tomato fruit borer, *Helicoverpa armigera* as compared to 7.85 per cent fruit damage by fruit fly and 8.20 per cent fruit damage by fruit borer in tomato grown as sole crop under CF system. In another study, when pea was intercropped with coriander and spinach recorded higher population of pea leafmer (*Chromatomyia horticola*) in NF system as compared to chemical farming system (Anonymous 2022). Yankit et al. (2019)cultivated tomato under Natural Farming (NF), Organic Farming (OF) and Conventional Farming (CF) systems and observed that incidence of invasive leaf miner, *Tuta absoluta* (Meyrick)) was significantly less in NF system as compared to organic farming (OF) and conventional farming (CF).They further observed that *T.absoluta* appeared in NF 4 weeks later than conventional farming.The SPNF system had seven species of natural enemies, viz; *Coccinella septempunctata* (L.), *Hippodamia variegate* (Goeze), *Episyrphus balteatus* (De Geer), *E. frequens* (Matsmura), *Metasyrphus confrator* (wiedemann), *Diadegma semiclausum* (Hellen), and *Diaeretiella rapae* (Mc Intosh), whereas, in the CF, only five species of natural enemies were recorded (Vipul 2021). The Shannon index described the SPNF system as a more diverse ecosystem in terms of natural enemies Barakzai et al. (2021) intercropped cauliflower with pea, coriander and mustard as trap crop and reported ZBNF system harboured with less pest diversity and more natural enemies as compared to the CF system.

Natural enemies' diversity indices revealed that the Natural Farming based system was more diverse than cauliflower-based CF system. Vishwajeet (2020) recorded five species of insect-pests viz. jassid, *Amrasca biguttula biguttula* (Ishida), brinjal shoot and fruit borer, *Leucinodes orbonalis* (Guen), green house whitefly, *Trialeurodes vaporariorum* (Westwood),cotton aphid, *Aphis gossypii* (Glover), serpentine leaf miner, *Liriomyza trifolii* (Burgess) and blister beetle, *Mylabris pustulata* (Latreille) in both *i.e.* Subhash Palekar Natural Farming (SPNF) as well as Conventional Farming (CF) Systems.Among natural enemies *C. septempunctata*, *H. variegata, E. balteatus*), *Ischiodon scutellaris* (F), were present in CF system whereas *C. septempunctata*, *H. variegata, Oenopia sexareata* (Mulsant), *E. balteatus , I. scutellaris* were present in SPNF system. In another study, the SPNF and CF had the same pest diversity, but delayed their incidence by 1-3 weeks in SPNF as compared to CF and attracted relatively more natural enemies (Rana et al. 2021). In Spiti Valley, Natural farming practices successfully controlled woolly apple aphid, *Eriosoma lanigerum* (Hausmann) by using low- cost locally sources inputs when compared to conventional farming methods (Vashisth et al. 2023). Bakshi et al. (2023) reported eleven species of natural enemies in apple orchards maintained under SPNF system and out of these eleven species, four species of coccinellids, five species of syrphids, one species of green lacewing and one species of Chalcidoid wasp and in CF system only eight species of natural enemies in apple ecosystem were recorded. Simpson index, Shanon index, maximum diversity, species evenness(J), species dominance was 1.50,0.88,2.16,2.39,0.90 and 0.10, respectively, whereas in CF system the value of these indices was 1.33,0.86,2.07,0.94 and 0.06, respectively.

Soil microarthropods population

Soil microarthropods population (per unit volume of soil; number/m^3) determined after the crop harvest in 2019. Highest population of soil microarthropods was found in NF (7054/ m^3 soil), which was significantly higher than CF (2015/m^3 soil). Soil microarthropods population was double in OF (4031/m^3 soil) in comparison to CF, but was statistically at par due to variability among replications. The soil microarthropods from orders namely Coleoptera, Diptera, Hymenoptera, Chilopoda, Hemiptera, Collembolan and Acarina were found under all the farming systems. However, apart from these orders, microarthropods from Dermaptera, Diplura and Isoptera were also present under NF, and were not found under OF and CF (Yankit et al. 2024). Soil microarthropods have been found to be sensitive to changes in land management practices (Parisi et al. 2005) and are thus being used as indicators of soil quality. Thus, apart from higher microarthropod population, additional diversity was there under NF. The abundance of soil microarthropods has been observed to be positively correlated with soil C and N, and negatively with soil pH (Wang et al. 2015). The pH of cow urine is in alkaline range, which might have increased the soil pH under NF system, where cow urine-based formulations were applied repeatedly. Higher microbial populations and higher pH under NF system might be the reason for significantly higher soil micro-arthropod population. Soil microarthropods have been reported to improve soil health through their roles in decomposition and nutrient cycling and direct and indirect suppression of plant pests.

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Nutri-Sensitive Agroecological Functioning for Sustainability

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Introduction

Nutritional garden involves growing a diverse array of fruits, vegetables, and herbs to provide a sustainable source of essential nutrients for a household. It emphasizes maximizing nutritional output from a small area of land, enhancing food security and promoting healthy eating habits. Nutri Garden, also known as a Nutrition Garden or Kitchen Garden, is a small-scale garden designed to provide a variety of vegetables, fruits, and herbs for household consumption. The primary purpose of a Nutri Garden is to improve food security and nutritional intake by ensuring the availability of fresh, diverse, and nutritious produce throughout the year. This concept is especially beneficial in areas with limited access to fresh produce, helping to combat malnutrition and promote healthier eating habits. Establishing a Nutri Garden of fruits and vegetables can provide a sustainable source of fresh, nutritious food. This type of garden can help meet dietary needs by offering a variety of vitamins, minerals, and other essential nutrients.

Nutri-garden is the basis of crop diversity in terms of fruits, vegetables, spices, medicinal & aromatic plants in mixed farming, and focuses more on soil fertility enhancement in organic approach which is targeted for long-term health and productivity. Moreover, natural farming practices for cultivation are not new to rural people. Technological options that have been explored earlier for efficient for soil carbon storage in agro-ecosystems through natural farm inputs, crop residue incorporation, mulch farming for conservation agriculture, choice of cropping system and intensification of agriculture. Based on the nutritional and ecological models that can restore soil organic carbon balance and its sustenance by appropriate management techniques would be the strategic perspective for building organic carbon in adequate proportion in soils.

Nutri Garden therefore, is an innovative option to i) bridge the gap between available resources and its utilization for sustainable livelihood, ii) address issues like malnutrition, iii) create additional revenue-generating opportunities for farmer communities and iv) introduce healthy eating practices. Most importantly, it gives direct access to diverse nutrient-rich food products. This is especially important in rural areas where people have limited income-earning opportunities and poor access to markets. Both long-term and short-term strategies need to be addressed effectively on issue of malnourishment amongst rural women and village people. The model therefor, emphasizes on bio-fortified crop production modules through agro-ecological practices to strengthen rural economy, food security and health in a sustainable manner.

Key Principles

Nutrient Dense Crops- Grow a wide variety of fruits, vegetables, and herbs to ensure a balanced supply of essential nutrients.

Sustainability- Use organic farming practices, such as composting, crop rotation, and natural pest control, to maintain soil health and reduce environmental impact.

Space Utilization- Optimize the use of available space through vertical gardening, container gardening and intercropping.

Water Management- Implement efficient watering techniques like drip irrigation, mulching, and rainwater harvesting to conserve water.

Community Involvement- Engage the community in the planning, establishment, and maintenance of the garden to promote ownership and knowledge sharing.
Health and Wellness-Encourage the consumption of fresh, home-grown produce to improve overall diet quality and educate on the health benefits of different crops and how to incorporate them into daily meals.

Establishment

Site Selection- Select a location with ample sunlight, good drainage, and easy access to water. Ensure the soil is fertile or can be improved with organic amendments (Kumar and Pathania 2023).
Planning- Design the garden layout, considering the space requirements of different fruit plants. Plan for successive planting to ensure a continuous supply of fruits around the year.
Soil Preparation- Test for soil pH and nutrient content. Amend the soil with compost, manure, and other organic matter to improve fertility and structure.
Plant Selection- Select fruit varieties which are well-suited to local climate and soil.
Planting- Follow recommended spacing guidelines to ensure proper growth and airflow between plants. Plant at the right depth after planting to establish roots.
Care and Maintenance- Water regularly, especially during dry periods, ensuring deep watering to encourage root development. Mulch the plants to conserve moisture, suppress weeds and regulate temperature in soil. Prune fruit plants to maintain shape, remove diseased branches, and encourage fruit production.
Harvesting- Harvest of fruits at the peak of ripeness for the best flavor and nutritional value. Handle fruits carefully to avoid bruising and damage.
Education and Community Engagement- Provide training and resources to community members on Nutri Garden practices.

Nutri Garden for Diet Diversity

Fruits

Apple, peach, plum, apricot, pomegranate: dietary fiber, vitamin C and antioxidants.
Berries (Strawberry): Rich in vitamins C and K, fiber and antioxidants.
Citrus Fruits (oranges, lemons): Excellent sources of vitamin C, fiber, and antioxidants.

Leafy Greens Vegetables

Spinach/ Coriander: Rich in iron, calcium, magnesium and vitamins A, C, K.
Kale: High in vitamins A, C, K and contains antioxidants and fiber.
Lettuce: Provides vitamins A, K and folate.

Root Vegetables

Carrot: Excellent source of beta-carotene (vitamin A), fiber, vitamin K and potassium.
Beets: High in fibre, folate (vitamin B9), manganese and nitrates.
Radish: Contain vitamin C, fiber and are low in calories.

Cruciferous Vegetables

Broccoli: Packed with vitamins C and K, fiber and folate.
Cauliflower: High in fiber, vitamins C and K and choline.
Cabbage: Contains vitamins C and K, fiber and folate.

Legumes

Peas: Provide protein, fiber, vitamins A, C, Kand B complex.
French beans: High in fiber, protein, vitamins A, C, and K and folate.

Tomatoes: High in vitamin C, potassium, folate and lycopene.

Agroecology functioning and SDGs

Agroecology focuses on ecological principles to design and manage agricultural systems. Sustainable Development Goals (SDGs) of United Nations to address global challenges and promote prosperity. Key SDGs related to agroecology include: Zero Hunger (Goal 2)-Nutri Gardens can enhance food security by providing a diverse and reliable food source. They can also contribute to nutritional education and healthier diets; Responsible Consumption and Production (Goal 12)-By using organic and sustainable practices, Nutri Gardens reduce waste and resource consumption. They promote circular systems where waste is recycled into resources; Climate Action (Goal 13)-Sustainable gardening practices can help mitigate climate change by sequestering carbon in the soil and reducing greenhouse gas emissions from conventional farming and Life on Land (Goal 15)-Nutri Gardens support biodiversity and ecosystem health by creating habitats for various species and using practices that protect and enrich the soil. By integrating these principles into a Nutri Garden, you can make a significant impact on sustainability and contribute to the achievement of various SDGs (Kumar et al. 2023).

Agro-ecological practices including natural farming aligns closely with several SDGs including SDG-1 (End poverty), SDG-2 (End hunger, achieve food security and improved nutrition and promote sustainable agriculture), SDG-6 (Ensure availability and sustainable management of water and sanitation for all), SDG-8 (Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all), SDG-9 (build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation), SDG-12 (Sustainable consumption and production patterns) and SDG-15 (Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss).

Conclusion

Indian government is increasingly recognizing the importance of nutrition and sustainable education practices. With increasing focus on holistic development of children, future policy directions for introducing nutrition-sensitive innovations in schools may include supporting the implementation of key strategies and initiatives, including nutrition-sensitive education, school-based nutrition gardens, and integration of government-non-government partnerships to implement and scale up nutrition-sensitive innovations. Our vision for a healthier and more prosperous nation is closely intertwined with our approach to food security and nutrition. The concept of nutrient-dense foods is an important step in this direction. Our commitment to natural farming further strengthens this vision. The synergy between Nutri Gardens and natural farming provides holistic solutions to the challenges we face. These initiatives allow us to grow diversified crops that meet different nutritional needs while maintaining ecological balance.

Let us embrace these practices with dedication and enthusiasm. Let us work towards a future where every family has access to fresh, nutritious food and our agricultural practices follow the principles of sustainability and environmental protection.

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Conservation of Pollinators –A Natural Farming Approach

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Introduction
The process of natural crop pollination in the environment has been occurring for millions of years, which benefits both pollinators and flowering plants. Pollinators assist reproduction in over 80 per cent of the world's flowering plants (Kaur and Kaleka 2022) and about 33 per cent of all crops require pollination. While some pollinators visit a wide range of flowers and are generalists, many pollinators have developed preferences for particular flower types, and vice versa. More than 90 per cent of the world's major plant types are visited by bees and flies, while just 6 per cent of crop varieties are visited by other species. The majority of the world's known species of bees (20,077 species) are wild in nature, that is, free-living and unmanaged, whereas the indigenous honey bees, *Apis cerana*, the exotic bee *Apis mellifera* and some bumble bees, stingless bees, and a few solitary bees, are managed and used commercially for pollination (Saha et al. 2022). Most arthropod pollinators have a preferred flower colour e.g. bees favour blue flowers, butterflies pink and red, beetles and bats prefer white flowers and humming birds favour red flowers. Additionally, the flower's phenology, shape, and food reward can all affect the pollinators visit.

Insect Pollinators
The insect pollinators because of their specific characters contribute greatly to pollination of various agriculture and horticulture crops.
Honey bees: These are fuzzy and carry an electrostatic charge, both their characters helps pollen grains adhere to their bodies, they also have specialized pollen carrying structure called as pollen basket or corbicula.
Bumble bees: In comparison to honeybees or other pollinators, bumble bees are thought to be very efficient pollinators as they can fly and remain active at lower temperatures, they can pollinate even plants with deep corollas with their larger tongue and do pollination [type of pollination in which bees use vibratory motions in order to remove or collect pollen from flowers incidentally fertilizing them (Devi 2020)].
Megachilid bees: Also known as leafcutter bees have large scissors like jaws to gather leaves, flower, petals and resins to construct nest. The bees carry pollen in scope which is distinguishing characteristics.
Halictid bees or sweet bees: Carry pollen on the tibia and femur of their hind legs, except for parasitic species.
Carpenter bees: Both female and male bees of species *Xylocopa* collect nectar from several plant species belonging to different families.
Stingless bees: These are excellent pollinators and can be used for commercial purposes and can be managed in home just like honey bees.

Need for natural farming
In last few decades industrialized agriculture, urban and suburban expansion, monocropping, intensive cultivation and excessive use of pesticides has lead to a sharp decline in the population of insect pollinators, leading to low productivity of agricultural and horticultural crops. Throughout the world, conventional farming has led to decline in soil health, environmental pollution, health hazards, loss of biodiversity and threat to ecosystem sustainability. Pesticide pollution is a major stressor for insect pollinators particularly honeybees where it contributes to the colony collapse disorder condition. Further, the ability

of bees to learn, navigate, and defend themselves from infections may be compromised by the sublethal effects of pesticides. Pesticides like DDT, benzene hexachloride (BHC), cyclodienes, and most organophosphorus and carbamate compounds are highly toxic to bees, and even endosulfan is recognized as a persistent pollutant. Various pesticides viz., Alachlor, Benomyl, Carbaryl, Diazinon, Dichlorovos, Alachlor, Benomyl, Carbaryl, Diazinon, Endrin Ethyl Mercury Chloride, Menazon, Nitrofen are banned pesticides and unsafe to bees (CIBRC 2023). Thus natural farming is the need of the hour, and further awareness among the farmers is also required.

Natural Farming

Zero budget natural farming popularly known as Natural farming, is an innovative farming approach. There are many working models of natural farming all over the world but nowadays the Subhash Palekar Natural Farming (SPNF) system developed by Padma Shree Sh. Subhash Palekar is practiced across different states with its adaptation first in Andhra Pradesh in India. In Himachal Pradesh, the practice of natural framing is also growing very fast. The natural farming is low input based, climate resilient, and low-cost farming system where all the inputs (insect repellents, fungicides, and pesticides) are made up of natural herbs and locally available inputs, thereby reducing the use of artificial fertilizers and industrial pesticides (Laishram et al. 2022). The nutrient requirements, as well as protection of plants from various pest and diseases are mostly met with the application of some indigenous farm products viz., *jeevamrit, beejamrit, neemaster, agniaster* and *brahmaster* indeed preventing pest occurrence.

Sustenance of honeybees and other pollinators

Pollination studies in chinese cabbage (*Brassica rapa* L. subsp. *chinensis* under SPNF and Conventional Farming (CF) systems at UHF indicated relatively higher abundance of insect visitors in SPNF system (4.35/100 flowers) followed by control (3.46) and CF system (3.10) (Dhuria et al. 2022). Among all insect visitors, *A. mellifera* (8.85/100 flowers) was the most dominant visitor and wild bees (0.53) including *Xylocopa sp*., *Bombus haemorrhoidalis* Smith*, Halictus sp.* and *Sphecodes sp.* were least abundant visitors. Similar trend was also observed in sweep net capture method. Relative abundance of insect visitors had positive correlation with temperature but negative correlation with humidity.

The studies on diversity, abundance of insect visitors and pollination efficiency of *A. mellifera* in onion crop (*Allium cepa* L. var Nasik Red) under natural and conventional farming systems during 2023-2024 at UHF indicated that the natural farming system attracted more insect visitors (1655) compared to the conventional system (1251) (Kumari 2024). The dominant insect species were *E. balteatus* and *A. mellifera* in natural and conventional systems, respectively. Diversity indices viz., Simpson and Shannon, indicated higher diversity in natural farming. Fluorescent coloured pan traps captured more insects in natural farming (1.73/trap) than conventional farming (1.22/trap), with peak insect activity during full bloom stage. Scan sampling showed that insect activity peaked at 1200hr and during full bloom, with *E. balteatus* being the most abundant visitor. Sweep net captures confirmed the higher insect count in natural farming system.

The diversity of pollinators visiting cashew panicles under organic ecosystem revealed that panicles were visited by twenty-seven species of pollinators. Among these, fifteen species belonged to the order Hymenoptera, nine belonged to Lepidoptera and two belonged to the order Diptera (Kumar 2014). In Hymenoptera, honey bees were the most dominant pollinators. *A. cerana* was the dominant pollinator among honey bees with a relative abundance of 34.46 per cent followed by *A. dorsata* (28.09%) and *A. florea* (21.33%). The mango flowers in conventional and organic system were visited by 21 species of insects belonging to the orders: Diptera, Hymenoptera, Lepidoptera and Odonata (Siqueira et al.

2008). In the organic farming, the number of Hymenopteran species were superior to conventional farming. *A. mellifera* was the most frequent accounting for 68.30 per cent of total visits in organic farming and 45.60 per cent in conventional farming. *Belvosia bicincta* (Diptera: Tachinidae) was the most frequent in conventional farming (17.70 %), while the *Musca domestica* (Diptera: Muscidae) (10.27 %) was the most frequent in organic farming. In addition, in conventional farming, there was concentration of bee visits in the morning, with gradual reduction during afternoon. The peak visitation was recorded between 8:30 a.m. and 11:30 a.m. In the organic farming, there were two visits peaks, one early in the morning (7:30 am to 8:30 a.m.) and another in the early afternoon (14:30 to 15:30), observing a quantitative balance in relation to the other zones. There were greater number of visits in organic farming, and this difference can be attributed to the absence of agrochemical application in organic area.
Sunflower crop grown under natural farming system of sunflower crop attracted more insect visitors (1265) compared to the conventional system (763). Among the Hymenopteran visitors, there were *A. mellifera*, *A. dorsata* L. *A. cerana*, *Bombus haemorrhoidalis* Smith, *Vespa* spp., *Ceratina* spp and *Halictus* species (sweat bees). Additionally, Lepidoptera, Hemipetrans and Coleopteran visitors have also been observed. In SPNF, maximum numbers was of *B. haemorrhoidalis, A. mellifera* (Janjuha 2024). The average number of flowers visited by *A. cerana* and *A. mellifera* foragers in one minute was significantly more in SPNF system followed by the control and CF system. The hive bees visited significantly more flowers per minute during 1200 h followed by 1500 and 1000 h, respectively (Dhuria et al. 2022). Jadhav et al. (2021) studied the effect of seed priming and direct application of agro-organic formulations on the growth of *Triticum aestivum* L. and *Brassica nigra* in pots. Four different agro-organic formulations viz. traditional and modified Panchagavya and Jeevamrit at different concentrations (1:50 to 1:200) were used for seed priming and direct soil application. Seed priming showed significantly higher germination percentage and seed vigour index (SVI) in wheat (98% and 2216) when primed with modified formulation, while in mustard (64% and 684) when primed with traditional formulation as compared to control (autoclaved distilled water). Direct soil application showed significant difference in the germination percentage (100%), SVI (1205 and 1443), shoot length (10.3cm and 10.63cm), root length (5.7cm and 7.53cm) and seedling length (12.06cm and 14.38cm) of wheat and mustard respectively on comparing with control when subjected to treatment with traditional formulation for wheat and modified formulation for mustard.

Conclusion

Natural farming system supports a greater diversity and abundance of insect visitors as compared to conventional farming system. The enhanced pollination in the SPNF system can lead to higher-quality seeds for farmers if they consistently apply indigenous farm products like *beejamrit, jeevamrit, ghan-jeevamrit, agniaster*, and *neemaster*. The SPNF system proves to be superior in terms of both the quantity and quality of seed yield and provides better benefits to pollinators. Thus, natural farming can play important role in sustainable crop production.

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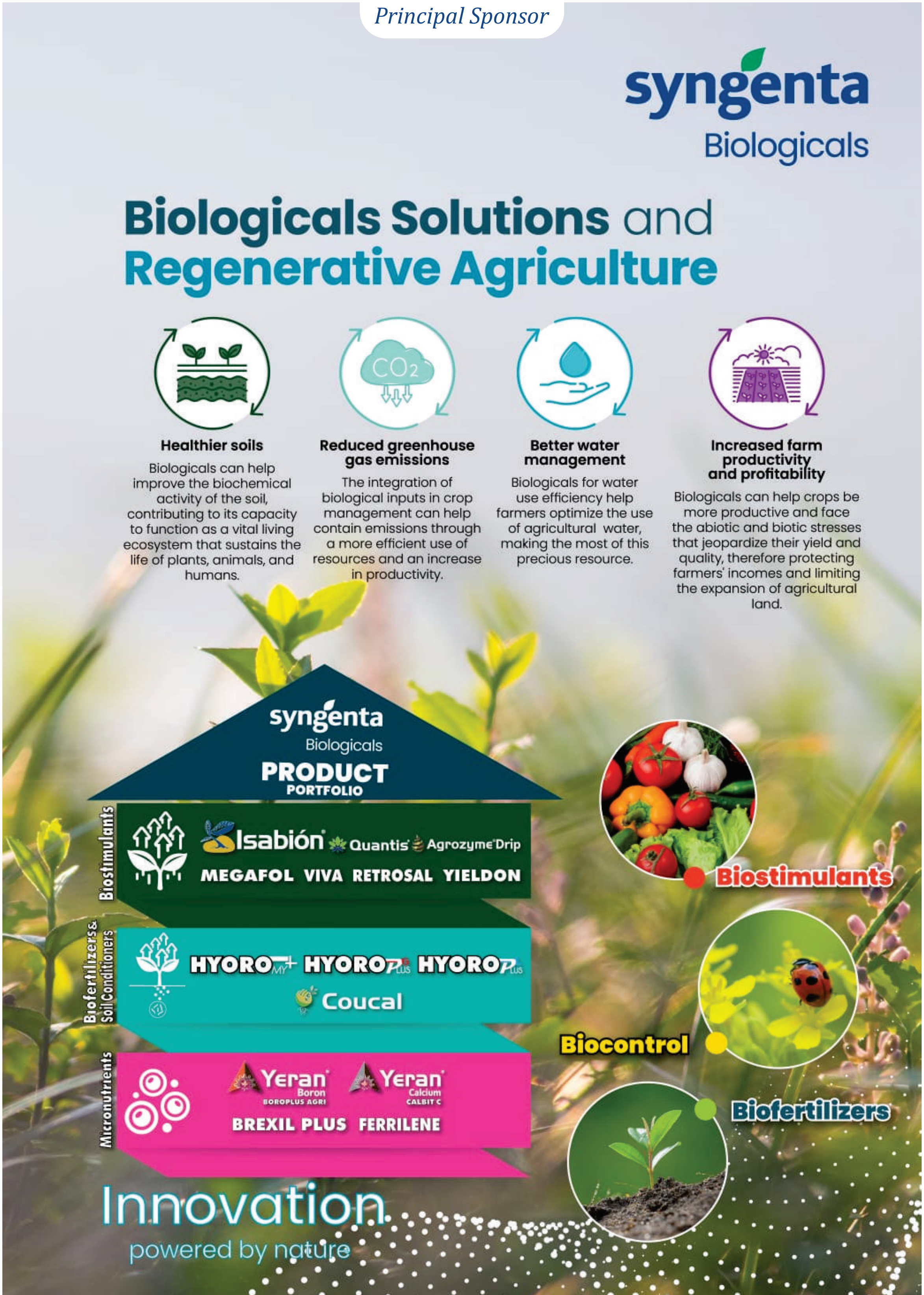
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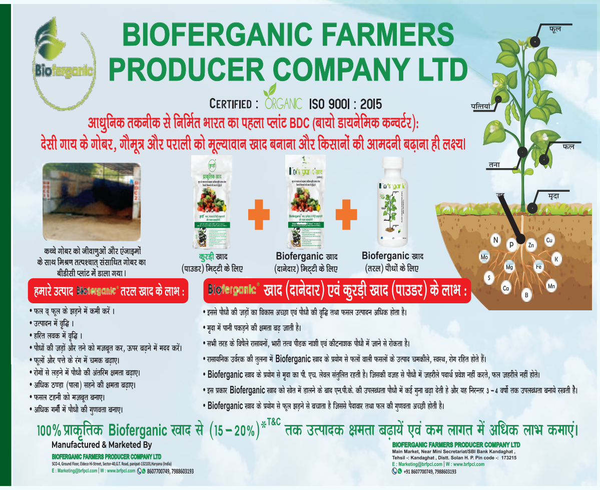

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