Natural Farming: Basics and Application

Agronomy Section

ICAR-National Dairy Research Institute

Karnal-132001, Haryana, India

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FOREWORD

India is an agrarian-based economy, and dairy is the single largest agricultural commodity contributing 5 per cent of the national economy and directly employing more than 8 crore farmers with a contribution of 30.1% of total Agriculture GDP. During 2022-23, India is ranked first in milk production (230.58 million tonnes) contributing 24.6 per cent of global milk production. Currently, India is facing the twin problem of feeding the ever-increasing human and livestock population and shrinking fertile land resources for agriculture. According to the recent estimate by the UNCCD, India's total reported land area degraded by approximately 30.5 million hectares from 2015 to 2019. This represents a degradation of 9.45 per cent of the country's landmass in 2019, compared to 4.42 per cent in 2015.

Furthermore, numerous scientific studies indicated that chemical-based farming can have detrimental effects on both the environment and human health. During the green revolution, unbalanced and excessive use of synthetic fertilizers and pesticides resulted in soil degradation, eutrophication of land and water bodies, loss of biodiversity, water pollution, and harm to living beings. Over time, this type of farming made it increasingly difficult to produce healthy crops. Natural Farming is a chemical-free farming system that integrates crops, trees, and livestock with functional biodiversity. It emphasizes on-farm biomass recycling, maintaining soil health, and excludes all synthetic chemical inputs. It is a cost-effective farming practice with scope for increasing employment and rural development. By improving soil health, suppressing weeds, controlling pests with natural predators instead of pesticides, and reducing reliance on antibiotics and growth hormones, natural farming creates a sustainable and resilient agricultural system that benefits both the environment and human health.

I am pleased to note that ICAR-National Dairy Research Institute, Karnal, is organizing a one-week training programme (Karyashala) funded by DST-SERB on "**Natural farming could be a game changer Agro-practice for Dairy-based farming in India**" from 15th to 22nd February 2024.

I wish the programme will be purposeful and meaningful to the participants and that the literature will be useful for students, researchers and policymakers across the country. I extend my best wishes for the success of the program. I would like to compliment the efforts of the whole agronomy section of ICAR-NDRI, Karnal, for this valuable publication for their untiring work and high level of enthusiasm.

(Dheer Singh)
Director, ICAR-NDRI

PREFACE

This book is an outcome of the one-week training programme (Karyashala) funded by DST-SERB on "Natural farming could be a game changer Agro-practice for Dairy-based farming in India" from 15th to 22nd February 2024. The editors' main aim is to provide insights to all extension workers, faculties, researchers and students about the agro-techniques follow in natural farming, organic farming and eco-friendly best management practices.

Under the current scenario, enhanced productivity, improved resilience and better quality of farm produce require improved knowledge of chemical-free farming practices to improve soil health by use of compost, planting cover crops, crop rotation and crop diversification to prevent soil erosion, suppress weeds, and preventing soil-borne diseases and pests. Natural Farming practices emphasize on-farm biomass recycling, maintaining soil health, and excluding all synthetic chemical inputs. It is a cost-effective farming practice with scope for increasing employment and rural livelihood.

The stakeholders should have comprehensive insights into natural farming practices. Furthermore, they can benefit from the knowledge of various research and innovations in natural and organic farming-based agro-techniques to create a sustainable and resilient agricultural system that benefits both the environment and human health. Therefore, the editors felt that resource persons' experience in this training should be clubbed together to form a unique proposition on climate-smart research and innovations for forage production and conservation.

The experts and resource persons in agronomy and animal science contributed immensely and tirelessly to quickly develop various chapters of this book. The editors extend their sincere thanks to all the experts who have contributed their valuable time and efforts to produce this book. The editors also sincerely thank the Scientific and Engineering Research Board (SERB), the Department of Science and Technology (DST), Government of India for financial assistance under the accelerated Vigyan scheme to publish this book.

The editors are grateful to the Director of ICAR-NDRI for his constant encouragement in organizing this Karyashala and creating a book for the participants. The editors hope this book will help participants and other extension people across the country gain valuable information on climate-smart technologies for quality forage production and the conservation of forages.

Editors

CONTENTS

OPPORTUNITIES FOR ORGANIC AND NATURAL FARMING IN INDIA

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The major problems of agriculture are decline in growth rate, factor productivity, farm income, shrinkage in net cultivable area, depleting groundwater table, malnutrition, environmental pollution and increasing cost of production. During pre-green revolution period (up to 1960s) the rate of national agricultural growth was not able to keep pace with population growth and 'ship to mouth' situation prevailed. This was the major factor for introduction and large-scale popularization of the high yielding varieties (HYVs) of crops, which were highly responsive to the chemical fertilizers and water. As a result, the total food grain production increased phenomenally – from mere 50.83 million tonnes in 1950-51 to 330.50 million tonnes in 2022-23 – indicating ~ 6.5 times increase (DES, 2023). This increase can be primarily attributed to large-scale adoption of HYVs, combined with other green revolution technologies (GRTs) in cereal crops, expansion of gross irrigated area (22.56 million ha in 1950-51 to 112.23 million ha in 2019-20) and increase in fertilizer nutrient consumption (0.07 million tonnes in 1950-51 to 29.79 million tonnes in 2021-22) (GoI, 2022). All of them put together have led to substantial increase in the cropping intensity (from 111.07 % in 1950-51 to 151.08 % in 2019-20) and productivity of crops, especially food grains (from 522 kg ha^{-1} in 1950-51 to 2419 kg ha^{-1} in 2021-22, GoI, 2022) culminating into the change the status of India from a food importer to net food exporter in many commodities. The total factor productivity growth score prepared by National Institute of Agricultural Economics and Policy Research, New Delhi has revealed that technology-driven growth has been highest in Punjab and lowest in Himachal Pradesh. It implies that some of the states like Himachal Pradesh, Uttarakhand, Madhya Pradesh, Rajasthan, Jharkhand and North-Eastern region of India have not been influenced much by the modern inputs of agriculture like chemical fertilizers and pesticides. On the other hand, it has been proved scientifically and convincingly that integrated use of organic manures with chemical fertilizers improves the use efficiencies of the latter owing to concurrent improvement of soil physical, chemical and biological properties. It is estimated that various organic resources having the total nutrient potential of 32.41 million tonnes will be available for use in 2025. To feed the projected population of 1.7 billion in 2050, 400 million tonnes of food need to be produced which is expected to require around 60 million tonnes of nutrients. Per hectare use of total nutrients ($N+P_2O_5+K_2O$) reduced from 160.1 kg in 2020-21 to 146.7 kg in 2021-22 (FAI, 2022). Similarly, per hectare use of chemical pesticides also reduced from 0.65 kg a.i ha^{-1} in 2021-22 to 0.48 kg a.i ha^{-1} in 2022-23 (DPPQS, 2023). This indicates that there is a movement towards agro-ecological farming in India supported by the Government in the form of organic farming (*Parambharagat Krishi Vikas Yojana*, Mission Organic Value Chain development for North-Eastern region), natural farming (*Bharatiya Prakritik Krishi Paddhati*, National Mission on Natural Farming) and integrated nutrient management (Soil health card). Conservative estimates indicate, around 15 million tonnes of nutrients can be shared through organic manures and other sources. Hence, niche area and crop approach for promotion of agro-ecological practices such as organic and natural farming is considered to be a viable and efficient option while in other areas (input intensive areas), agro-ecological practice of towards organic approach otherwise called as integrated crop management having components of integrated nutrient management, integrated water management, integrated weed management, integrated disease management and integrated insect management would be better in achieving the targets of food production besides ensuring sustainability in agriculture.

Natural Farming

Natural Farming (Bhartiya Prakratik Krishi Paddhati) is a way of chemical free farming based on livestock and locally available resources, with no chemical fertilizers and pesticides and rooted in Indian tradition. It is aimed at promoting traditional indigenous practices which gives freedom to farmers from externally purchased inputs (seeds to some extent, fertilizers, herbicides, insecticides, fungicides etc) and is largely based on on-farm biomass recycling with major stress on biomass mulching, use of on-farm livestock dung-urine formulations (concoctions); time to time working for soil aeration and exclusion of all synthetic chemical inputs directly or indirectly. Agroecological practices are an alternative to conventional high-input agriculture, resulting in better yields without compromising the needs of the future generation and avoiding intergenerational conflict. Natural farming is considered to be one of the agro-ecology practice and the UN Food Systems Summit, 2021 emphasized the scaling up of Agroecology as a game changing solution for farmers, citizens and the planet. Several other recommendations related to agroecology have come after global consultations to find alternatives to present forms of conventional agriculture, with their deleterious impacts on water, climate, nutrition and farmer well-being. Various countries have adopted such practices on a large scale to achieve the Sustainable Development Goals and simultaneously address issues of food security and climate Change. Sustainable agriculture practices involve mixed cropping, increase the diversity of crops produced and raise the diversity of insects, other animals & plants in and around the fields and promote microbial diversity and intensity in the soil. Further, these practices are aimed to increase the organic matter content of the topsoil, raising its ability to retain and store rainwater.

Food and Agriculture Organization (FAO) defined zero budget farming as the practice of agriculture without using any credit, and without spending money on purchased inputs. Natural Farming considered and often referred as low-budget or zero budget farming relies on livestock based on-farm inputs for nutrient and soil enrichment and various botanical concoctions for plant protection. These were initially thought to be main pillars and promoted as components of Natural Farming. However, the practices have evolved with time and farmers are also using innovations like Pre-Monsoon Dry Sowing or multi-variate cropping (a method of green manuring using different crop species), green manuring etc. along with the components of Natural Farming. Difference between organic and natural farming is given in Table 1.

Table 1. Differences in terms of concepts and practices between Natural and Organic Farming

Practices/inputs	Natural Farming (NF)	Organic Farming (OF)
Concept	NF mostly relies on on-farm inputs for nutrients, insect-disease management with mandated practice of multi-cropping (intercrop, cover crop, trap crop), mulching (soil and crop residue mulch), *Whapasa* and application of concoctions prepared from cow dung and urine.	OF allows use of off-farm inputs as per national standards for organic farming apart from on-farm inputs for nutrient, insect-disease management. Practices such as multi-cropping (intercrop, trap crop, cover crop etc), mulching etc are optional.
Cropping during summer/fallow	Multi-variate cropping / Pre-monsoon dry seeding with mixture of minimum of 9 crops of different crop types for biomass addition	Monocrop of green manures such as *Sesbania aculeata, Sesbania rostrata, Crotalaria juncea etc* are grown. Optionally, summer ploughing is also recommended for pest management.
Seed treatment	Seed treatment with *beejamrit* prepared using desi cow dung, cow urine, lime, virgin soil and water	Seeds are treated with bio-control agents such as *Trichoderma*, *Pseudomonas and* bio-fertilizers such as *Azospirillum, Azatobacter, PSBs etc*
Nutrient management	Application of an enriched microbial culture such as *jeevamrit* and *Ghana jeevamrit* prepared using desi cow dung, cow urine, jaggery, pulse flour and virgin soil as a microbial enhancer for native nutrient supply	Mainly through green manuring, legume crops, biofertilizers, vermicompost, enriched composts, VAM, panchagavya, cow urine, non-edible oilcakes, effective microorganisms (EM) consortium cultures and biodynamic (BD) formulations (BD-501, BD-502 etc).
Plant protection	Pest and disease control are carried out using bio-formulations such as Neem Seed Kernel Extract, *Neemaster, Brahmaster, Agniaster, Dashparni ark,* Butter milk etc., prepared from desi cow urine, cow dung, tobacco, green chilli, garlic; neem, karanj, custard apple, castor & datura leaves and water etc.	Pest and disease control is primarily through bio-control agents such as *Pseudomonas spp., Trichoderma* spp., *Trichogramma* spp. etc; Bio-pesticides like Neem based formulations, plant based extracts, pest repellent plants (trap crops) on the ridges and borders; and using Yellow / blue sticky traps etc. light traps and Inter-cultivation practices.
Standards and certification	No Standards and certification system is available as of now. However, committee has been constituted for defining standards and certification process.	National Programme for Organic Production (NPOP) standards having equivalence with European Union, USDA and Switzerland standards. PGS and Third party certification exists.

Research Status

Indian Council of Agricultural Research through ICAR-Indian Institute of Farming Systems Research, Modipuram initiated All India Network Programme on Organic Farming during 2004-05 to establish long-term experiments on organic farming and develop package of practices for organic farming. This network programme covers 16 States by involving 10 State Agricultural Universities, 8 ICAR Institutes and 1 Special heritage university. Over the years, organic farming packages for 72 cropping systems have been developed besides identification of suitable varieties, development of 8 integrated organic farming system models for 7 states and documenting the best practices of organic farmers. Case studies from organic farming interventions under the scheme in States like Sikkim, Meghalaya, Tamil Nadu, Kerala and Rajasthan are highlighted in the nature day event of Conference of Parties (CoP 26) during 2021. In addition, experiments on natural farming were also initiated from *kharif* 2020 at 20 locations in 16 states covering 8 major cropping systems where in complete natural farming practices are compared with other agroecological practice such as organic farming and integrated crop management. Centre for Science and Environment (CSE) during 2022 highlighted the holistic benefits of organic and natural farming based on the experimental evidences particularly on organic farming generated during a period of 2004 to 2020 under All India Network Programme on Organic Farming and published as "Evidence (2004-2020) on holistic benefits of organic and natural farming in India" (Amit Khurana *et al.*, 2022). Ravisankar *et al.,* (2021) documented the organic farming research in India: potential technologies and way forward.

Agroecological Benefits of Organic and Natural Farming

Soil physical and chemical properties: Data from 74 cropping systems were used for analysis concerning different benefits obtained under organic farming. Organic approach is better than integrated and inorganic approach. It is also evident that bulk density is more favourable with integrated approach than with inorganic approach across all the locations and cropping systems. Long-term trends with organic approach indicate that soil bulk density is lowest throughout at Dharwad, Jabalpur, Raipur, Umiam, Narendrapur and Sardarkrushinagar. Soil organic carbon is consistently highest with organic farming at all locations and cropping systems. Among all three approaches of crop production namely organic, integrated and inorganic, it is evident that organic carbon in soil is much better with organic approach than with integrated and inorganic approaches. It is also evident that organic carbon increase is more in integrated approach than inorganic approach. Long-term trends at 16 centres indicate that by and large, organic carbon is consistently highest with organic approach at all centres. These centres are Bajaura, Bhopal, Calicut, Coimbatore, Dharwad, Jabalpur, Karjat, Ludhiana, Modipuram, Pantnagar, Raipur, Ranchi, Ajmer, Umiam, Narendrapur and Sardarkrushinagar. Soil organic carbon improvement under natural farming was also observed in Natural Farming during the initial 3 years of experimentation.

Deficiency in soil nitrogen is major limiting factor in crop production. Results of the study indicate that the five-year mean available nitrogen with organic approach is higher than inorganic in 74 per cent of cropping systems. Within these, it is significantly higher in 12 per cent cropping systems. Similarly, mean available nitrogen with integrated approach is higher than inorganic in 62 per cent cropping systems. Long-term trends indicate that available nitrogen with organic approach is highest throughout at Bhopal, Dharwad, Jabalpur, Karjat, Ludhiana and Ranchi. At Coimbatore, Pantnagar, Umiam, Calicut, Modipuram and Sardarkrushinagar it is highest either in initial or the last few years.

Out of 62 cropping systems at 16 centres for which available phosphorus was recorded, mean available phosphorus is highest in 58 per cent cropping systems at 13 locations with organic approach. It is highest in 23 per cent with integrated approach at eight locations. The five-year mean available phosphorus with organic approach is higher than inorganic in 74 per cent cropping systems. Long-term trends with organic approach indicate that available phosphorous is highest throughout at Bhopal, Dharwad, Jabalpur, Karjat, Ludhiana, Modipuram and Ajmer. At Bajaura, Calicut and Sardarkrushinagar, it is highest either with organic and integrated approach. Similarly, Long-term trends with organic approach indicate that available potassium in soil is highest throughout at Dharwad, Jabalpur, Karjat, Ludhiana, Modipuram, Ranchi, Ajmer and Sardarkrushinagar. At Coimbatore, it is highest with organic approach except in the last few years. At Umiam and Narendrapur, it is mostly highest with integrated approach. At Bajaura, it is highest in later years with integrated approach.

Soil biological properties: Among all three approaches, out of 32 cropping systems at eight centres for which microbial parameters were observed, mean bacterial count is highest in 84 per cent cropping systems with organic approach at all centres. In 13 per cent, it is highest with integrated approach. The five year mean bacterial count with organic approach is higher than inorganic in 91 per cent cropping systems. Mean fungi population is highest in 72 per cent cropping systems with organic approach at seven centres. In 12 per cent, it is highest with integrated at two centres. The five-year mean fungi with organic approach is higher in 78 per cent cropping systems. Among all three approaches, out of 32 cropping systems, mean soil actinomycetes are highest in 69 per cent cropping systems with organic approach at all centres. In 25 per cent, they are highest with integrated approach at three centres. The five-year mean soil actinomycetes with organic approach are higher than inorganic in 84 per cent cropping systems. Similar trend was also observed for phosphorus solubilizing bacteria. Collectively, mean values of bacteria, fungi and soil actinomycetes with organic approach are higher than with inorganic approach in 21 cropping systems (about 66 per cent).

Food quality and nutrients: Actual values of 28 different food quality and nutrient parameters in 15 crops cultivated with three approaches and six methods under the AI-NPOF in 2018–19 was compared. These crops were from five food groups i.e. vegetables, oilseeds, pulses, spices and cereals. Compared with inorganic approach, across 51 sets of test results, in 67 per cent cases, results are higher with organic approach and in 64 per cent cases they are higher with integrated approach.

Yield: The consolidated evidence reflects that, out of the 504 times that yield results were recorded during 2014–19, 41 per cent of the times yields were highest with organic approach, followed by 33 per cent with integrated approach. When five-year mean yields are compared, in 27 out of 31 crops (87 per cent) yields were higher with organic approach than with inorganic approach as part of one or more cropping systems. Out of this, in 14 crops (52 per cent), the mean yield was significantly higher (>20 per cent). Yield obtained under natural farming experiments over a period of two years indicate that yield of legume (soybean/cowpea) and tuber (cassava) based cropping systems are either better or comparable with that of integrated crop management.

Natural enemies: Diversity in crops is a key factor in agricultural systems in India during earlier years. It provided stability and resilience to the systems as well as economic security to the farmers. However, after the introduction of modern technology, more emphasize upon high yielding varieties focused on single species. This resulted in the erosion of genetic diversity base of agro-ecosystems. Many research studies have proved that improvement in genetic-diversity under organic and natural farming. Significant improvement in population of *coccinelids, syrphids, micromus, chrysopa, spiers etc* were observed under organic farming than conventional production system.

Other benefits: Organic and Natural Farming also extends other set of agro-ecological benefits such as minimum energy use, water pollution, maintaining bio-diversity, better ecosystem services, employment for workers, reduced exposure to pesticides, minimum pesticide residues, reduced soil erosion, reduced nutrient loss due to erosion, more storage of water in soil, and improved nutritional quality for livestock and human population.

Scope

Success stories of natural farming from different states of India have been documented by NITI Aayog (NITI, 2022). Natural farming with set of agro-ecological practices can improve the sustainability in farm income by reducing the paid-out costs. However, area and crop specific approaches needs to be emphasized while adopting and promoting natural farming. Initial research findings clearly indicates that yield, income and soil health related advantages especially in legume and tuber crop-based cropping systems in hills, rainfed and partially irrigated areas. In addition to application of Jeevamrit and Ghanjeevamrit, farmers are using FYM, Neem cake, panchagavya, fish amino acid for nutrient management, yellow sticky traps, pheromone traps, neem seed kernel extracts, neem oil, plant extracts, bio-control agents such as Trichoderma, Pseudomonas for pest management and drip irrigation method of water management. In Himachal Pradesh, cost of cultivation was reported to be lower under natural farming as mainly horticultural crops like apple, other fruits and vegetables are grown. The major gap in respect of natural farming is found to be no standard package practices are being adopted by farmers and varies significantly among the farmers even in the same villages. Therefore, area and crop specific standardization of packages are essential for promotion of natural farming.

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NATURAL FARMING TO ENSURE SUSTAINABILITY IN AGRICULTURE

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In our country, farming is not just an occupation but a way of life. However, the agricultural sector is currently grappling with numerous challenges, including the excessive use of chemical fertilizers, pesticides, and the over-exploitation of underground water (blue water). These issues are compounded by the challenges posed by changing climate scenarios. In the post-independence era, traditional agricultural practices were initially predominant. However, as time progressed, the landscape of agriculture has transformed, and the sector has witnessed a shift towards more modern and technologically intensive methods. This evolution has brought with it both opportunities and challenges that require careful consideration and sustainable solutions to ensure the long-term health and productivity of our agricultural practices

Traditionally, small Indian farms thrived on sustainable practices that included windbreaks, organic husbandry, crop rotation, and leaving fields fallow for extended periods to preserve soil nutrients. These practices not only reduced the pressure on land but also maintained soil equilibrium. A variety of crops such as rice, millets, sorghum, wheat, maize, and barley were cultivated, with times when rice and millets collectively surpassed the production of wheat, barley, and maize combined. India's food grain production was 50.8 million tonnes at the time of Independence. The Green Revolution in the 1960s introduced high-yielding varieties and chemical fertilizers and boosted grain production to 308.65 million tonnes in 2020-21. However, the Green Revolution led to a reduction in the diversified gene pool.

Soil fertility has declined due to mismanagement and overuse of chemical fertilizers and pesticides, which has led to infertile soil, depletion of groundwater, increased cultivation expenses, and distress for farmers. It's important to address these challenges and adopt sustainable agricultural practices. Coarse grains are a great source of protein, essential vitamins and minerals, and amino acids like methionine and cysteine that our diets used to rely on. However, with time, there has been a shift in dietary patterns, and the consumption of processed foods has increased. The focus has shifted towards more cereals and fewer coarse grains, along with a decrease in the intake of foods of animal origin, fruits, and vegetables. This shift has led to a deficiency in micronutrients in Indian diets, particularly in iron, zinc, calcium, vitamin A, folate, and riboflavin. The consequences of such deficiencies include conditions like anaemia, keratomalacia leading to blindness, and fertility issues. It is crucial to raise awareness about the nutritional value of coarse grains and promote a more balanced and diverse diet that includes a variety of foods to address these micronutrient deficiencies and ensure overall health and well-being.

Natural Farming

Natural Farming represents a chemical-free agricultural approach deeply ingrained in Indian tradition, further enriched by a contemporary understanding of ecology, resource recycling, and on-farm resource optimization. This method is recognized as an agroecology-based, diversified farming system that seamlessly integrates crops, trees, and livestock while promoting functional biodiversity.

At its core, Natural Farming relies on on-farm biomass recycling, placing significant emphasis on practices such as biomass mulching, the utilization of on-farm cow dung-urine formulations, and the maintenance of soil aeration. It distinctly excludes the use of all synthetic chemical inputs. This holistic approach is anticipated to reduce dependence on external inputs, marking it as a cost-effective farming practice. Moreover, Natural Farming holds promise for enhancing employment opportunities and fostering rural development.

What is Natural Farming?

Natural Farming is not merely a technique; rather, it is a perspective that encourages viewing ourselves as integral parts of nature rather than separate entities. It emphasizes the avoidance of manufactured inputs and equipment. Distinct from other agricultural approaches, Natural Farming shares connections with fertility farming, organic farming, and sustainable agriculture.

Natural farming is an agricultural approach that avoids the use of synthetic chemicals, instead relying on diverse farming systems rooted in agroecology, integrating crops, trees, and livestock. This method maximizes the utilization of functional biodiversity and promotes the use of on-farm inputs prepared by farmers. The indigenous breed of cow, such as the Desi cow, holds a crucial role within the natural farming system. Additionally, other cattle dung and urine are utilized in preparing concoctions that enhance natural or ecological processes within and around farms.

Aims and Objectives of Natural Farming

- Preserve natural flora and fauna
- Restore soil health and fertility and soil's biological life
- Maintain diversity in crop production
- Efficient utilization of land and natural resources (light, air, water)
- Promote natural beneficial insects, animals and microbes in soil for nutrient recycling and biological control of pests and diseases
- Promotion of local breeds for livestock integration
- Use of natural / local resource-based inputs
- Reduce input cost of agricultural production
- Improve economics of farmers

How Natural Farming is Done?

Natural farming represents a holistic and diversified approach that seamlessly integrates crops, trees, and livestock, thereby optimizing the functional biodiversity available. When implemented effectively, natural farming has the potential to enhance farmers' income and yield various benefits, including the restoration of soil fertility and environmental health, as well as the mitigation and reduction of greenhouse gas emissions. This method relies on building upon natural or ecological processes within and around farms.

One distinguishing feature of natural farming is the avoidance of both chemical and organic fertilizers in soil management. Instead, the approach encourages the natural decomposition of organic matter by microbes and earthworms directly on the soil surface, gradually enriching the soil with essential nutrients. Unlike traditional farming practices, natural farming abstains from ploughing, tilling of soil, and weeding. The promotion of a healthy soil microbiome aids in retaining and enhancing soil organic matter. Essential concoctions are employed to augment soil fertility, fostering a sustainable and naturally balanced agricultural ecosystem.

Natural farming Practices

Natural farming aims to restore soil health, maintain biodiversity, ensure animal welfare, emphasize the efficient use of natural/local resources, and promote ecological fairness. It is an ecological farming approach that collaborates with natural biodiversity, fostering the soil's biological activity, and managing the complexity of living organisms, both plant and animal, to thrive alongside the food production system. Key practices essential for adopting natural farming include:

- No external inputs
- Local seeds (use of local varieties)
- On-farm produced microbial formulation for seed treatment (e.g. bijamrita),
- On-farm made microbial inoculants (Jivamrita) for soil enrichment,
- Cover crops and mulching with green and dry organic matter for nutrient recycling and for creating a suitable microclimate for maximum beneficial microbial activity in soil.
- Mixed cropping
- Managing diversity on the farm through the integration of trees
- Management of pests through diversity and local on-farm-made botanical concoctions (viz., neemastra, agniastra, neem ark, dashparni ark etc.);
- Integration of livestock, especially of native breed for cow dung and cow urine as essential inputs for several practices and
- Water and moisture conservation

Following natural farming principles, plants derive 98% of their nutrients from the air, water, and sunlight, with the remaining 2% being supplied by high-quality soil teeming with beneficial microorganisms. To foster this, the soil is blanketed with organic mulch, promoting the creation of humus and fostering the growth of friendly microorganisms. Instead of conventional fertilizers, farm-made bio-cultures, including 'Jeevamrit,' 'Beejamrit,' and 'Ghanjeevamrit,' are introduced to enhance the soil's microflora. Jeevamrit and Beejamrit, derived from minimal cow dung and urine from the indigenous Desi cow breed, play a vital role in this system. The microbial content of cow dung and urine from Desi cows is considered purest for natural farming practices.

In natural farming, decomposition of organic matter by microbes and earthworms takes place directly on the soil surface, gradually enriching the soil with essential nutrients. Farm-made pesticides such as Dashparni ark, Neem Astra, Agni Astra, and Brahmastra are employed to manage pests and diseases in an eco-friendly manner. Weeds are recognized as essential components and are utilized as living or dead mulch layers.

Emphasizing diversity, natural farming advocates for multi-cropping rather than the conventional single-crop approach, promoting a more resilient and sustainable agricultural system.

Benefits of Natural Farming

Natural farming emerges as a comprehensive solution to a myriad of challenges, addressing issues like food insecurity, farmers' distress, health concerns linked to pesticide and fertilizer residues, global warming, climate change, and natural calamities. The manifold benefits of natural farming include:

Improved Yield: Farmers practicing natural farming report comparable or even higher yields per harvest compared to conventional farming.

Enhanced Health: By eschewing synthetic chemicals, natural farming eliminates health risks, resulting in food with higher nutritional density and improved health benefits.

Environment Conservation: Natural farming promotes healthier soil biology, increased agrobiodiversity, and responsible water use, contributing to smaller carbon and nitrogen footprints.

Increased Farmers' Income: By making farming more viable and aspirational, natural farming boosts farmers' net incomes through cost reduction, minimized risks, similar yields, and additional income from intercropping.

Employment Generation: Natural farming generates employment opportunities through input enterprises, value addition, and local marketing, reinvesting surpluses back into the village.

Reduced Water Consumption: Natural farming optimizes water use through diverse crops that mutually benefit each other and ground cover to minimize unnecessary evaporation, achieving more crop yield per drop.

Minimized Cost of Production: Encouraging the use of on-farm, natural, and home-grown resources for essential biological inputs helps significantly reduce production costs.

Elimination of Synthetic Inputs: Natural farming rejects synthetic fertilizers, pesticides, herbicides, and weedicides, preserving soil biology, structure, and organic carbon.

Rejuvenated Soil Health: The immediate impact of natural farming is felt in soil biology, fostering the well-being of microbes and organisms like earthworms, vital for maintaining soil health.

Livestock Sustainability: Integrating livestock into the farming system, with eco-friendly bio-inputs like Jeevamrit and Beejamrit derived from cow dung, urine, and natural products, plays a crucial role in ecosystem restoration.

In essence, natural farming emerges as a holistic and sustainable approach, addressing multifaceted challenges while promoting the well-being of farmers, ecosystems, and communities.

What is the nation doing?

Recognizing the knowledge-intensive nature of natural farming and the need for widespread training and capacity building, the Government of India has launched the National Mission on

Natural Farming (NMNF). Several states across the country have embraced natural farming practices, with notable initiatives in states like Andhra Pradesh, Chhattisgarh, Kerala, Gujarat, Himachal Pradesh, Jharkhand, Odisha, Madhya Pradesh, Rajasthan, Uttar Pradesh, and Tamil Nadu.

Various states have implemented distinctive programs, such as the Andhra Pradesh Community-Managed Natural Farming (APCNF) by Rythu Sadhikara Samstha (RySS) and the Prakritik Kheti Khushhal Kissan (PK3) Yojana in Himachal Pradesh. Each state's policies narrate a unique story, reflecting their individual approaches, yet all share a common commitment to fostering sustainable and natural farming practices.

Conclusion

Natural farming blends traditional wisdom with modern science to promote ecological balance, conserve biodiversity, and reduce greenhouse gas emissions. It also promotes economic sustainability for smallholder farmers and aligns with multiple Sustainable Development Goals.

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LOW BUDGET NATURAL FARMING: OPPORTUNITIES AND CHALLENGES

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India has become self-reliant in food production after successful adoption of high input intensive technologies. However, indiscriminate and increased use of commercial inputs led to adverse impact on ecosystem. In this adverse condition, food grain production of India in present scenario has almost reached its zenith in recent years. According to many experts, modern chemical agriculture has negative effects on soil health and productivity in long run. Use of high cost commercial inputs and chemicals only escalates cost of production and makes agriculture non-viable especially for small and marginal holders. The excessive use of modern high input responsive technologies, soil and water contamination with pesticides and chemicals caused enough degradation on ecosystem which led to again going back with basic natural farming approach. Further, farmers are forced to remain trapped in debt by taking credit from easily available but high interest charging non –institutional sources for purchase of high cost inputs. According to National Sample Survey Office (NSSO) survey report, nearly 43.4 million (48.6%) rural farmer households are indebted in the country and of them about 80 per cent were small and marginal farmers.

Natural farming is a farming approach emphasizing the importance of producing crops along with animals particularly, indigenous cow so that synergistic effects of different parts of the system can be used, relying on easily available 'ingredients' to produce crop treatments on-farm, and microorganisms to build soil fertility (FAO, 2019). The approach is built on the 'four pillars' of Low Budget Natural Farming (LBNF) (1) stimulation of microbial activity to make nutrients available to plants and protect against pathogens using a microbial inoculum, '*jiwamrit*' (liquid) and '*Ghanajiwamrit'* (solid) (2) another source of plant protectants using microbial inoculum, '*Bijwamrit*' (3) production of stabilized soil organic matter and conservation of top-soil by mulching ('*acchadana*') and (4) soil aeration ('*whapahasa*') by improving soil structure and reducing tillage. Low budget natural farming requires only 10% water and 10% electricity than conventional farming system. LBNF is an innovative method of farming referred as 'back to the basics' or root of the farming. It is perceived that adoption of LBNF leads to elimination of use of commercial inputs which in turn causes significant reduction in cost of production. Reduction in cost of production can have favourable implications for farmers especially in terms of breaking their vicious cycle of debt. Hence, LBNF can prove to be an alternate farming system possessing sustainable and ecofriendly attributes and also produces chemical free food in minimal/zero investment having positive implications on human health.

Low Budget Natural Farming

Low budget natural farming (LBNF) as the name suggests, is a method of natural farming where cost of production will be negligible (FAO, 2016). Also known as *'Zero Budget Spiritual Farming*' it involves traditional agricultural practices which require no cost inputs, available in farm itself, nothing to be purchased from the outside. Here, naturally available inputs from farm itself are used for growth of the plants, to improve soil productivity and crop yield. LBNF is an age old natural agricultural system adopted by our ancestors over the past several centuries. But due to population pressure and growing food demand, more importance was given to increasing food production than achieving sustainability and environmental concerns and as a consequence the significance of natural farming has narrowed down. The system of natural farming was popularized by Japanese scientist Masanobu Fukuoka with four broad principle of farming viz., no till, no fertilizer, no weeding and no pesticides (Tripathi *et al.,* 2018). In India, Zero Budget Natural Farming, which is now Low Budget Natural Farming, was popularized by Subhash Palekar, a farmer-scientist and agriculture graduate from Maharashtra.

The movement of LBNF was first started in Karnataka state in collaboration with Subhash Palekar and Karnataka State Farmers' Association (KSFA), a member of La Via Campesina (LVC) [1] (FAO, 2016). This movement was composed of all section of rural farmers and urban members and spontaneously spread across the farming community (Khadse *et al*., 2017). KSFA was pivotal in scaling of LBNF in Karnataka. Further, the large spread of LBNF was collective effort from peasant members and movement allies and spread to other parts of country (Khadse & Rosset, 2019). Realizing the importance of LBNF, Andhra Pradesh also initiated Zero-Budget Natural Farming (APZBNF) programme through Rythu Sadhikara Samstha (RySS)[2]. A pilot project was conducted in 2016 across the 704 villages of the states as a result around 10,000 farmers successfully adopted ZBNF (RySS, GoAP).

Pillars of ZBNF

Low budget natural farming is based on sustainable agro-ecological system approach which helps in balancing the ecosystem. The principles of LBNF were developed by Subhash Palekar who is popularly known as '*Krishi ka Rishi'* and also *'Father of zero/low budget natural farming'*. LBNF addresses two major issues of Indian agriculture: first, the agro-ecological principles and other farming practices of LBNF enhance the soil fertility (Palekar, 2006), and secondly, creates autonomy of farmers by de-linking of farmers from the vicious cycle of debt by not purchasing high-cost inputs from external agencies (Rosset and Torres, 2012). The four driving wheels of ZBNF described by Subhash Palekar are Jivamrita, Bijamrita, Acchadana and Whapahasa (Fig.1). ***Jivamrita*** is a fermented mixture of microbial culture prepared from cow dung and urine, jaggery, pulse flour, water and soil. It stimulates beneficial microbial activity and adds nutrients to the soil.Further, several field experiments confirmed that jivamrita enhances physiological growth and yield attributes of the crops (Table 1). According to Subhash Palekar, about 500 liters jivamrita is required per hectare of land and should be sprayed twice in a month and a single cow sufficient for 12 hectares of land. ***Bijamrita*** is prepared from cow dung, urine, and lime and used for microbial coating of seeds to protect from insects, pests and soil borne diseases. Study conducted by Vyankatrao (2019) confirms that when legume seeds are treated with Bijamrita showed high germination rate, seedling growth and seed vigour index (Table 2).

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[1] La Via Campesina is an international movement brings together peasants, small and medium size farmers, landless people and agricultural workers from around the world.
[2] Not-for-profit organization established by GoAP.

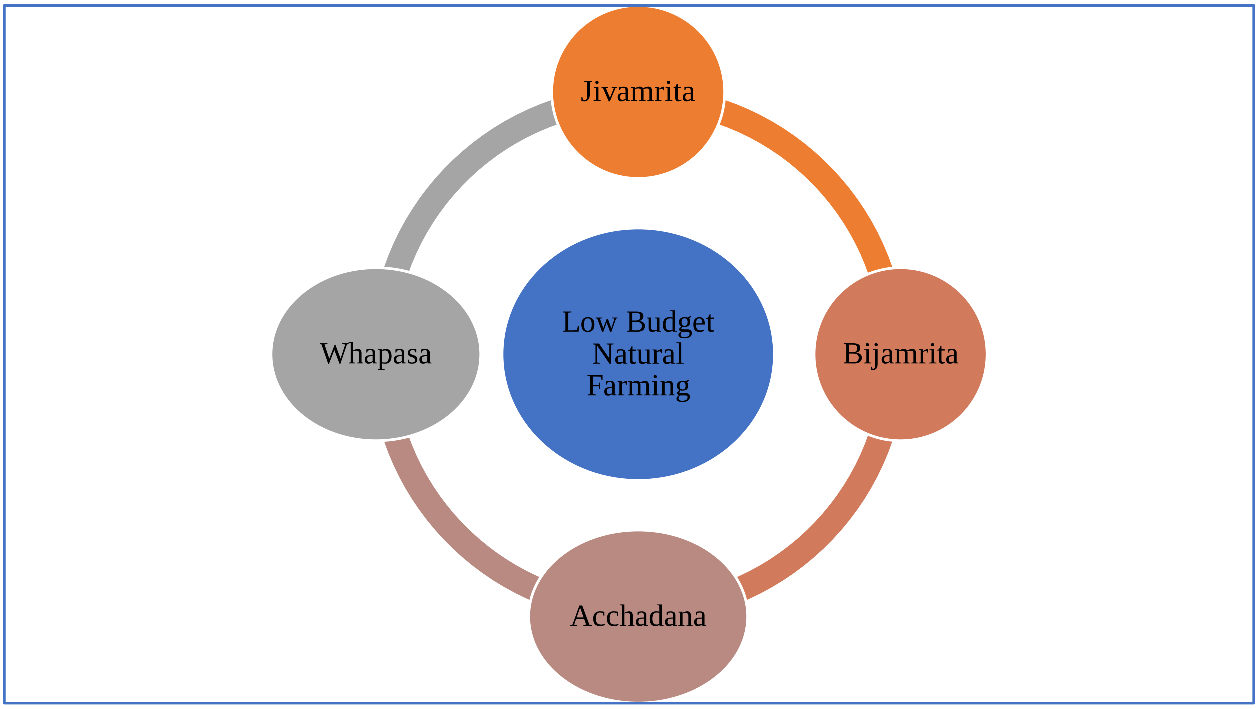

Fig. 1 Four Wheels of LBNF

Table 1 Effect of Jivamrita on crop yield

Author	Location	Crop	Yield(t/ha)		
			T_0	T_1	Difference
Sharvan et al (2018)	Moradabad (Uttar Pradesh)	Cauliflower	21.49	24.49	3.00 (13.96)
Sharvan et al (2019)	Moradabad (Uttar Pradesh)	Cabbage	25.55	34.95	9.40 (36.79)
Boraiah et al (2017)	Arsikere (Karnataka)	Capsicum	2.52	3.09	0.57 (22.62)
Boraiah et al (2017)	Arsikere (Karnataka)	Capsicum	3.02	3.79	0.77 (25.46)
Boraiah et al (2017)	Arsikere (Karnataka)	Capsicum	3.64	4.68	1.05 (28.80)
Boraiah et al (2017)	Arsikere (Karnataka)	Capsicum	10.08	11.45	1.37 (13.46)
Boraiah et al (2017)	Arsikere (Karnataka)	Capsicum	7.88	9.64	1.76 (22.28)
Boraiah et al (2017)	Arsikere (Karnataka)	Capsicum	7.38	8.33	0.96 (12.98)
Boraiah et al (2017)	Arsikere (Karnataka)	Capsicum	3.84	4.81	0.97 (25.36)

Note; T_0=Control (Without Jivamrita); T_1= Treated (With Jivamrita) and Values in parenthesis indicates percent change).

Table 2 Effect of bijamrita on germination and seedling growth on legume crops

Crop	Treatment	Germination (%)	Root Length (cm)	Shoot length (cm)	Seedling Length (cm)	Seed Vigor Index
Moth bean	T0	83	1.94	3.48	5.42	450
	T1	95	2.84	4.26	7.1	675
Green gram	T0	97	2.39	3.12	5.51	534
	T1	85	1.62	2.54	4.16	354
Ground nut	T0	81	5.7	2.75	8.45	684
	T1	93	11.74	6.48	18.22	1694

Source; Vyankatrao, 2019; Note: T_0=Control (Without Bijamrita) and T_1= Treated (With Bijamrita)

Acchadana (Mulching) is nothing but covering the soil with crop residues and cover crops to conserve soil moisture, to enhance water retention capacity and to prevent weeds. The field study support the fact that mulching has increased yield and water use efficiency of crops than no-mulching (Table 3).

Table 3 Effect of mulching on yield and water use efficiency (WUE) of crops

Study	Location	Crop	Yield (tonn/ha)		WUE(kg $ha^{-1}mm^{-1}$)	
			T0	T1	T0	T1
Chakraborty et al (2008)	New Delhi	Wheat	4.20	5.140	8.73	12.79
Chakraborty et al (2008)	New Delhi	Wheat	3.73	4.10	9.70	10.29
Kar et al (2007)	Dhenkanal (Orissa)	Potato	3.46	6.00	9.31	20.32
Kar et al (2007)	Dhenkanal (Orissa)	Potato	6.75	8.99	15.66	26.06
Kar et al (2007)	Dhenkanal (Orissa)	Potato	9.00	12.81	18.41	33.27
Kar et al (2007)	Dhenkanal (Orissa)	Potato	11.20	14.93	21.05	34.16
Dash et al(2018)	Bhubaneswar	Potato	19.293	20.218	43.70	45.80

Note: T_0= Without Mulch and T_1= With Mulch

Whapasa (Moisture/Soil aeration) is the changes in water management where air and water molecules present in the soil helps to increase water availability and water use efficiency (FAO, 2016; Khadse & Rosset, 2019). Intercropping, construction of contour and bunds to harvest rainwater, use of local species of earthworms are the other important principles of LBNF (FAO, 2016).

Current status of implementation and recent policy initiatives

According to Economic survey 2018-19, more than 1.6 lakh farmers are practicing LBNF under different schemes like RKVY, Paramparagat Krishi Vikas Yojana etc. Finance minister, Government of India announced to promote and scaling up of LBNF to different parts of the country.

Table 4 Implementation of ZBNF in different states of India

States	Current status of Implementation
Andhra Pradesh	All the 13 districts
Karnataka	Implemented in 10 agro-climatic zones
Kerala	Implemented in Wayanad, Palakkad, Thrissur and Ernkulam
Punjab	Adopted in 1000 Acres
Himachal Pradesh	Implemented across the state under Prakartik Kheti-Khushal Kisan scheme
Haryana	Adopted in 80 acres in Kurukshetra District

Source: https://timesofindia.indiatimes.com

However, there is no actual allocation of new funds, states has to utilize funds from schemes like Rashtriya Krishi Vikas Yojana-Remunerative Approaches for Agriculture and Allied sector Rejuvenation (RKVY-RAFTAAR) and Paramparagat Krishi Vikas Yojana to promote LBNF. Andhra Pradesh after successful implementation of LBNF on pilot has planned to cover all the districts and become India's first State to adopt 100% natural farming by 2024 (Jebaraj, 2019). After positive impact several other states also planned to implement of LBNF, details are given below in table 4.

Challenges of LBNF

Low budget natural farming has started drawing attention of the Government due to its potential economic and environmental benefits. However, many experts/critiques have skeptical view on performance and efficacy of LBNF model. Only limited studies are available to claim that LBNF leads to significant reduction in input costs and increase in yield. Further, assessment of LBNF method is done by Palekar himself, independent and comprehensive economic assessment studies are still not available (EPW, 2019). Several reports also suggest that returns under LBNF started declining after few years of adoption, which raises uncertainty towards strengthening of farmers' income. It is also said that LBNF model is not suitable to marginal farmers since availability of land is limited. Some farmers also had opinion that cost production is not zero in LBNF as they have to spend on inputs like irrigation, machineries and tools.

According to experts and experiments, the benefits of LBNF extracted only by middle peasantry section, while inclusion of small and marginal farmers' remains wrangling. Further, marketing of LBNF produce is the serious cause of concern, very limited markets are available in the country. On the issue of profitability, it is reported that many farmers reverted to conventional farming after few years of adoption of LBNF (EPW, 2019). According to experts, immense potential social, economic and ecological benefits are derived from LBNF, however, studies limited studies are available to establish the facts of potential benefits of LBNF.

Way forward

LBNF though has immense economic and environmental benefits, requires error- free policies towards its implementation. The extensive field studies need to be conducted to gather evidences and facts on benefits of LBNF as well as for standardization of application rates for various crops. Initially, efficacy of model should be validate on pilot basis before taking up country-wide adoption. In-depth scientific multi-location studies are required to assess economic viability and long term impact of LBNF before scaling up. Further, sound institutional mechanisms needs to be created to overcome the hurdles for adoption of LBNF.

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ROLE OF ENDOGENOUS EARTHWORM SPECIES IN NUTRIENT TRANSFORMATION

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The role of endogenous earthworm species in nutrient transformation represents a dynamic and intricate interplay within soil ecosystems. These humble organisms, often overlooked, play a crucial role in shaping the nutrient cycling processes that underpin the health and productivity of soils. Ecosystem services encompass a diverse range of direct and indirect advantages offered by natural ecosystems to promote the well-being of human societies, contributing significantly to the economic value of the planet. Earthworms, recognized as 'keystone species' and labeled as 'ecosystem engineers' since 1994, play a pivotal role in the soil-forming process. Referred to as 'ecosystem services managers,' they establish a potential symbiotic relationship with humans. Earthworms are classified into three primary ecological groups based on the services they provide and their impact on ecosystem processes. Epigeic species, the most common, enhance soil roughness and create macro-pores by dwelling in litter and producing casts at the soil surface. Anecic species, on the other hand, live in vertical burrows that extend into the soil layers. Lastly, endogeic species, the third category, form horizontal or randomly oriented burrows throughout the upper soil layers while feeding on decaying organic matter.

Earthworms play a crucial role in boosting crop yield, with their impact contingent on factors like crop residue, earthworm density, and fertilization rate. They perform various functions by sustaining life through the regulation of bio-geochemical cycles and other biosphere processes, including decomposition, climate regulation, pollution remediation, and interactions with biodiversity. Furthermore, the life processes of earthworms contribute to several services vital for the operation and self-sustainability of agroecosystems. These services encompass primary production, nutrient cycling, development of soil structure, and functions related to soil hydraulic systems, among others. The content will discuss the biology of earthworms, the mechanisms by which they contribute to nutrient transformation, and the broader ecological implications of their activities.

Earthworm Diversity and Adaptations: Earthworms, classified under the phylum Annelida, exhibit remarkable diversity in terms of species and adaptations to different environments. While there are numerous earthworm species globally, we focus on endogenous species, those native and well-adapted to their respective habitats.

Endogenous earthworms have evolved specific adaptations that enable them to thrive in various soil conditions. Their segmented bodies, covered in setae, or tiny bristle-like structures, aid in locomotion and burrow construction. These adaptations allow them to navigate through soil, creating a complex network of burrows and channels that serve multiple ecological functions.

- **Aeration**: Earthworms burrow through soil, creating channels that enhance aeration. Improved oxygen levels facilitate the activities of aerobic microorganisms responsible for decomposing organic matter and transforming nutrients.
- **Mixing**: Earthworms ingest soil along with organic matter, which passes through their digestive system. During this process, organic matter is broken down into simpler compounds, and minerals are released from soil particles. The mixing action of earthworms helps distribute organic matter and nutrients more evenly throughout the soil profile.
- **Soil Structure Improvement and Water Regulation:** Earthworms are renowned for their role as soil engineers, shaping the physical structure of the soil through their burrowing activities. The creation of burrows and channels improves soil structure in several ways. Firstly, earthworm burrows increase soil porosity, allowing for better water infiltration and root penetration. The channels created by earthworms serve as conduits for water movement, reducing the risk of waterlogging in saturated conditions. This has implications for plant health, as adequate water drainage is essential for preventing root suffocation and facilitating nutrient uptake. Secondly, the burrowing activities of earthworms contribute to soil aggregation. The mucus produced by earthworms as they move through the soil binds soil particles together, creating aggregates. Soil aggregation improves soil stability, prevents erosion, and enhances the overall structure of the soil. Earthworms mitigate soil erosion, counteract soil compaction by improving water infiltration as well as gas exchange and thus, improve plant growth (Andriuzzi *et al*., 2015).
- **Organic Matter Decomposition and Cast Formation**: The primary ecological service provided by earthworms is their role in organic matter decomposition. Earthworms are detritivores, feeding on a variety of organic materials such as decaying plant matter, leaves, and other debris found in the soil. This consumption initiates a series of processes that result in nutrient-rich cast production. As earthworms ingest organic matter, it undergoes physical and chemical breakdown within their digestive systems. Enzymes produced by both earthworms and associated microorganisms facilitate the decomposition of complex organic compounds into simpler forms. These casts act as concentrated reservoirs of plant-available nutrients, effectively transforming organic matter into a more accessible form for vegetation.
- **Nutrient Cycling and Availability:** The nutrient-rich casts produced by earthworms contribute significantly to nutrient cycling in soil ecosystems. These casts, often deposited on the soil surface or incorporated into the soil through burrowing activities, serve as sources of essential nutrients for plants. Earthworms significantly altered the relative abundance of some microbes associated with the soil N and P cycles (*Flavobacterium*, *Pedobacter*, *Streptomyces*, *Bacillus*, *Bacteroidota*, *Actinobacteria* and *Firmicutes*). This was consistent with the pattern found in the significantly changed metabolites which were also involved in the microbial N and P metabolism (Fig. 1).

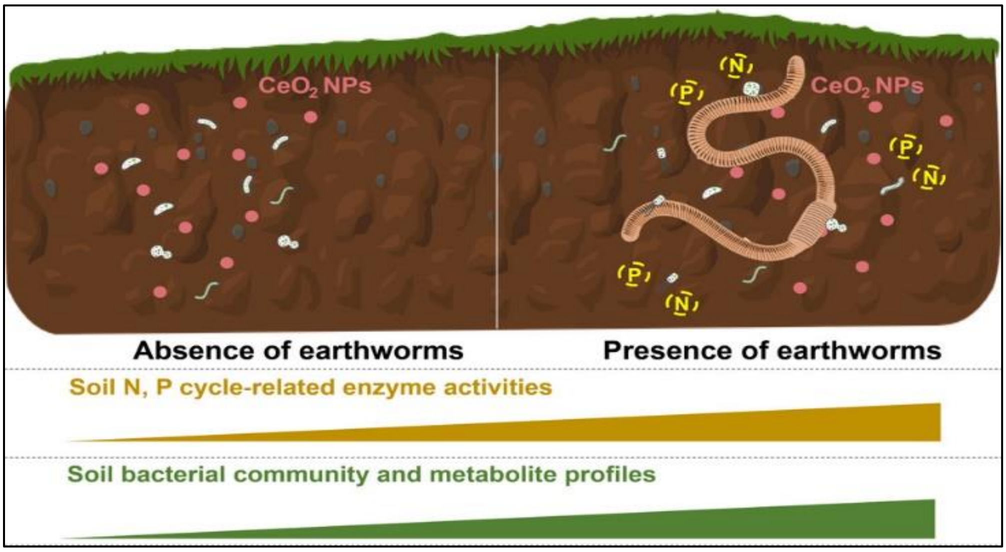

Fig. 1: Role of Earthworms in soil N and P cycle related enzymes

- **Effect on macro-nutrients:** Earthworms improve the organic matter mineralization in the soil and consequently increase the amount of nitrogen in the soil, as of superior nitrification in earthworm casts. In terrestrial ecosystems, a major amount of nitrogen can bypass directly through earthworm biomass. Up to 60-70 kg nitrogen per ha for one year was estimated to return to the soil in the form of dead. Earthworm tissues decompose rapidly and the nitrogen is mineralized readily. Due to the presence of nitrogen-fixing bacteria in the gut of earthworm and earthworm casts the nitrogen fixation in casts is relatively better than that in soil, which increases the activity of nitrogenase enzyme. Nitrogen undergoes transformation in the digestive systems of earthworms. Through microbial processes, organic nitrogen present in ingested material is converted into ammonium (NH_4^+) and nitrate (NO_3^{-1}) a form readily usable by plants (Fig. 2). This ammonification process is a vital component of the nitrogen cycle facilitated by earthworm activities. The highest nitrogen content in the earthworm treated bins was related to the difference in N-forms, in which conventional compost contains higher 'ammonium-N', while vermicompost tended to contain higher 'nitrates-N, the most available nitrogen form' (Suthar and Singh, 2008).

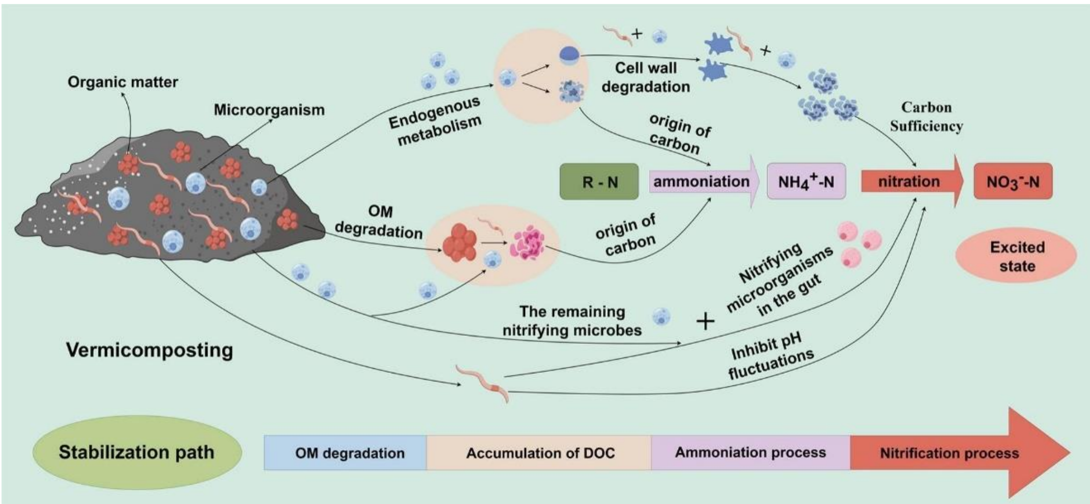

Fig 2. Earthworms mediated N mineralization pathway

Phosphorus, another crucial nutrient, experiences changes in its chemical form within earthworm guts. Earthworm casts contain more P than the soil without earthworms available in the surrounding area. Earthworms had a positive correlation with soil P accumulation in the soil. These increases in the amount of available P in earthworm digestibility may be due to increased phosphatase activity in the casts. Organic phosphorus compounds are mineralized into inorganic forms, enhancing the availability of phosphorus for plant uptake. Earthworms, therefore, contribute to the phosphorus cycle by transforming organic phosphorus into a form that plants can assimilate (Fig. 3).

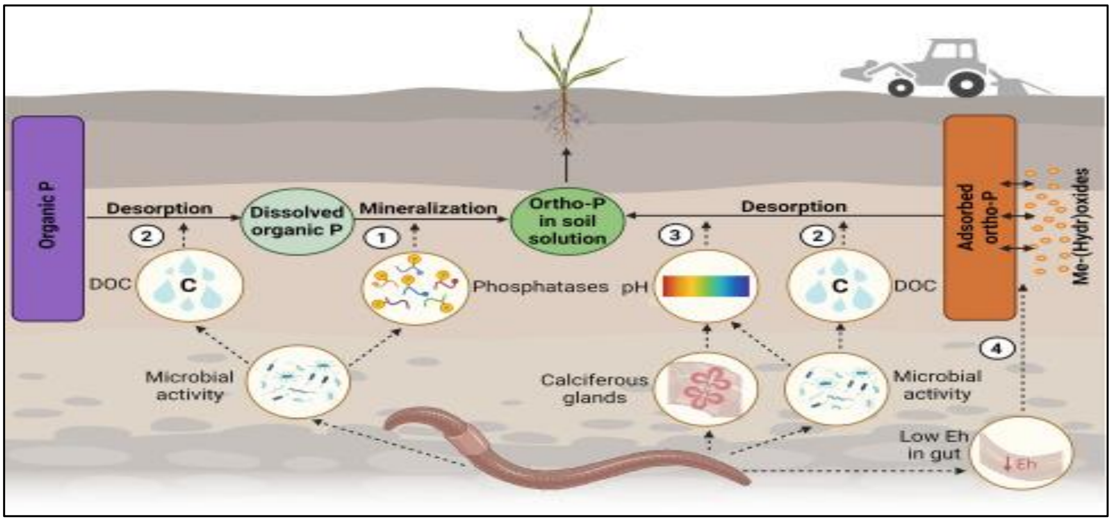

Fig 3: Earthworms mediated phosphorous transformation in soil

Apart from nitrogen and phosphorus, earthworms influence the availability of potassium and micronutrients in the soil. The casts they produce exhibit higher concentrations of these elements compared to the surrounding soil, indicating the transformative role of earthworms in nutrient cycling.

- **Effect on micro-nutrients :** The *Eisenia andrie* species was the top contributor with increases in Zn, Cu, Mn, B and Fe of 91 %, 1770 %, 1400 %, 4400 % and 361 %, respectively. These results indicate an accumulation of these micro-elements in the earthworm treated compost due to enhanced microbial activity in the earthworm's gut and the cast (Dey et al., 2019). These can prompt the release of available metabolites to enhance the rate of mineralization (Kaviraj and Sharma, 2003)

➢ **pH Regulation and Soil Chemistry:** In addition to nutrient cycling, earthworms play a role in regulating soil pH, a factor with profound implications for nutrient availability. The decomposition of organic matter in the digestive systems of earthworms results in the release of organic acids. These acids contribute to a mild acidification of the soil in the immediate vicinity of earthworm burrows. The localized changes in pH within earthworm burrows can influence the solubility of certain minerals, making them more available for plant uptake. While the overall impact on soil pH may be subtle, the microenvironments created by earthworm activities underscore the intricate ways in which these organisms shape soil chemistry.

- **Carbon Sequestration**: Earthworms can contribute to carbon sequestration by incorporating organic carbon into the soil through their feeding and casting activities. This helps mitigate climate change by storing carbon in the soil, thereby reducing atmospheric carbon dioxide levels.
- **Microbial Activity Enhancement:** Earthworms exert a significant influence on soil microbial communities, contributing to enhanced microbial activity and diversity. The interactions between earthworms and microorganisms are multifaceted, involving both direct and indirect mechanisms. The burrowing activities of earthworms create channels and pores in the soil, improving aeration and facilitating the movement of gases. This enhanced aeration is conducive to the growth and activity of aerobic microorganisms, which play key roles in nutrient cycling and organic matter decomposition. The casts produced by earthworms provide a rich substrate for microbial colonization. The microbial communities within earthworm casts are diverse, representing a dynamic consortium of bacteria, fungi, and other microorganisms. By promoting beneficial microbial species, earthworms indirectly enhance plant health and nutrient uptake. This interplay between earthworms and microorganisms highlights the interconnected nature of soil ecosystems and the collaborative efforts of different soil-dwelling organisms in nutrient cycling.
- **Residue Incorporation and Ecosystem Dynamics:** Earthworms contribute significantly to the incorporation of plant residues into the soil, a process that influences nutrient cycling and ecosystem dynamics. The consumption of plant debris by earthworms not only aids in organic matter decomposition but also ensures the efficient recycling of nutrients within ecosystems. In agricultural settings, earthworms play a vital role in managing crop residues. By consuming and incorporating residues into the soil, they contribute to the reduction of surface debris.
- **Conservation and Biodiversity Considerations:** Recognizing the pivotal role of endogenous earthworm species in nutrient transformation underscores the importance of conservation and biodiversity efforts. Earthworms, as key components of soil biodiversity, contribute to the overall health and functioning of ecosystems. Conservation measures that support earthworm populations can have cascading positive effects on soil fertility, plant health, and ecosystem resilience.

Conclusion

In conclusion, the role of endogenous earthworm species in nutrient transformation is a multifaceted and integral aspect of soil ecology. These unassuming organisms, through their interactions with organic matter, microorganisms, and soil structure, exert a profound influence on nutrient cycling, soil fertility, and ecosystem health. Earthworms, as ecosystem engineers, shape the physical and chemical properties of the soil. From organic matter decomposition and cast formation to pH regulation, microbial activity enhancement, and soil structure improvement, their contributions are diverse and interconnected. Recognizing the ecological importance of earthworms prompts a reevaluation of soil management practices. From organic farming and reduced tillage to the conservation of biodiversity, there are actionable steps that can be taken to support and enhance earthworm populations.

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AUTOMATION AND CONTROL IN AGRICULTURAL PROCESSING TECHNOLOGY

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The growing population and effect of climate change in India have put a huge responsibility on the agriculture sector to increase food-grain production and productivity. Advancement in digital technologies has made revolutionary changes in agriculture by providing smart systems that can monitor, control, and visualize various farm operations in real-time and with comparable intelligence of human experts. The potential applications of Internet of Things (IoT) and Artificial Intelligence (AI) in the development of smart farm machinery, irrigation, weed and pest control, fertilizer applications on fields, greenhouse cultivation, storage structures, drones for plant protection, crop health monitoring, etc. are the main concerns for the innovative and modern development. The main objective is to provide an overview of recent research in the area of digital technology-driven agriculture and identification of the most prominent applications in the field of agriculture engineering using artificial intelligence and internet of things. It may help in understanding how digital technologies can be integrated into agriculture practices and pave the way for the implementation of AI and IoT-based solutions in Indian agricultural farms.

Artificial Intelligence (AI): Artificial intelligence leverages computers and machines to mimic the problem-solving and decision-making capabilities of the human mind. It is the science and engineering of making intelligent machines, especially intelligent computer programs. AI technology is being increasingly integrated into farm machinery and automation systems. Machine learning algorithms can process vast amounts of data and provide actionable insights. AI-powered applications can recognize It is the ability of a computer or a robot controlled by a computer to do tasks that are usually done by humans because they require human intelligence and discernment. AI is the ability of software to solve problems and perform tasks that otherwise requires human intelligence. A common, well-established application of AI is identifying 'normal' or expected shapes, colours, patterns and so on and also therefore detecting deviances from these norms. Already, AI in robotic milking systems decides if a cow should be milked or not at a given time and reports to the farmer about disruptions to normal feeding patterns, milk quality and more. Some dairy farmers are now also using virtual fence systems, similar to technologies for pet dogs, where AI manages the movement of pastured cows to optimise pasture use. By incorporating the use of digital technologies like artificial intelligence and internet of things, better insights can be formed effectively from data gathered from the agricultural field and allowing farming practices to be planned systematically with minimal manual labor. Over the decades, the agriculture sector has realized the importance of precision farming. Precision farming is a sustainable alternative that will enhance production by providing a precise amount of inputs reducing the overuse of potential environmentally damaging pesticides and other inputs. Despite the challenges due to climate change and other factors, the digital technology driven agriculture provides a plethora of methodologies for automating and enhancing agriculture production and productivity. Digitization in agriculture enables real-time analysis that helps in more effective spraying, land management, water management, and even land surveillance. The use of emerging digital technology will allow the agriculture industry to achieve several other benefits such as reducing input costs and wastage, achieving sustainable practices along with enhancing productivity to meet the growing food demand. Digital technology driven agriculture is gaining more and more global attention due to the incredibly easy field management capability and powerful real-time monitoring systems.

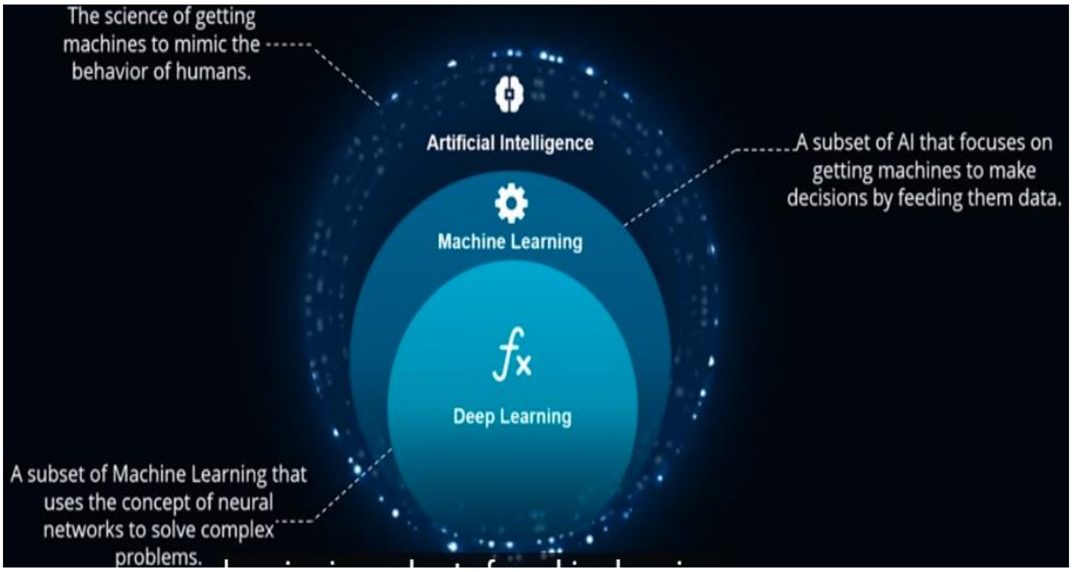

Fig.: Artificial Intelligence (AI) control

Mechanization converted agricultural activities that require days of human sweat and draft animal labor into a few hours of activities. This can be considered as the first level of automation that transformed agriculture tasks in developing countries like India. Agriculture mechanization in India is at an early stage and growing at a rate of 7.5% per annum and this is going to get smarter and faster with the advancement in digital technologies. One of the main issues of recent times is extensive labor migration. When studying the workforce employed in Indian agriculture, it was observed that the percentage of agricultural workers to total workers decreased from 59.1 in 1991 to 54.6% in 2011 and was expected to be 40.6% in 2020 and all these were a few main reasons for moving towards mechanization along with reducing the drudgery. Minimizing the drudgery associated with the agriculture tasks helps the women workers to step forward and make a key contribution to agriculture activities.

Automated farm machinery encompasses a wide range of devices and systems, such as:

Harvesting robots: These robots are designed to autonomously harvest identify ripe produce, and perform precise harvesting actions.

Seeding and planting machines: These machines are equipped with sensors depths. They can optimize seed placement for improved germination rates and crop yield.

Crop monitoring drones: Drones equipped with cameras and sensors can This information helps farmers identify issues like pest infestations, disease

Weed control robots: These robots use computer vision and machine learning damaging the crops. They can reduce the need for chemical herbicides and manual labour.

Irrigation systems: Automated irrigation systems use sensors and weather data to determine when and how much water to apply to crops. They can precisely control water distribution, optimizing water usage and reducing water wastage.

Robotic milking: In dairy farming, robotic milking systems can automatically milk cows without human assistance. These systems use sensors to identify cows.

Automation is the use of various control systems for operating equipment in agricultural farm processing such as machinery, farm processes, and other applications with minimal or reduced human intervention. The biggest benefit of automation is that it saves labour; however, it is also used to save energy and materials and to improve quality, accuracy and precision.

Mechanization in the agriculture sector is an essential factor for sustaining production in which the production system tends to become a commodity-driven agribusiness. In the agriculture, dairy and livestock sector, which is largely integrated with an associated industry and the adoption of mechanization, has been more common. Plough machine, milking machines, fodder handling, and feeding machines, harvesting systems, milk processing etc. In the past twenty years, electronics and computer technologies have significantly pushed forward the progress of automation in the agriculture processing industry. Research, development and applications of computerized quality evaluation and automatic control of various process variables such as, temperature, pressure, flow, humidity, consistency and viscosity etc. have been accomplished time after time during the period. Much advancement has been taken place in the overall agriculture and food processing technology. Automation has been achieved by various means including mechanical, hydraulic, pneumatic, electrical, and electronics and computers, usually in combination.

Automation or automatic control: Automation is the use of various control systems for operating equipment such as machinery, processes in factories, boilers and heat treating ovens, switching in telephone networks, steering and stabilization of ships, aircraft and other applications with minimal or reduced human intervention. Some processes have been completely automated. The biggest benefit of automation is that it saves labour; however, it is also used to save energy and materials and to improve quality, accuracy and precision.

Industrial automation control: Most industrial processes require certain variables such as temperature, flow, level or pressure and concentration, remain at or near some reference value (set-point). The set-point is a value for a process variable that is desired to be maintained. The system that serves to maintain a process variable at the set point is called controller which is the part of a control system. A process variable is a condition of the process fluid that can change the manufacturing process in some way. In an automatic process control (APC) system, controller performs the basic operation used by many systems provides regulation or command to the process variable to be controlled. Goal of control is to determine the value or state of some physical quantity and often to maintain it at that value, despite variations in the system or the environment.

The types of automation are: Fixed automation, Programmable automation and Flexible automation. Fixed automation is a system in which the sequence of processing (or assembly) operations is fixed by the equipment configuration. Each operation in the sequence is usually simple, but the integration and coordination of many such operations in one piece of equipment makes the system complex. Typical features of fixed automation are (1) high initial investment for custom-engineered equipment, (2) high production rates, and (3) relatively inflexible in accommodating product variety.

Programmable automation and its features: In programmable automation, the production equipment is designed with the capability to change the sequence of operations to accommodate different part or product configurations. The operation sequence is controlled by a program, which is a set of instructions coded so that they can be read and interpreted by the system. Some of the features of programmable automation are (1) high investment in general purpose equipment, (2) lost production time due to changeovers of physical setup and reprogramming, (3) lower production rates than fixed automation, (4) flexibility to deal with variations and changes in product configuration, and (5) most suitable for batch production.

Flexible automation is an extension of programmable automation. A flexible automated system is capable of producing a variety of parts (or products) with virtually no time lost for changeovers from one part style to the next. There is no lost production time while reprogramming the system and altering the physical setup. Accordingly, the system can produce various mixes and schedules of parts or products instead of requiring that they be made in batches. Features of flexible automation are (1) high investment for a custom-engineered system, (2) continuous production of variable mixtures of products, (3) medium production rates, and (4) flexibility to deal with product design variations.

Computer-integrated manufacturing (CIM): As defined in the text, computer-integrated manufacturing (CIM) denotes the pervasive use of computer systems to design the products, plan the production, control the operations, and perform the various information-processing functions needed in a manufacturing firm. True CIM involves integrating all of these functions in one system that operates throughout the enterprise.

Instrumentation, process control and measurement system in agricultural processing: Sensors are used in assessing various process variables in agricultural farm processing by their quantitative evaluation which involve an instrument as a physical means of determining the value or magnitude of a quantity or the process variable. Instruments provide the quantitative (objective) values of a farm processing variable primarily by sensing it by the use of suitable sensors and then modifying the sensed signals into the suitable form for further processing to be made them eligible for display or data acquisition/ storage. Recent advances in electronics, physics, Mechatronics, material sciences and other branches of science and technology have resulted in the development of many sophisticated and high precision measuring devices and systems, catering to varied measurement problems in dairy and food processing and other plants.

Basic functional elements of a measurement system for an agricultural farm processing are those that form the integral parts of all instruments and shown in the figure below. There are three basic functional elements in the measuring system, such as *Transducer Element, Signal Conditioning* or Intermediate Modifying Element and *Data Presentation Element* as shown in the figure below.

Transducer Element senses and converts the desired input to a more convenient and practicable form to be handled by the measurement system. An appropriate sensor is used to senses and converts the process variable under evaluation to a more convenient and practicable form to be handled by the next stage of the measurement system. The input variable could be pressure, acceleration or temperature and the output may be displacement, voltage or resistance change depending on the type of transducer element. It converts the input physical variable to usable form, mostly in the form of electrical signal. *Signal Conditioning* or Intermediate Modifying Elements are employed for manipulating and processing the output of the transducer in a suitable form. *Data Presentation Element* is integrated for giving the information and display about the measurement or measured variable in the quantitative form.

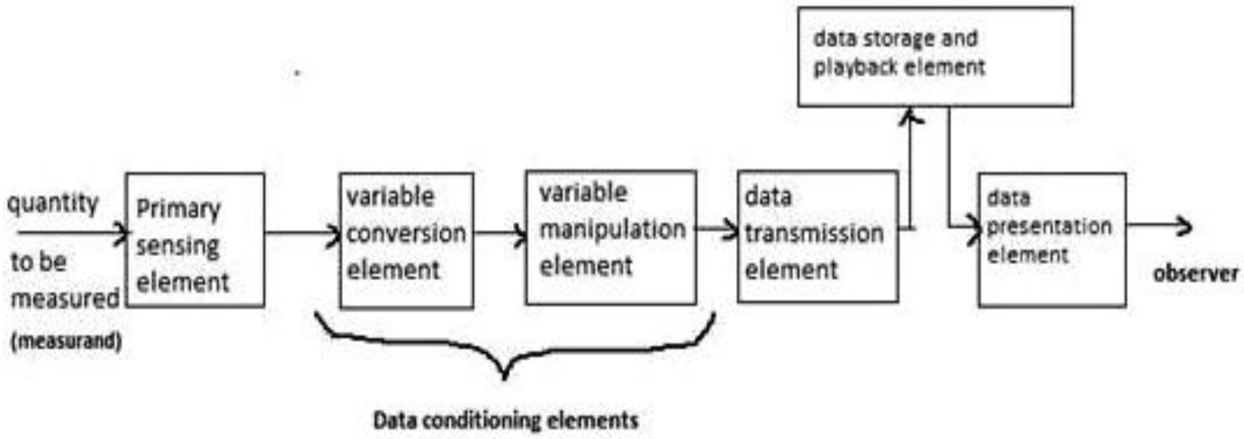

Fig.: Functional elements of a generalized measuring system/instrument

Basic stages of measuring system consists of the primary element that senses the quantity under measurement then the intermediate or the signal conditioning element that modifies suitably the output of the primary element and at the last the end device which is basically the data presentation element that renders the indication possible on a calibrated scale.

Internet of Things (IoT): IoT has enabled the connectivity of various devices and sensors on the farm. Farmers can collect real-time data on soil moisture, temperature, humidity, and crop growth, among other parameters. This information can be analyzed to make data-driven decisions, such as adjusting irrigation schedules, applying fertilizers, or predicting yield outcomes. Meanwhile, security is a top concern for large-scale IoT deployment, which is subject to new, disparate kind of threats and attacks. IoT is the vast network of digitally connected devices and machines and the digital connection of the machines or things occurs over the Internet.

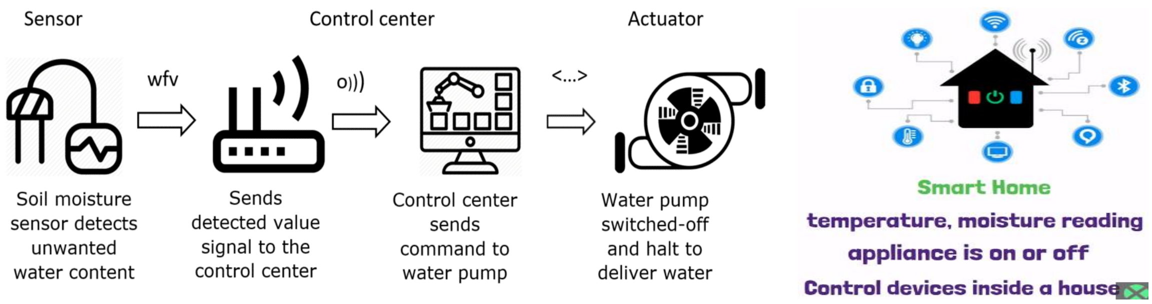

Fig.: Flow-diagram of IoT: Soil moisture sensing-sending data-control center & command-ON/OFF water pump

It is the network of physical devices, vehicles, buildings and so on embedded with electronics, software, sensors and network connectivity that enable these objects to collect and transmit data via the internet. The IoT Network of physical devices, vehicles, buildings and so on embedded with electronics, software, sensors. IoT provides robust communication between the physical world and the digital systems, a concept of the fourth industrial revolution. Use of IoT in industry is sometimes also referred to as Industrial IoT (IIoT). In the IIoT framework, remote sensors gather information generated by machines (and increasingly, human beings too) to increase efficiency, promote better decision making, and build competitive advantages, regardless of industry or company size.

IoT platforms serve as the bridge between the devices' sensors and the data networks, wherein the connected IoT devices exchange information using Internet transfer protocols.

Conclusion

AI (Artificial Intelligence) has had a significant impact on the future of agricultural robots, transforming the way farmers work and managed on the agricultural farms. The agricultural robots market has been witnessing steady growth in recent years, driven by the increasing demand for automation in the farming industry. Internet of Things (IoT) applications is the forthcoming fifth-generation (5G) mobile networks. AI is planned to provide much broader services on a farm, a partner that helps farmers protect crop health, boost grain production and improve the overall farm productivity.

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SOIL HEALTH AND ITS IMPORTANCE FOR SUSTAINABLE FARMING

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By 2050, the world population will be 9.6 billion, with India's population anticipated to reach 1.7 billion. To meet rising demand, India must produce 430 million tonnes (more than 60%) of food grains to ensure food security (FAO, 2022). Approximately 95% of our food is produced directly or indirectly on our soil. As a result, the primary factors for meeting future food security targets will be the utilization and timely supply of quality seeds, fertilizers, and water, as well as the implementation of current technology that assist resource management accuracy. More than any other available resource, crop production relies heavily on soil health for sustainable farming and food security. Soil health can also be defined in terms of soil fertility. Soil fertility refers to soil's inherent capacity to provide an adequate and balanced amount of nutrients and favourable properties as a habitat for plant growth. However, soil fertility is primarily determined by soil physical, chemical, and biological qualities such as soil structure, texture, water-holding capacity, soil pH, nutrient-supplying capacity, soil micro and macro fauna, soil biodiversity, and so on (Fig 1). A healthy soil has an adequate amount of key nutrients such as nitrogen (N), phosphorus (P), potassium (K), and micronutrients, which are required for plant growth, development, and increased production. Plants take these nutrients and are necessary for various physiological processes, including photosynthesis, protein synthesis, and fruit production. Thus, soil health has a direct impact on crop yield and quality.

Nutrient-rich soil can provide all the required elements, resulting in increased crop productivity and improved produce quality, including better taste, appearance, and nutritional content, but insufficient nutrients can cause stunted growth, reduced yield, and even poor harvests. Soil health impacts the health of soil microorganisms, which are crucial for nutrient cycling and soil structure maintenance. Healthy soils with enough organic matter content can absorb carbon dioxide from the environment, which helps to moderate climate change by storing carbon in the soil and lowering greenhouse gas concentrations in the atmosphere. Well-nourished plants can survive unfavourable conditions and recover more quickly from perturbations. Soil health is critical for guaranteeing sustainable agriculture, protecting ecosystem health, conserving biodiversity, and providing nutritious food for humans and animals (Patra *et al*, 2015). Proper soil management methods, such

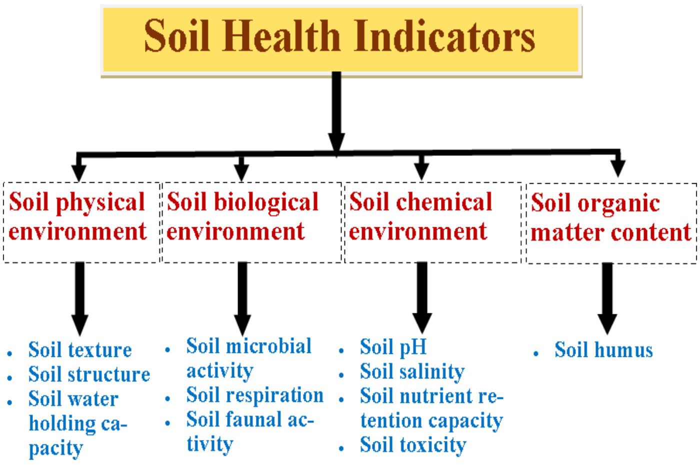

Fig. 1. Measures of Soil Health

as judicious fertilizer application, organic matter integration, and erosion control, are critical for maintaining and increasing soil fertility over time. Transformation of the fertilizer sector, with an emphasis on efficiency rather than input rate, necessitates focus on restoration of soil health through increase in soil organic carbon content in the root zone by adopting recommended management practices such as conservation agriculture and agroforestry (Lal, 2020). Therefore, soil health refers to the quality and capacity of soil for sustenance of the dependent living community that essentially depends on soil's biological, chemical and physical environment. Hence, a soil's characteristics could influence changes in soil organic matter concentration and nutrient status.

Soil health status in India

As early as 1947, Indian soils were known to be low in N; crops such as berseem, wheat in parts of Punjab, and crops grown on light textured soils responded to fertilizer P and those grown in lateritic soils responded to fertilizer K application. During the Green Revolution period, deficiencies of several micronutrients emerged because of the cultivation of high-yielding crop cultivars, micronutrient-free NPK fertilizers, and farmer's access to irrigation water. Although the adoption of these technologies increased crop productivity from 710 kg/ha in 1961-62 to 2300 kg/ha in 2020-21, which helped India achieve self-sufficiency in food grain production transforming the country from a "ship to mouth" status to a net food exporter (Wani and Singh, 2021). However, the large withdrawal of essential plant nutrients caused micronutrient and secondary nutrient deficiencies in many Indian soils. For example, field-scale Fe deficiency was noticed as early as 1960s and P and K during the 1970s.

Similarly, Zn deficiency in field soils was observed in 1969-70, just a few years after introducing high-yielding cultivars. A decade later (1979-80), Mn deficiency was observed in wheat and forage berseem in rice-wheat/berseem rotation in coarse-textured soils. First reported during 1980-81, S deficiency is now recognized as the fourth significant limiting nutrient following N, P and K. In the 1990s, B deficiency was reported, followed by Cu during the last decade (Das *et al.*, 2022). The deficiencies appeared faster in the northern states than in other parts of the country, which may be attributed to the rapid adoption of Green Revolution technologies in irrigated areas. The Green Revolution, although giving abundant food to the country through intensive agriculture, has also destroyed India's delicate agro-ecosystems over time. Over six decades of green revolution, fertiliser use has increased from 0.30 million tonnes in 1960-61 to 32.54 million tonnes in 2020-21. Out of which 20.40 million tonnes N fertilizers and 8.98 million tonnes P_2O5 fertilizer consumed in India. The entire amount of MOP (3.15 million tonnes K_2O) and more than half of the urea consumed in the country is imported. Therefore, disruption of global fertilizer supplies and escalating energy prices arising from several geo-political factors could significantly impact the country's fertilizer availability. Though fertilizer use in India increased significantly, a considerable mismatch exists between crop nutrient uptake and additions through fertilizers. For instance, the uptake of primary nutrients by crops during 2015-16 was 36.6 million tonnes whereas the application of fertilizer nutrients was 26.8 million tonnes leaving a gap of 9.8 million tonnes. The gap widens to 13 million tonnes when nutrient use efficiencies are considered.

The imbalance could still be higher in many regions because of the great disparity in fertilizer use. Currently, 13 states account for 92% of total fertilizer consumption in the country. Apparently, the gap in fertilizer use is filled by indigenous soil nutrient supply, leading to nutrient mining and degradation of soil fertility, thus rendering the production system unsustainable. Nutrient-wise analyses revealed that the gap between nutrient uptake and application of fertilizer nutrients was largely on account of K, leading to its mining from the soil. Presence of K-bearing minerals, such as muscovite, biotite and illite in alluvial soils releases substantial amounts of non-exchangeable K towards K uptake by plants resulting in depletion of non-exchangeable K in soils.

Furthermore, the deterioration of soil fertility is evident from the progressively declining fertilizer response ratio from 12.1 kg grain per kg NPK in 1960-69 to 5.1 kg grain per kg NPK in 2010-17 (Gupta *et al*., 2021). In general, fertilizer use efficiencies in Indian soils are low (N: 30- 45%, P: 15-25%, K: 50-60%, S: 8-12%, and micronutrients: 2-5%) as compared to developed countries and the global average of 59%. Such low-use efficiencies are often attributed to imbalanced nutrient application, poor attention to organic sources, Poor quality products and methods of application, lack of site-specific and integrated nutrient management (INM), and little or no recycling of crop residues (Meena *et al.,* 2023b). Current fertilizer consumption in India is skewed towards N: 32.54 million tonnes of NPK fertilizer use in 2020-21 consists of 20.40 million tonnes N, 7.66 million tonnes P (as P_2O_5), and 3.15 million tonnes K (as K_2O) yielding N:P:K use ratio of 6.7:2.4:1. Fertilizer N is a crucial factor

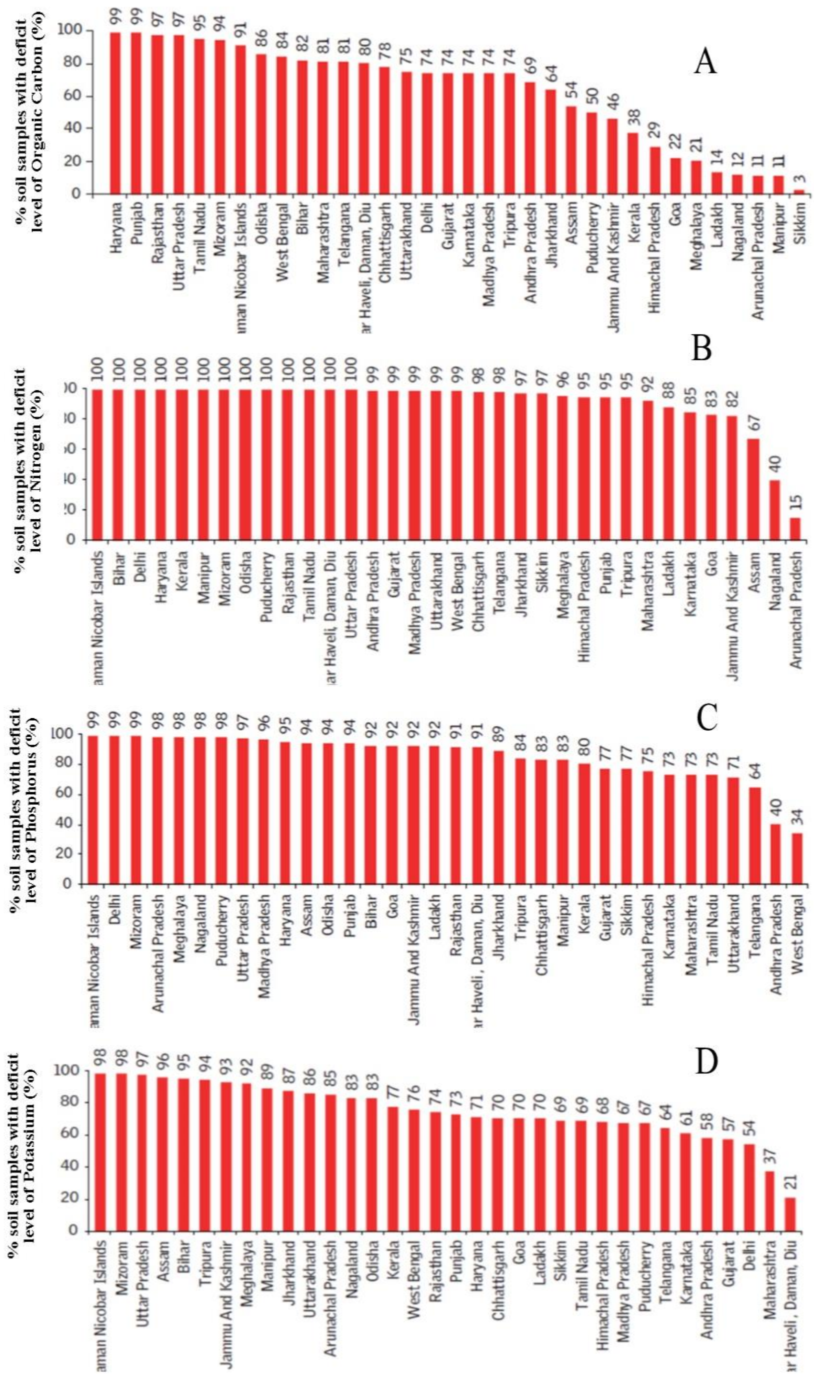

Fig. 2: Organic Carbon (A), Nitrogen (B), Phosphorus (C) and Potassium (D) deficiency in soils of India

for increasing productivity provided balanced nutrient approach is adopted else the law of minimum kicks in. However, fertilizer N efficiency has declined from ~75 % in the late sixties to ~15 %, suggesting imbalanced nutrition. The organic matter content of soils, specifically SOC stock, is critical for soil health and ecosystem function. The total SOC stock in Indian soils is estimated to be 11.338 Petagrams. Organic carbon deficiency mainly occurs in states like Haryana, Punjab, Rajasthan, Uttar Pradesh, etc. Nitrogen, phosphorus, and Potassium deficiency (Fig 2) are also reported in most of the states in India (Khurana and Kumar, 2022).

Regaining Soil Health for Sustainable Farming

1. Improvement in organic matter

Soil organic matter (SOM) serves as a storehouse for a variety of vital plant nutrients. Its presence in the soil is essential for preserving and rejuvenate the soil health. The addition of agricultural residues, compost, FYM, green manure, and animal-derived material provides organic matter as well as certain soil nutrients, which are often immobile in most soils and hence not readily available to plants. These nutrients become accessible in the soil through the processes of decomposition, mineralization, and nutrient cycling, where the plants readily absorb them. SOM maintains the soil's cation exchange capacity, which allows positively charged nutrients to be held, aids in nutrient leaching, enhances water-holding capacity, and promotes soil aggregate formation (Rao *et al.,* 2017). Adding organic matter, such as mulch made from weeds and agricultural wastes, boosts crop productivity while protecting soil from erosion. Crop residues impact the rate of mineralization and breakdown, releasing nitrogen into the soil, whereas residues with low nitrogen aid with nitrogen immobilisation, reducing nitrogen losses (Meena *et al.,* 2023b). Compost manure from green waste from parks, gardens, and houses can help preserve soil fertility by increasing soil microbial activity. It has also been helpful in lowering the prevalence of plant diseases. Thus, keeping an adequate amount of SOM is critical for controlling the long-term soil health and fertility.

2. Crop diversification and cover crops

Maintaining soil health and fertility requires an adequate and balanced supply of nutrients. Crop diversification has balanced the soil nutrients by cultivating various types of crops and cultivars with varying nutrient inputs and growth behaviours (Fig 3). As we know, water-intensive crops like rice and sugarcane deplete the water table; crop rotation in the same area with less water-demanding nutrient-rich crops like, maize, legumes, oilseeds, and millets might replenish the water table and preserve the soil's nutritional status.

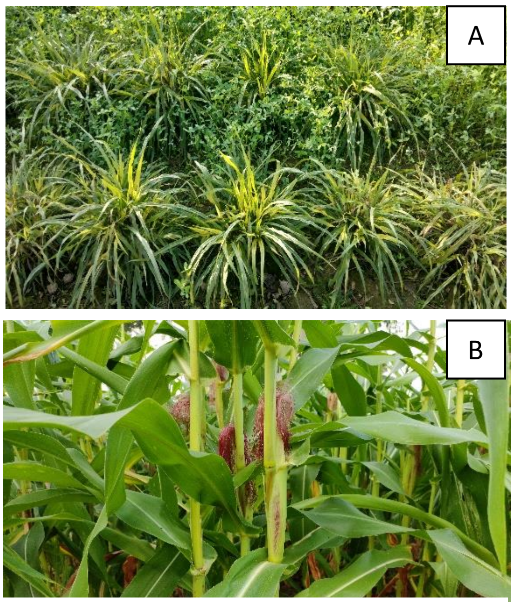

Fig 3: Crop diversification showing the inclusion of legume in between grass (A) and adding baby corn in rotation (B).

Cereal-cereal-based cropping systems are nutrient-exhaustive and degrade the soil's biological fertility to cereal-legume-based systems (Meena *et al.,* 2023a). Diversifying crops are also effective for managing soil-borne plant diseases because they disrupt a pathogen's life cycle, preventing it from growing. The use of cover crops helps to decrease soil erosion. Crops with tap roots help soil aeration by forming macropores in compact soils and infiltration, whereas crops with fibrous root-like grasses promote aggregation and contribute significantly to soil health. Cover crops improve soil fertility by introducing organic matter into the soil through their biomass. These crops immediately assist to reduce the leaching of essential soil nutrients such as nitrate. Legumes roots are colonised by nitrogen-fixing bacteria, hence utilising legumes as cover crops might increase soil nitrogen content even more due to their nitrogen fixation potential. Mycorrhizal fungi colonise over 90% of terrestrial plants, allowing them to acquire soil nutrients better and cope with environmental challenges. Cover crops also impact mycorrhizal fungi, modulating the rhizosphere with a more favourable fungal composition to preserve soil processing and health.

3. Tillage Practices

Any physical disturbance to the soil impacts plant roots and alters the soil biota. Soil compaction makes it harder for roots to develop, and reduced water penetration and drainage further inhibit plant growth. Excessive tillage has several negative consequences on soil production, mainly by changing the physical and biological characteristics of the soil (Alam *et al.,* 2014). Some sensitive micro biotas are significantly impacted, affecting soil biological diversity. Repeated tillage techniques may disrupt the extra radical hyphal network of arbuscular mycorrhizal fungi, resulting in a poor delivery of soil nutrients to their host plants. Tillage exposes the soil to air, which lowers soil moisture content and disrupts the habitats of many soil microorganisms, which are critical for soil health. Tillage reduces soil covering and makes it more vulnerable to erosion. Non-inversion tillage is chosen over regular inversion tillage because it creates less disruption to the soil and its organisms (Nunes *et al*., 2018). To compensate for this loss, farming approaches that need tillage for optimum crop yield must be supplemented with more organic matter via compost, vermicompost and green manure.

4. Nutrient and pH management

Soil pH is critical for sustaining soil organism diversity and the availability of numerous key micronutrients. Acidic soils are favoured by nutrients such as Fe, B, Cu, Zn, Mn, and Ni, allowing plants that require these minerals to thrive. Alkaline soils, on the other hand, are good in Mo, K, S, Ca, P, and Mg, making them ideal for crops that can fix nitrogen. Legume crops, such as lucerne, berseem and clover, thrive well on soil with a pH of approximately 6.2. Most soil microorganisms require a pH of approximately near neutral. Microbial activity generally diminishes with lower pH (5.0 or below), as shown with microorganisms such as nitrifying bacteria. As a result, maintaining soil pH in accordance with crop requirements is critical for soil health management and crop yield. Sulphur additions can reduce the pH of alkaline soils with high $CaCO_3$ concentrations. Acidic soil (low pH) can be treated with lime to raise the pH. Furthermore, lime decreases soil Al and Mn toxicity. $CaCO_3$, $Ca(OH)_2$, and CaO can stimulate sensitive nitrogen-fixing microorganisms' activity (Wiedenfeld, 2011).

Supplementing soil with $Ca(NO_3)_2$ usually raises its pH if leaching does not occur. Meanwhile, $(NH_4)_3PO_4$ and urea gradually increase soil acidity and cause Al and Mn toxicity. SOM amendments are essential because they buffer soil pH by releasing anions and cations during decomposition. Interestingly, SOM binds H^+ at negatively charged sites in acidic soils while releasing H^+ ions in basic soils. It is important to note that soil pH rises during the earliest stages of SOM breakdown. Soil pH rises further owing to mineralization by soil microorganisms; but long-term microbial breakdown and nitrate leaching can lower soil pH. Overall, the influence of SOM on soil pH is determined by the quality and quantity of organic matter present, as well as the pace of decomposition and the absorption or loss of decomposition products.

5. Biofertilizers

A sustainable strategy is essential to preserve soil health and fertility while preserving the natural health of the ecosystem. Chemical fertilisers degrade soil ecosystems and negatively affect humans, animals, and the environment. Biofertilizers may be a better option than the sole application of chemical fertilisers to achieve sustainable agriculture. Biofertilizers comprise living or latent cells, which are applied to soil, seed or seedlings to improve nutrient availability and uptake from soil (Fasusi *et al.,* 2021). Carrier substance facilitates microbial inoculum handling and long-term storage while increasing water ration capacity and efficacy. Applying biofertilizers to soil improves rhizosphere dynamics by attracting beneficial microorganisms. These bacteria deliver macronutrients and micronutrients to plant roots and aid in nutrient management for sustainable agriculture. Biofertilizers slowly release nutrients into the soil and plant, providing a constant supply for extended periods and aiding in soil nutrient maintenance.

Biofertilizers are several types of soil bacteria that assist in keeping soil and plants healthy. The many kinds of biofertilizers with specific microorganisms include: (1) Nitrogen-fixing biofertilizers, which include nitrogen-fixing bacteria and supply nitrogen to the soil and plants. These nitrogen fixers are classified as either free-living microorganisms (*Azotobacter, Clostridium, Bejerinkia, Klebsiella, Nostoc*) or symbiotic microbes (*Rhizobium, Anabaena, Frankia, Azospirillum*). They transform atmospheric nitrogen into a usable organic form of nitrogen; (2) Phosphate solubilizing biofertilizers improve soils with phosphorus. P is found in soils in an insoluble form of phosphate, making it difficult for plants to absorb. Bacteria such as *Bacillus subtilis*, *Bacillus circulans*, *Phosphaticum*, and *Pseudomonas putida* are capable of solubilizing insoluble phosphate, therefore they may be employed as biofertilizers for crops that require P. Some fungi, such as *Penicillium* spp. and *Aspergillus* spp., are also used as phosphate solubilizing biofertilizers (Khoso *et al.,* 2023). (3) Phosphate mobilising biofertilizers include various categories of mycorrhizal fungi, such as arbuscular mycorrhiza (Glomus spp., Sclerocystis spp., *Acaulospora* spp., etc.) and ectomycorrhiza (*Amanita* spp., *Boletus* spp., *Laccaria* Microorganisms such as *Bacillus* spp. and *Aspergillus* spp. can solubilize silicates, releasing K from the metal, mobilising it, and making it available for plant acquisition; (5) Sulphur oxidising biofertilizers are composed of microbes such as *Thiobacillus* spp. and are used as sulphur oxidizers because these microbes oxidise sulphur into sulphates, which are well utilised by plants; (6) Plant growth-promoting biofertilizers are made up of rhizobacteria that help plants grow and develop. *Azospirillum* secretes auxins, gibberellins, and ethylene; Rhizobium and Bacillus produce indole acetic acid; and Pseudomonas promote root growth and influence organic matter decomposition for improved nutrient availability (Khoso *et al.,* 2023). Biofertilizers help plants survive environmental conditions. Arbuscular mycorrhizal fungi (AMF), alone or in conjunction with nitrogen-fixing bacteria, have increased plant production under salt and drought stress conditions. AMF improves plant photosynthetic efficiency and anti-oxidative response during drought stress. Inoculation of seeds with rhizobacteria *Pseudomonas* spp. improves seed germination and growth under water stress conditions. Biofertilizers help protect the plant against numerous infections. *Bacillus subtilis*, for example, provides resistance to a variety of fungal and viral diseases that affect banana, tomato, pepper, cucumber, and other plants. As a result, utilising biofertilizers for plant disease control may be a more effective technique for sustainable crop production and soil health.

6. Composting and Vermicompost

Naturally and sustainably, improving soil fertility and structure through composting is essential to soil health management. Organic matter and critical minerals make compost a nutritional powerhouse that promotes plant development and healthy soil ecology. Composting improves nitrogen cycling, reduces pathogens, and increases soil biodiversity. Beyond its biological effects, compost increases soil water retention and drainage, reduces erosion, and buffers pH. Compost reduces landfill trash and mitigates climate change as a carbon sink. Composting promotes environmentally friendly agriculture and economic benefits by lowering chemical inputs and improving soil resilience.

Vermicompost, an organic manure created by earthworms during the vermicomposting process, can effectively increase soil quality and fertility. After feeding on organic materials such as plant leftovers and other biological wastes, earthworms form a humus-like substance known as vermicast (worm casting), or worm compost. After going through the digestive system of worms, vermicast becomes clean, odourless, and rich in nutrients such as N (2-3%), P (1.55-2.25%), and K (1.85-2.25%), as well as numerous micronutrients. Vermicomposting effectively recycles organic waste into nutritional compost, potentially increasing soil health and crop plant productivity. Vermicompost promotes soil microbial activity and qualities such as porosity and water penetration rate. It improves soil oxygen availability, keeps soil temperatures stable, and aids in crop output. Earthworms like *Lampito mauritii, Eisenia foetida*, and *Perionyx excavatus* are often employed in vermicomposting to generate eco-friendly organic fertilisers that agricultural plants can use easily. Vermicompost use in crops such as rice and lentils has produced greater yields than chemical fertilisers. Not only can vermicompost improve crop output, but it also substantially impacts the chemical and physical qualities of soil, which have deteriorated owing to the uneven and inappropriate use of chemical fertilisers. Furthermore, vermicompost protects plants from infections and illnesses, therefore it is convincing to say that vermicomposting is a rapid and highly effective procedure for producing organic manure and managing soil health and ecosystem productivity (Jack and Thies, 2006).

Conclusion

To summarize, the soil health status in India is at a critical juncture, reflecting the cumulative impacts of intensive agricultural practices, land-use changes, and environmental stressors resulting in nutrient depletions and emerging multi-nutrient deficiencies. For sustainable farming, adequate nutrient replenishment and minimizing fertiliser use disparity are essential. With per capita land availability already low, any further increase in food grain production will come through efficient and precise management of land resources aimed at maintaining or enhancing soil fertility. In addition, government initiatives, research efforts, and farmer education and awareness programs play crucial roles in promoting sustainable soil management practices across diverse agro-climatic zones in India.

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NUTRIENT MANAGEMENT PRACTICES IN ORGANIC FARMING

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During the era of the green revolution, the introduction of high-yielding varieties, an extension of irrigated areas, the use of high-analysis NPK fertilizers and an increase in cropping intensity, propelled India towards self-sufficiency in food production. In the process, the relative contribution of organic manures as a source of plant nutrients vis-à-vis chemical fertilizers declined substantially. An increase in the resistance of insect pests to chemical pesticides has also been noticed. Health hazards associated with intensive modern agriculture, such as pesticide residues in food products and groundwater contamination are matters of concern. The occurrence of multi-nutrient deficiencies and an overall decline in the productive capacity of the soil due to non judicious fertilizer use, have been widely reported. Such concerns and problems posed by modern-day agriculture gave birth to new concepts in farming, such as organic farming, natural farming, bio-dynamic agriculture, do-nothing agriculture, eco-farming, etc.

Organic agriculture is a holistic production management system that promotes and enhances agro-ecosystem health, including biodiversity, biological cycles, and soil biological activity. It emphasizes the use of management practices in preference to the use of off-farm inputs, taking into account that regional conditions require locally adapted systems. This is accomplished by using, where possible, agronomic, biological, and mechanical methods, as opposed to using synthetic materials, to fulfil any specific function within the system. Organic farming is an alternative method that sustains productivity and benefits both farmers and consumers. Therefore, it is essential to shift towards organic farming to improve the quality of life.

Nutrient management in organic farming

Nutrient management is one of the main challenges facing the organic farmer. In the long-term, the challenge is to balance inputs and offtakes of nutrients to avoid environmental pollution. Both of these goals must be achieved for the most part through the management of organic matter. Efficient management of nutrients, soil structure and soil biology should ensure good yields of crops and healthy animals. Therefore, farmers should maintain the inherent soil fertility by replacing the nutrients removed by the crops or livestock grazing by using organic manures, green manures, composts, cover crops, animal manures (raw or composted), biofertilizers etc. The following are the nutrient management practices:

Manures

Nutrients typically enter the farm primarily through animal feed and bedding, while animal manure plays a crucial role in distributing essential elements such as N, P, K, S, and Mg throughout the farm. Additionally, manure contributes valuable organic matter. Although Table 1 provides estimated nutrient concentrations for various manure sources, the actual nutrient content varies based on factors like manure storage and handling methods, livestock diet, animal maturity, and weather conditions. Implementing effective manure management practices is crucial for minimizing nutrient losses and maximizing crop growth benefits. Concentrated organic manures, such as oilcakes, blood meal, and fish manure, have a higher nutrient content than bulky organic manure. They are also known as organic nitrogen fertilizers. Bacterial action converts their organic nitrogen into readily usable ammonical nitrogen and nitrate nitrogen, which is then used by crops. These organic fertilizers are relatively slow acting but supply available nitrogen for a more extended period. Additionally, there are other concentrated organic manures like meat meal, bone meal, fish meal, and blood meal. Processed organic fertilizers include seaweed, wood ash, bone meal, fish emulsion, and cottonseed meal.

Table 1. Nutrient content in commonly used manures (% of dry matter)

Source of nutrients	N	P	K
Cattle manure	1.85	0.81	1.69
Pig manure	2.04	1.38	1.38
Chicken manure	2.91	1.37	1.54
Sheep manure	3.00	0.62	2.68
Human manure	1.20	0.06	0.21

Source: Howeler, R. (2017)

Table 2. Average nutrient content of animal-based concentrated organic manures

Organic manures	Nutrient content (%)		
	N	P_2O_5	K_2O
Blood meal	10 - 12	1 - 2	1.0
Meat meal	10.5	2.5	0.5
Fish meal	4 - 10	3 - 9	0.3 - 1.5
Horn and Hoof meal	13	-	-
Raw bone meal	3 - 4	20 - 25	-
Steamed bone meal	1 - 2	25 - 30	-

Source: Reddy and Reddy (2019)

Compost

Composting is the natural process of 'rotting' or decomposition of organic matter by microorganisms under controlled conditions. Composting has become a preferable option to treat organic wastes to obtain a final stable sanitized product that can be used as an organic amendment. Compost is a rich source of organic matter. In addition to being a source of plant nutrient, it improves the physico-chemical and biological properties of the soil. As a result of these improvements, the soil becomes more resistant to stresses such as drought, diseases and toxicity; helps the crop in improved uptake of plant nutrients; and possesses an active nutrient cycling capacity because of vigorous microbial activity. These advantages manifest themselves in reduced cropping risks, higher yields and lower outlays on inorganic fertilizers for farmers. As with other organic materials, compost application improves content, cation exchange capacity, soil porosity, aggregate stability, and water-holding capacity (Choudhary *et al*, 2018). The extent of these improvements, however, relies on the existing levels of soil organic matter. Table 3 shows compost made from different agro-industry waste and crop residues.

Table 3 The mean nutrient content of some composted organic sources

Organic source	Organic carbon (%)	Total N (%)	Phosphorus (%)	Potassium (%)	C/N ratio
Press mud compost	33.17	3.1	1.95	3.5	10.7
Vermicompost	23.1	1.59	1.63	1.07	15.7
Wheat straw compost	35.33	0.92	0.60	1.11	38.40
Mustard straw compost	33.59	1.04	0.54	1.35	33.59
Castor cake compost	23.0	3.48	1.24	0.84	10.8
Sugarcane trash compost	28.6	0.5	0.2	1.1	56.2

Source: Indoria *et al* (2018)

Green manuring and cover crops

Green manure and cover crops are terms used to indicate the same purpose of maintaining soil fertility and productivity, rather than a focus on commercial harvest. Green manures can be grown as improved fallows, as seasonal green manures in rotation with other crops, or in strips between crops. Typically, a green manure crop is cultivated to produce extra biomass, aiming to sustain soil organic matter and enhance nitrogen availability. A cover crop is grown to suppress weeds and prevent soil erosion during the non-crop season, by keeping the ground covered with a living vegetation with living roots holding on to the soil. This again is a means of managing soil organic matter as the top soil has the maximum humus and is often washed by rains, drifted by wind, and burnt by sun. A catch crop is grown to retrieve nutrients still present in the soil following the harvest of the main crop. This approach serves as a method for managing soil organic matter, especially in the topsoil, which is susceptible to being washed away by rains, eroded by wind, and depleted by sunlight.

Table 4 Biomass production and N accumulation of some green manure crops

Crop	Age (Days)	Dry matter (t/ha)	N accumulated
Sesbania aculeata	60	23.2	133
Sunnhemp	60	30.6	134
Cow pea	60	23.2	74
Pillipesara	60	25.0	102
Cluster bean	50	3.2	91
Sesbania rostrata	50	5.0	96

Source: Reddy and Reddy (2019)

Crop residues

During the processing of agricultural crops at the time of harvesting, a large amount of residues is generated. These crop residues are used as animal feed, soil mulch, manure, thatching material for rural homes, fuel for domestic and industrial purposes, a carbon-rich biomass, crop residues contain car-bon (40-45%), nitrogen (0.6-1%), phosphorus (0.45-2%), potassium (14-23%), and micro elements, which are necessary for crop growth (Table 5) (Wang *et al,* 2020). Crop residues are an important source of organic matter; they can be reapplied into the soil to recycle nutrients and improve its physical, chemical, and biological properties (Kumar and Goh, 1999). The application of crop residues into the soil reduces the risk of erosion and improves water retention in the soil. In addition, the nature of crop residues and the way they are handled may significantly affect the amount of nutrients available to plants as well as the content and quality of organic matter in the soil (Yadvinder Singh, 2005). The release rate and content of nutrient are related to the properties of crop residues (C/N ratio and chemical composition), the climate (temperature and moisture), the soil conditions (pH and water content) and the method of applying crop residues into soil (direct and indirect). Usually, it is assumed that C/N ratio greater than 25:1 leads to the rapid immobilization of inorganic nitrogen while lower C/N ratio results in mineralization. Apart from limiting the development of pathogens, some crop residues inhibit (allelopathic effect) the growth of weeds by reducing their access to light, changing soil temperature, and producing chemical substances.

Table 5. Nutrient content of crop residues (on a dry basis)

Properties	Rice straw	Wheat straw	Corn stover	Rape stalk	Cotton stalk
C (%)	40.74±1.76	42.1±1.19	43.86±1.31	42.93±1.62	45.83±1.71
N (%)	0.79±0.27	0.60±0.15	1.00±0.25	0.77±0.32	1.12±0.23
P (%)	1.97±2.17	0.45±0.22	0.95±0.49	0.78±0.51	1.40±0.58
K (%)	17.41±6.38	23.45±7.68	17.73±7.00	14.66±6.15	12.64±3.98
S (%)	0.36±0.12	0.37±0.11	0.39±0.22	0.62±0.19	0.42±0.24

Source: Wang *et al* (2020)

Crop rotation

Diversified crop rotation is essential not only for crop production optimization, but also for enhancing soil health by increasing soil fertility, nutrient efficiency, and preventing the spread of soil-borne diseases (Martin *et al*, 2020). Including legumes in the rotation, such as beans, alfalfa, or clover, can lead to a nitrogen benefit for subsequent crops. This is attributed to biological nitrogen fixation and less nitrogen immobilization compared with a non-legume as the preceding crop. Crop rotation is a valuable technique in organic farming that involves planting non-legume crops to enhance soil organic matter and break pest and disease cycles. By changing the planting sequence, farmers can disrupt the life cycles of pests and pathogens that target specific crops, preventing their buildup. By shortening the life cycles of soil-borne pathogens aligned with a species plant or crop genotype, the diversified crop rotation offers a good chance for the development of certain soil-functional microorganisms (Yang *et al.*, 2020).

Biofertilizers

Biofertilizers are defined as preparations containing living cells or latent cells of efficient strains of microorganisms that help crop plants' uptake of nutrients by their interactions in the rhizosphere when applied through seed or soil. They expedite specific microbial processes in the soil, thereby increasing the accessibility of nutrients in a form readily assimilated by plants. Incorporating biofertilizers is a vital aspect of integrated nutrient management, offering a cost-effective and renewable source of plant nutrients to supplement chemical fertilizers for sustainable agriculture.

Biofertilizers:

1. **Nitrogen Biofertilizer:** Rhizobium is a symbiotic, aerobic soil bacterium which fixes atmospheric Nitrogen in symbiotic association with legumes. Nitrogen fixed by Rhizobium can vary from 25 kg N to 200 kg N/ha depending on crop and growth condition. Table 6 presents some cross-inoculation groups of Rhizobium. Azospirillum is associated symbiotic nitrogen fixer, aerobic free living can fix 20-40 Kg N/ha. Anabaena azollae which fixes atmospheric N in a symbiotic association with azolla. It is an ideal biofertilizer for rice. Blue Green Algae (Cyanobacteria) are photosynthetic, free-living and prokaryotic organisms which fix nitrogen symbiotically but some cyanobacteria are known to form symbiotic associations. Examples of cyanobacteria are Anabaena, Nostoc, Plectonema etc.

Table 6 Cross-inoculation group of Rhizobium

S. No.	Rhizobium spp.	Cross-inoculum group	Legume types
1	R. leguminosarum	Pea group	Pisum, Vicia, Lens
2	R. trifolii	Clover group	Trifolium
3	R. meliloti	Alfalfa group	Melilotus, Medicago, Trigonella
4	R. lupini	Lupini group	Lupinus, Orinthopus
5	R. japonicum	Soybean group	Glycine

Source: Tamang *et al,* (2023)

2. Phosphorus Biofertilizer

Phosphorus solubilising biofertilizer (PSB): A group of heterotrophic microbes, mainly bacteria, which are known to have the ability to solubilise inorganic P from insoluble sources by release of a variety of organic acids. Microbes are – Bacillus sp., Pseudomonas sp. etc and these are biofertilizers for all crops.

Phosphorus mobilizing biofertilizer (PMB): A group of endomycorrhiza (Glomus, Gigaspora etc.) can take up, accumulate and transfer large amounts of Phosphorus to the plant by releasing the nutrients in root cells.

Organic soil amendments

Organic amendments are the safest and most effective means to promoting soil fertility. Rock minerals such as rock phosphate or limestone are naturally occurring mineral that can be used in agriculture to improve soil fertility and crop production (Zapata and Roy, 2004). It is environmentally friendly. As a natural source of phosphorus, it avoids the use of inorganic fertilizers which contribute to greenhouse gas emissions during its manufacturing process. In addition to increasing soil phosphorus, it adds other nutrients such as Ca, Mg etc to the soil and thereby improves the pH of soil. Additionally, it also improves soil texture and aeration and resists soil erosion.

Crop Diversification

Crop diversification means growing a variety of different crops on a piece of land. It helps reduce the risk of crop failures due to pests, diseases, or adverse weather. It can improve soil health by reducing the depletion of specific nutrients. The addition of functional biodiversity to cropping systems across multiple spatial and temporal scales, through diversified crop rotations, integration of cover crops, green manures, and species mixtures (inter- and multi-cropping), can enhance resource use efficiency, promote the provision of ecosystem services and reduce negative environmental impacts without compromising crop yields in the production of food, feed, and raw materials (Tamburini *et al.,* 2020).

Animal Integration

Integrating livestock into the farm system has many benefits to the soil in terms of soil structure, plant diversity, microbial diversity etc. Many farmers are integrating livestock into the rotation for the additional benefits as dung incorporated in to rotation increasing organic manure in the soil; Grass leys and cover crops can help with weed control and cycling nutrients; Spreads financial risk over different enterprises. Environmentally, integrating crop livestock system (ICLS) can increase carbon (C) accumulation and biodiversity and have the potential to reduce GHG emissions thereby strengthening environmental sustainability (Hilimire, K., 2011). Despite several advantages to ICLSs, there may also be disadvantages in some situations, one of which is that this system can be complex to operate and manage. ICLS demands a greater knowledge (both crop and livestock) and commitment as livestock need continuous (constant) care from people involved in the operation. Other potential negative impacts of ICLS include soil compaction, which reduces the crop growth and affects the growth of succeeding new crops. Cattle grazing can cause soil compaction if they are allowed to graze when the soil is too wet, therefore, management strategies encourage residue grazing only when the soil is dry (Sanderson *et al,* 2013).

Conclusion

Organic farming uses sustainable practices such as composting, cover cropping, and microbial activity to improve soil fertility. It avoids synthetic chemicals and promotes a balanced nutrient cycle for long-term environmental health. By focusing on organic matter, crop rotation, and mineral amendments, nutrient management aligns with regenerative principles. These practices maintain plant vitality and promote resilient ecosystems, emphasizing the importance of a natural and environmentally friendly approach to nutrient management in agriculture.

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COMPOSTING: TURNING WASTE TO WEALTH

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The Industrial and Green Revolution caused an increase in yield per unit area, but it also increased the use of chemicals (fertilizers) and thus contamination of soils. Organic farming is an age-old practice, because of industrial revolutions it was not taken as a high priority but again nowadays to reduce the heavy load of chemicals in soil and for sustaining the yields, this agricultural practice is gaining attention. The chapter glances into the formulation and creation of nutrient-rich composts through nitrogen conservation measures and supplementation with N, P, and K. Additionally, it studies the possibility of bio-based fertilizers generated from agricultural waste, food waste, sewage sludge, and seaweed compost. It emphasizes the necessity for nutrient-enriched vermicompost and how to increase the amount of macronutrients in it. In addition, the chapter discusses the idea of use of seaweed and sewage sludge composts for nutrient recovery.

Introduction

The generation of waste at a global scale is estimated to be 3.5 million Mg per day. It will be doubled by 2050 and can have triple value by 2100. In sub-Saharan Africa and South Asia, the production rate is growing fast (Hoornweg *et al*., 2013). Because waste contains valuable and renewable materials, it should be recycled to the maximum extent possible. In addition to the apparent advantages, there is an opportunity to reduce the environmental impact of industrial processes. To achieve this goal, we require innovative technologies, and waste sorting plays a crucial role in this process (Boas Berg *et al*., 2018) The successful adoption of material recycling is crucial, as the release of nutrients into the environment poses a more significant risk to food security than the depletion of resources. (Stiles *et al*., 2018). Organic waste materials can be creatively repurposed in various environmentally advantageous ways, such as composting which is also a foundational technique that transforms kitchen scraps, yard waste, and agricultural residues into soil amendments rich in nutrients. Organic waste can be used for energy production via anaerobic digestion which produces biogas for cooking or electricity. The use of agricultural residues like mulch proves to be an effective strategy for moisture retention, weed suppression and improvement of soil structure. Another method entails integrating organic waste into animal feed or utilizing it for vermiculture, where worms break down organic matter into valuable castings (Vermicomposting). By embracing these approaches, we not only mitigate the environmental impact of organic waste but also actively contribute to sustainable practices in agriculture and waste management and it can also save money on fertilizer and soil amendments. In this chapter, we will deal with the different organic formulations, their production processes and their uses for providing plant nutrients and sustaining soil health.

1. Nutrient-rich compost formulations

Composting is an aerobic, thermophilic, microorganism-mediated and solid-state fermentation process by which various organic substances are converted into more stable compounds that are precursors of humic substances. While compost-derived bio-inputs offer valuable benefits to plants, a notable drawback is their inability to provide the necessary macronutrient concentrations essential for plant nutrition when compared to chemical fertilizers. By improving the nutritional characteristics of compost, it is possible to develop an agricultural bio-input that not only provides nutrients to the soil but also enhances its physicochemical and microbiological attributes (Óscar *et al*., 2017). The nutritional status of compost can be increased by reducing the losses of nutrients or supplementing some extra quantity of macro-nutrients during the composting process.

1.1 Nitrogen conservation during composting

During the first phase of composting nitrogen is volatilized and consequently it cannot be used by the plants when compost has been applied to the crops. Many factors contribute to the nitrogen volatilization as ammonia i.e. temperature, aeration, C/N ratio, mixing, and pH. To minimize nitrogen losses, various approaches have been developed. These include the addition of salts or bacteria capable of converting ammonia into nitrites and nitrates, as outlined in the provided table 1.

Table 1. Nitrogen conservation strategies

Strategy	Principle	Remark
Adsorption	Addition of biochar to adsorb ammonia Addition of medical stone to the compost Addition of sawdust mixed with KH_2PO_4 to adsorb ammonia	Reduction of the loss of nitrogen from 52% to 20 % Decrease emissions of ammonia and N_2O Reduction of the ammonia evaporation rate
Precipitation	Ammonia precipitation with crystals of struvite	Reduces the loss of nitrogen from 44.3 % to 27.4 %
Oxidation of ammonia	Addition of ammonia oxidizing bacteria and enzymes	Decreases the losses of nitrogen as NH_3 and NO_2
Modification of physicochemical variables	Controlled conditions of composting (temperature, pH, particle size and moisture)	Total nitrogen was found 3.2 % higher at the end of the process

1.2 Compost supplementation with N, P and K

Enriching the compost with nutrients, and sometimes introducing bacteria and other microorganisms to support plant growth is a crucial approach for increasing the nutritional qualities of the compost (Ahmad *et al*., 2008). Generally, the introduction of nutrients into the compost has the potential to result in a unique biofertilizer. This biofertilizer can be advantageous for the soil and thus attracts farmers due to its enhanced nutritional characteristics and cost-effectiveness. To obtain the appropriate concentrations of nitrogen required for plant growth in compost, nitrogenous chemical fertilizers (Urea, CAN, and CN etc.) can be added as a supplement. Typically, these nitrogenous compounds are added at the initial stages of the composting process (Pandey *et al*.,2009). For better composting a C/N ratio of 30 is desired and for this the addition of different manure from animals and other nitrogenous residues such as the putrescible municipal solid waste, oilseed cakes and cereals husks can be used to increase the nitrogen content. Some other findings related to compost supplementation are presented in Table 2.

Table 2 Supplementation of compost with N, P, K and inoculation with microorganisms

Nutrient	Feedstocks	Supplement	Remark
Nitrogen	Paddy straw	Poultry manure, rock phosphate, Urea	Reduces the C/N ratio
	Wheat straw	Urea and cyanamide to adjust moisture	Increases the total nitrogen content
	Straw bed	Cow dung with calcium ammonium nitrate (CAN)	Maize yield was found similar to the application of mineral fertilizer plus CAN
Phosphorus	Paddy straw	*A.niger*, *A.flavus*, *T. Harzianum* Poultry manure, rock phosphate and *A. Awamori, T. viride*	Phosphorus levels increases by 8 % and soluble phosphorus by 1.565 mg/gm
	Green waste	Addition of 0.5 % sulphur powder and rock phosphate	Water-soluble P increases in all mixtures
Potassium	Cattle manure, Poultry manure	Banana peels	Increased levels of potassium

2. Bio-based fertilizers

The escalating demand for food necessitates a corresponding increase in fertilizer and nutrient requirements to achieve higher yields and productivity. While chemical fertilizers play a pivotal role in supplying essential nutrients to plants, they also have detrimental effects on the soil. Therefore, there is a pressing need to identify less harmful and sustainable nutrient sources that can boost crop yields without causing soil damage. Bio-based fertilizers produced from different bio-wastes offer a pathway to attain a sustainable supply of plant nutrients without imposing adverse effects on the soil. Different types of bio-waste and their uses as bio-based fertilizers are discussed below-

2.1 Agricultural waste

- Significant quantities of **"wood ash"** are produced by electricity plants. A range of factors, including the type of incinerator, raw materials, and procedure parameters, may influence the composition of ashes generated during incineration. Wood ash acts as a useful alkali with good fertilizing properties. Additionally, it acts as a neutralizing agent for acidic soils, according to data by (Väätäinen *et al*., 2011).

- **"Poultry litter"** after processing with biological or physical methods can be used in agriculture.
- "**Pig manure**" and "**cattle manure**" can also be used for supplying plant nutrients. Anaerobic co-digestion of cattle manure with the addition of sweet potatoes provided a better yield of biogas and bio-fertilizer as compared to mono-digestion (Montoro *et al*., 2019).
- Besides these several more products like biochar, compost, vermicompost, slurry, digestate etc. can also be produced from agricultural waste.

2.2 Food waste

- Phosphate fertilizers can be acquired through the pyrolysis process of slaughter waste, also with the participation of various other biomass sources such as meat residue, wood, and corn (Zwetsloot *et al*., 2015).
- **Fish meat** and fish waste becomes a valuable fertilizer material abundant in nitrogen, phosphorus, and calcium, especially following composting with the inclusion of a bulking agent (Radziemska *et al*., 2018).

2.3 Sewage sludge

- **Sewage sludge** can undergo various treatment approaches, including biological methods such as composting, anaerobic digestion, and stabilization with earthworms as well as chemical and thermal methods like drying, incineration, and pyrolysis (Cieślik *et al*., 2015).
- Anaerobic digestion was found to be a more effective approach for recovering valuable nutrients compared to incineration.
- Sewage sludge is rich in phosphorus that can be recovered.

3. Nutrient-Enriched Vermicompost

While vermicomposts are advocated as organic fertilizers, their utilization as commercial fertilizers in agriculture faces constraints due to their comparatively lower concentrations of macro-nutrients compared to inorganic fertilizers. Vermicompost, produced from materials like cow dung and banana wastes have been documented to contain approximately 0.96% N and 0.21% P (Padmavathiamma *et al*., 2008). So, it is necessary to enrich the macro-nutrient contents in vermicompost and several methods are advocated for this which are discussed below: -

- Several species of *Azotobacter* and *Azospirillum* increases the N content, while phosphate-solubilizing bacteria like *Pseudomonas striata* increases the available P content in vermicompost.
- The vermicompost enrichment with $ZnSO_4$ and $FeSO_4$, even at lower doses of application causes sufficient reduction of As levels in rice grain and soil, increases grain yield, and also makes risk parameters (TCR, SAMOE) somewhat benign (Sengupta *et al*., 2023).

6. Sewage sludge compost

Sewage sludge is obtained during mechanical, chemical and biological treatment. It is rich in organic matter, nitrogen, phosphorus, calcium, magnesium, sulphur and other micronutrients essential for plants. It contains nitrogen and phosphorus up to 2% and 1.5% respectively. Compost application exhibited the following outcomes: (1) It did not show any discernible impact on rapeseed germination but proved advantageous for plumelet development at lower application rates (<150 tons per hectare); (2) it resulted in favourable yield responses for barley and Chinese cabbage (Wei *et al*., 2005).

8. Seaweed compost

Algae, particularly marine macroalgae such as seaweeds, have the ability to swiftly grow in biomass when nutrients are abundant. Consequently, cultivating seaweeds in aquaculture wastewater provides an opportunity to efficiently reclaim a significant portion of these excess nutrients. This process not only aids in nutrient recovery but also generates a valuable biomass resource (Mata *et al*., 2010). Composting is a low-cost approach to stabilize these nutrients. Seaweed contains rich quantities, particularly of potassium (K), micronutrients and some growth activators such as cytokines, auxins and alginates, which help in improving the soil structure.

Conclusions

Global waste is on the rise and expected to double by 2050. Recycling, especially of organic waste, is a crucial solution. This chapter focuses on sustainable solutions like nutrient-rich compost, biofertilizers, and slow-release organic fertilizers. Sewage sludge and seaweed compost also offer potential benefits to agriculture. Overall, the chapter emphasizes the importance of eco-friendly solutions to address waste challenges and provide nutrients for agriculture.

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CARBON FARMING AND ORGANIC SOIL AMENDMENTS: ENHANCING CARBON SEQUESTRATION

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Carbon farming is an eco-friendly agricultural method and offers for combating climate change by enhancing soil carbon storage. This chapter explores how combining carbon farming techniques with organic soil enhancements strengthens carbon storage potential. Practices like agroforestry, cover cropping, conservation tillage, rotational grazing and biochar application improve soil quality, fostering microbial activity and enhancing structure. Organic soil amendments such as compost, manure and biochar replenish soil carbon, improve nutrient circulation and reduce greenhouse gas emissions. With structured implementation, carbon farming promotes resilient agriculture, mitigates climate impacts and fosters sustainable land management. Integrating carbon farming and organic soil enhancements provides a holistic strategy for enhancing soil carbon reserves, agricultural productivity and climate resilience.

Introduction

Agricultural cropping systems and pastures constitute one-third of the world's arable land and have the potential to sequester a significant amount of atmospheric CO_2, storing it as soil organic carbon (SOC) and enhancing the soil carbon budget. An enhanced soil carbon budget achieves two objectives: enhancing soil health to bolster crop productivity and providing a reservoir from which carbon can be transformed into enduring forms for long-term storage, aiding in the mitigation of global warming. As stated by the Carbon Cycle Institute (2020), "Agriculture is the one sector that has the ability to transform from a net emitter of CO_2 to a net sequestered of CO_2, there is no other human managed realm with this potential. Soil organic carbon enhances crop productivity by boosting nutrient retention and water retention capacity, facilitating effective drainage and aeration, reducing topsoil loss through erosion, and offering substrates for soil microbiomes. (Lal, 2004). SOC can convert to soil inorganic compounds like calcium and magnesium carbonates for long-term storage. Carbon farming's success hinges on modelling metabolic fluxes, understanding regulation, and reorganizing carbon distribution within plant-microbe-soil systems. Techniques like altering crop rotations, tillage methods, and land cover changes, such as converting cropland to forests or perennial grasses, enhance soil carbon storage effectively.

Carbon farming represents an effective approach to achieving more sustainable food and related product production. It aims to simultaneously implement a variety of natural farming methods and produce marketable products. According to the Intergovernmental Panel on Climate Change (IPCC), Agriculture, Forestry and Other Land Uses (AFOLU) is unique due to its capacity to mitigate climate change through greenhouse gas (GHG) emission reductions, as well as enhance removals (IPCC, 2019). An agroforestry system intentionally blending trees, crops, and livestock within agricultural production holds promise for enhancing carbon sequestration and reducing greenhouse gas emissions from terrestrial ecosystems, thereby assisting in mitigating global climate change. Moreover, agroforestry can generate substantial quantities of biomass and is considered particularly well-suited for replenishing soil organic carbon (SOC).

Soil amendment with organic input is a common practice in conventional agricultural practices (e.g., in annual cropland or forage land) and involves manuring, mulching, green manuring and biochar addition. Agroforestry systems offer diverse feedstocks for bulking agents, including residues from annual crops, small woody biomass from pastures, leaf litter, as well as twigs, branches, and woody biomass from trees, which can be utilized in composting, pelleting, or biochar production. Adding organic amendments such as biochar, compost and manure to soil for enhancing C sequestration and reducing GHG emissions is well documented. Within croplands, application of biochar derived from various feedstocks, has been shown to increase soil organic C content, reduce CO_2 and N_2O emissions and increase CH_4 uptake, as compared to no application of biochar.

Carbon Cycle in Agriculture

The carbon cycle in agriculture is a dynamic process where carbon moves through various stages within the farming ecosystem. Plants absorb carbon dioxide during photosynthesis and convert it into organic compounds. When plants decompose, carbon is transferred to the soil. Soil microorganisms break down organic matter, releasing carbon dioxide into the atmosphere. Agricultural practices play a role in shaping this cycle; carbon is stored in the soil through methods such as cover cropping and reduced tillage. Nevertheless, intensive farming and deforestation can upset this equilibrium, adding to greenhouse gas emissions. Grasping and overseeing the carbon cycle in agriculture is imperative for sustainable farming practices. Some of the practices that influence the carbon content in soil (SOC) are given in Table 1.

Table 1 Carbon farming practices and their impact on carbon sequestration

Carbon farming practices	**Description**	**Impact on carbon sequestration**
Agroforestry	Combining trees and crops on agricultural lands through integration techniques.	Enhances biodiversity and ecosystem services while boosting carbon storage in aboveground biomass and soil organic matter.
Cover cropping	Planting cover crops during fallow periods.	Enhances soil richness, mitigates erosion, and boosts carbon sequestration via the accumulation of biomass.
No- till and conservation tillage	Minimized soil disruption during tillage procedures.	Preserving soil carbon stocks, improving soil structure, and reducing carbon loss from erosion and decomposition are key objectives.
Rational grazing	Managed grazing systems for livestock.	Encourages the retention of carbon in grassland soil, boosts soil vitality and richness, and enhances the yield of forage.

Carbon sequestration mechanism in agricultural soils:

Physical mechanism

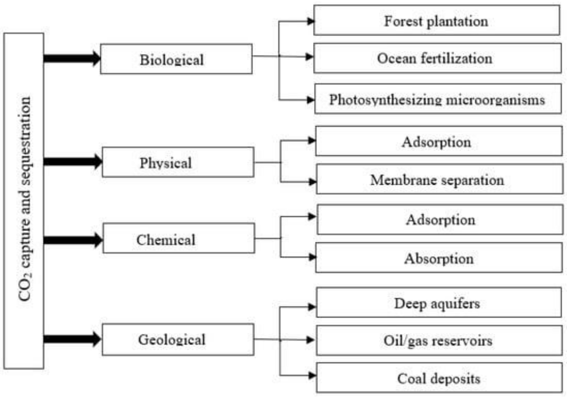
Soil aggregate formation represents a key process in stabilizing soil organic carbon (SOC). When soil is tilled, it breaks down soil aggregates, leading to the significant transfer of protected SOC pools having mean residence times of decades to active pools, which typically have mean residence times of only weeks. Additionally, cycles of drying and rewetting following tillage practices can further accelerate SOC decomposition rates by exposing physically protected SOC within aggregate fractions. Moreover, the level of SOC protection also varies with soil texture; clay soils tend to safeguard more carbon compared to sandy soils in similar environmental conditions.

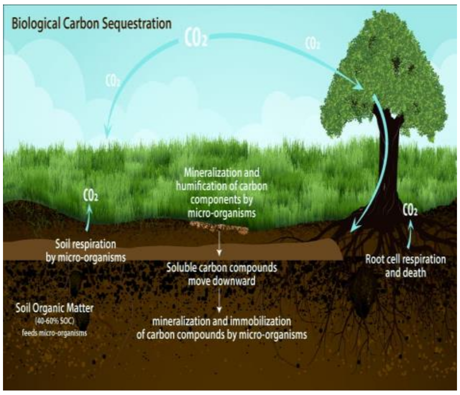
Chemical mechanism

The soil organic carbon (SOC) exhibits thermodynamic instability, yet it endures in soil, sometimes for extended periods, spanning thousands of years. Nonetheless, the persistence of SOC primarily stems from ecological factors rather than molecular characteristics. Environmental variables like reactive mineral surfaces, climate patterns, water availability, soil acidity, redox state, and microbial community collectively regulate SOC longevity. While the 'recalcitrance' of humic substances may have limited relevance to SOC cycling, the molecular composition of plant inputs and organic matter (OM) plays a secondary role in determining carbon residence times, ranging from decades to millennia. Nevertheless, it remains uncertain whether enhancing the joint physical and chemical mechanisms of SOC stabilization is achievable through the introduction of OM enriched in compounds resistant to decomposition, such as black carbon and aliphatic C. Notably, prevalent stable forms of carbon encompass bicarbonate and carbonate ionic forms, alongside carbonated salts existing in the solid phase under typical soil environmental conditions. Consequently, the formation of soil carbonates serves as an effective mechanism for binding carbon, contributing to its stabilization.

Biological mechanism

The mean residence time (MRT) of soil organic carbon (SOC) varies widely, ranging from brief moments to thousands of years. Only SOC with a long MRT significantly impacts atmospheric CO2 and CH4 levels. Decomposition rates are predominantly influenced by environmental and biological factors rather than the molecular structure of SOC. Microbial activity is the primary driver of SOC decomposition, utilizing approximately 10–15% of SOC-energy, while abiotic chemical processes have a minor role. Biotic mechanisms, such as the creation of stable micro-aggregates and non-hydrolyzable compounds, are crucial for SOC stabilization. Micro-aggregates, formed by microbial cells, root exudates, and faunal mucus, combine to form macro-aggregates (>250 mm), which include particulate organic matter, fungal hyphae, and fine roots. Biological protection enhances secondary recalcitrance through microbial by-products and humic polymers, while spatial inaccessibility is increased by SOC occlusion within aggregates, hydrophobicity, and intercalation within phyllosilicates in acidic soils.





Challenges in Carbon Farming

Carbon farming initiatives (CFI) necessitate agro-environmental policies that encourage farmers to embrace optimal farm management practices. However, engaging farmers in such programs proves challenging, primarily due to the intricate scheme design and its execution, along with conflicting objectives between policy-makers and farmers (Salas, 2018). Several other factors impact the adoption and implementation of new farm management practices, including landholders' personal interests and farm or land characteristics. Some barriers to carbon farming are directly linked to landholders' interests, alongside inadequate skills or management capabilities. Additionally, political instability significantly influences the acceptance and execution of such practices (Conant *et al.,* 2011). Moreover, uncertainty regarding environmental impacts and a lack of awareness about these schemes and policies can undermine their adoption. Farmers have acknowledged insufficient access to information about available carbon farming options. Indeed, many farmers lack a clear understanding of carbon farming and detailed knowledge about its advantages and disadvantages. This situation is exacerbated by high input costs and concerns about the impact of carbon farming on yields and farm productivity. Forests account for about 75% of global biomass, while oceanic plants, primarily algae, represent less than 1% of global carbon biomass (Sayre and R. microalgae, 2010).

Soil amendments for carbon storage:

Organic amendments

1. **Animal manure**: Animal waste serves as a carbon source, and its incorporation into various crop fields affects carbon levels. When 200 Mg ha^{-1} yr^{-1} of animal manure is annually applied to crop fields, it results in notably higher soil organic matter (SOM) levels compared to neighbouring fields. According to Powlson, over periods exceeding 49 years, the mean annual rates of soil organic carbon (SOC) sequestration due to manure application ranged from 10 to 22 kg C ha^{-1} yr^{-1} per ton of dry solids. Conversely, shorter-term experiments (ranging from 8 to 25 years) involving farmyard manure, cattle slurry, and boiler litter indicated SOC sequestration rates between 30 and 200 kg C ha^{-1} yr^{-1} per ton of dry solids. The primary objective of such experiments is to enhance soil quality and crop productivity, with a focus on effective carbon management. Moreover, the application of animal waste elevates soil salt concentrations, with long-term usage significantly boosting SOM levels.

2. Crop residues: The annual global production of crop residues amounts to approximately 3.4×10^9 tons. When 15% of this total residue is applied to the soil, it contributes to an increase in the soil's carbon content. Crop residues refer to the leftover materials from crops, with the intensive agricultural system significantly boosting their production. This increase can lead to enhanced soil organic matter (SOM) and soil aggregation, thereby promoting carbon storage. The degradation rate of crop residue varies depending on its composition; for instance, substances with high lignin content pose challenges for microorganisms in initiating degradation. Researchers have categorized three mechanisms for SOM stabilization: chemical, biochemical, and physical stabilization. Agricultural practices like incorporating crop residues into the soil not only augment SOM but also enrich the soil's nutrient content.

3. Composting: Composting involves the deliberate and regulated decomposition of various organic materials, such as animal waste, woody substances, and other biodegradable waste. During composting, carbon (C) becomes available in a form that plants can absorb. As compost matures, approximately 50% of the carbon transforms into humic substances, which are considered more stable over time. When compost is applied to different areas, there is a significant increase in soil organic carbon (C) compared to the initial levels. This practice offers a dual benefit: it enhances carbon storage in the soil while also promoting plant growth and improving yields, thus providing an environmentally beneficial alternative to chemical fertilization. Research by Farina *et al.* (2018) indicates that applying compost at a rate of 10 Mg ha^{-1} $yr.^{-1}$ leads to greater carbon sequestration.

4. Bagasse: Utilizing various types of biomasses in soil represents an effective strategy for enhancing carbon sequestration in agricultural areas. Research indicates that applying bagasse as a biomass in the field demonstrates significant potential for sequestering carbon, estimated at approximately 1200–1800 tons of carbon per year. Moreover, employing biochar derived from bagasse serves as a natural organic amendment for soil, aiding in water retention. Studies have explored the effects of different ashes, such as those from bagasse and rice husk, on wheat soil, with a focus on monitoring soil organic carbon content and enzymatic activity. Bagasse ash has been observed to augment soil organic content by 525 kilograms per hectare annually, while rice husk ash does not exhibit a similar increase in soil organic matter (Kameyama *et al.,* 2010). Additionally, bagasse ash promotes soil dehydrogenase and cellulose activity. However, comprehensive, long-term investigations are imperative to evaluate the broader impacts of ash application on the physical, chemical, and biological properties of soil.

5. Biochar: Biochar, often derived from the decomposition of crop residues and wood chips under low oxygen conditions at temperatures ranging from 350°C to 600°C, retains over 50% of the carbon from the original biomass when formed under optimal temperature and oxygen levels. Its resistance to microbial degradation allows it to remain stable in soil for extended periods, potentially thousands of years, thereby mitigating the release of carbon dioxide from terrestrial sources into the atmosphere.

Conclusion

Sustainable agriculture is crucial due to increasing human demands and environmental impacts. Carbon farming is a comprehensive approach that combines agroforestry and silvopastoral systems to enhance agricultural production, food security, and mitigate GHG emissions. Carbon farming efficiently retains organic carbon stocks, surpassing mono-cropping, and improving soil quality.

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DAIRY BASED INTEGRATED FARMING SYSTEM FOR SUSTAINABLE LIVELIHOOD AND EFFICIENT RESOURCE UTILIZATION

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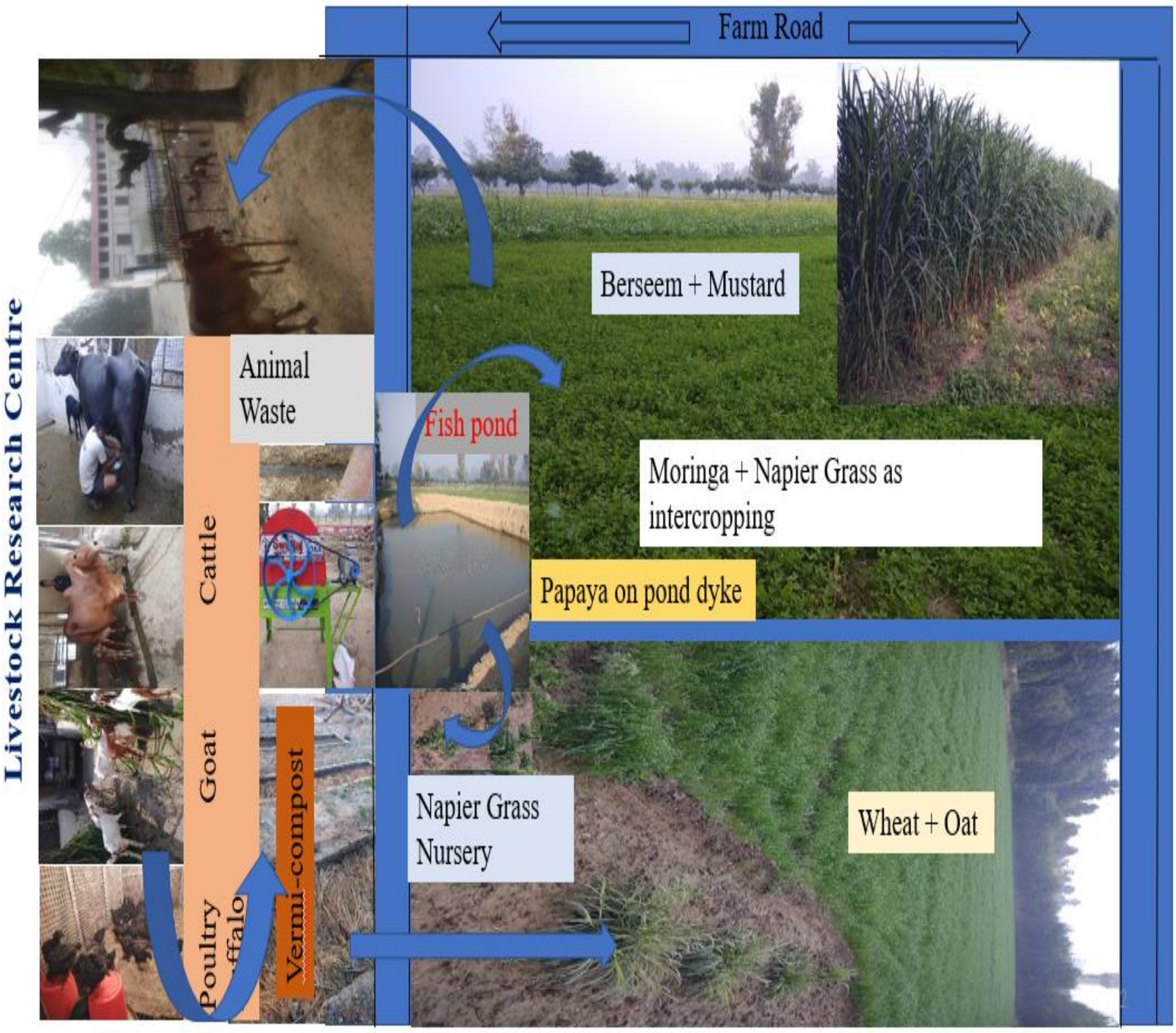
India holds around 15% of the world's livestock population in 2% of world's geographical area, resulting in great pressure on land. The agricultural production system is threatened by the adversities of climate change, land degradation, low productivity, and environmental degradation. The average size of agricultural landholding in India is gradually shrinking from 2.28 ha in 1970-71 to 1.08 ha in 2015-16. The farming sector is highly sensitive to climatic uncertainties and is also highly impacted by population growth, resource scarcity, and degradation. It is supposed to follow a similar trend in the future too. The intensive use of synthetic fertilizers/pesticides, fossil energy, and water has resulted in agricultural system degradation and inefficiency. Therefore, there is a need to design and develop sustainable agricultural production technologies that can potentially ensure household-level food and income security with a minimum environmental degradation. It is difficult to achieve livelihood security and sustainability for these farmers with a single farm enterprise. Integration of diverse farm enterprises like crops, livestock, and other farm enterprises plays a synergistic role in food production, livelihood, and the provisioning of various tangible and non-tangible benefits and keep the resources within the framework of the economy. An integrated farming system offers effective management of various enterprises which has the potential to improve input use efficiencies and other ecosystem services. It provides opportunities to capture ecological interactions among the various enterprises, and provides opportunities to utilize labor and other resources more efficiently. Thus, futurist food, nutritional and livelihood security, and environmental sustainability are supposed to be achieved by integrated farming systems.

The small and marginal farms need multi-enterprise farming activities that are complementary and technically feasible in the interest of the productivity of the whole farming system. An integrated farming system encompasses diversified cropping, livestock, piggery, and poultry at a single point. In integrated farming systems, each enterprise is linked with the other in a closed loop. The integration of land-based enterprises such as dairying, aquaculture, poultry, duckery, apiary, and horticultural crops within the biophysical and socio-economic environment of the farmers is important to make farming more profitable and dependable. Integration of various enterprises helps in ensuring not only food, nutrition and livelihood security but also social, economic and environmental sustainability. For this reason, the IFS models have been suggested by several workers for developing small and marginal farms across the country. IFS aim least dependence on outside resources and efficient recycling of available farm resources, as in this system nothing is wasted and the by-product of one system becomes the input for other.

Keeping these facts in view, ICAR-NDRI has initiated the research work on "Developing dairy based integrated farming system model for income enhancement of small farmers". The dairy production tends to be more complex than crop production because animals too often play a pivotal role in the overall farming system. Any constraint imposed on animal may also restrict the system as a whole. In general, dairy production in integrated farming systems aims to (i) raise productivity through better utilization of available resources (ii) recycling and reuse of farm waste within the system, and (iv) optimize the allocation of resources through rational management. The project is laid on an area of 1.0 ha with different sub-components viz., cereal crops (0.4 ha), fodder crops (0.4 ha), dairy (cattle-3; buffalo-3, goats-10), poultry (20 birds), fish pond and vermin-compost pits (0.2ha). The potentially important technologies that could make a significant increase in productivity in IFS are implemented. Since the supply of green fodder throughout the year is a major challenge, hence emphasis is being given on production of quality greed fodder and feeding strategies for dairy animals.



Layout of Dairy-based IFS Model at NDRI, Karnal

Hybrid Napier and Moringa-based model of fodder production has been developed in 0.4 ha for round-the-year quality fodder availability. About 30 percent of the allocated area is covered under perennial fodder crops (Hybrid Napier and Moringa) and rest of the area (70%) under annual fodder crops like maize + cow pea in summer, cowpea in rainy season and berseem during winter season as intercrop between moringa and napier rows. The average green fodder yield of 2552 q/ha with dry matter yield of 461q/ha has been recorded from four cuttings of hybrid Napier.

The animals (three Sahiwal cattle, three Murrah buffaloes and 20 Barbari goats) are maintained on fodder available from the system under cut and carry system and during summer months UMMBs are supplemented. The total milk yield of 6378 liters from cattle, 6215 liters from buffaloes and 1257 liters from goats was recorded with cost benefit ratio of 1:1.59, 1:1.78 and 1:1.98, respectively. Various nutrients viz., 119.8 kg N, 45.3 kg P and 71 kg K are also supplied by the recycling of farm waste, dung and urine in FYM/vermin-compost to the system. Effect of UMMB supplementation on milk production in buffaloes is also assessed. An average increase of 26.95 % in milk yield has been recorded due to its supplementation with cost benefit ratio of 1:8.23. Similarly, the supplementation of polyherbal mixture from the day of calving to till the day 10 of postpartum in cattle increased milk yield by 21.53 %. The net return of Rs. 4,15,700/- was generated with 58.9 % contribution from dairy production, whereas food/fodder crops and subsidiary enterprises contributed 35.9 and 5.2 %, respectively to the net income. Studies carried out at ICAR-NDRI suggest that the developed integrated farming system model had higher profitability, promoted efficient waste recycling and reduced energy use efficiency compared to prevailing production system. Farm-based crop animal integration enhances nutrient recycling which favours soil fertility build-up and carbon sequestration.

Table 1. Ingredients of polyherbal mixture

Ingredients	Quantity (g)
Methi : *Trigonellafoeenum-graecum*	25
Ajwain: *Trachyspermum ammi*	25
Saunf: Foenicum vulgare	25
Sowa: *Anethum graveolens*	25
Sundh: Zingiber officinale	25
Bari elaichi*: Elettaria cardamomun*	15
Black salt	25
Jaggary (Gur)	250

The developed model not only increases the production and profitability but also ensures the food and nutritional security through regular supply of milk and eggs round the year and has potential to increase resource use efficiency and overall resilience of the production system. Hence, emphasis needs to be given on development of dairy based IFS module for different situations to fit into socio-economic condition of small and medium famers. This approach is able to minimize farmers' risks due to climatic and market uncertainties, provides constant income and employment to the farmers throughout the year on sustainable basis, and could lead to higher system productivity. Availability of key inputs and support services need to be strengthened and improved to enable the small and marginal farmers for dairy based IFS development. A favourable policy environment in terms of access to micro-credit and assured market will have to be provided for up scaling the developed models. In other words, future agriculture lies in dairy based integrated farming by marginal and small farmers. Integrated farming system, depending upon the resource availability, can definitely improve their livelihoods and standard of living and can be recommended as an economically feasible and environmentally robust production model for ensuring household-level livelihood security in the northern plains of India.

The way forward

The finding proved that wise integration of crops along with dairy animals and other components sustainably harnesses the food-energy-carbon nexus by improving food production, economic returns, and nutrient use efficiency. Thus, considering food production, energy dynamics, economic returns, and resource use efficiency, location specific integrated farming system models could be recommended for agricultural planning in India. However, the development of suitable dairy based IFS models for a resource and input diverse situations remains challenge, thus location-specific suitable interventions are required. Some of the issues mentioned below needs to be addressed through location specific research and policy interventions.

Researchable issues

- Resource characterization at household level needs to be done for promotion of livestock based IFS in a targeted domain.
- The resource optimization through enterprise integration using matrix analysis and regression models would provide long-term sustainability in terms of livelihood, economic returns, and efficient resource use.
- On-farm evaluation of farming system models using critical input intervention needs to be made for real time and specific situation.

Farmer's perspective

- A clear understanding of the benefits of IFS among farmers would promote easy adoption in target areas.
- The establishment of self-help groups (SHGs) and farmers' producer company will help them in building associations wherein mutual profits can be enhanced.
- Location-specific dairy based IFS models need to be developed which can cater the requirement of farming community for wider adoption of IFS.

Policy initiatives

- Policy support in terms of subsidies and credits needs to be offered for small farm enterprises based bankable IFS models.
- The facilities for marketing, infrastructure, and value addition may be developed on regional scale to benefit small and marginal farmers.
- Quality input availability and resource recycling technique needs to be ensured to harness maximum gains in IFS.

PHYSIOLOGICAL ADAPTATIONS OF CROPS UNDER DIFFERENT PRODUCTION SYSTEMS

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Physiological changes in crop production systems refer to changes or adaptations that occur at the physiological level of plants in response to various environmental factors, stressors, or management practices. These changes play a pivotal role in cropping systems, providing a crucial foundation for understanding and managing the physiological processes that enable farmers and agronomists to optimize crop yield by implementing effective cultivation practices. Crop yield can be enhanced by optimizing factors like photosynthesis, nutrient uptake, and water use efficiency. Moreover, efficient use of resources such as water, nutrients, and sunlight is essential for sustainable agriculture.

Knowledge of physiological changes helps in efficient use of resources such as water, fertilizers, and pesticides, contributing to better resource management. Identification of physiological responses to stressors aids in developing crops with improved resistance to diseases and pests, thereby reducing the reliance on chemical interventions. Moreover, physiological studies assists in developing crops that can better withstand changing climatic conditions, contributing to climate-smart agriculture.

Understanding how different crops respond physiologically helps in choosing suitable crops for specific environments and implementing effective crop rotation strategies. Moreover, physiological insights contribute to the production of crops with enhanced nutritional content, superior taste, and overall quality. Managing physiological aspects can reduce the environmental impact of farming by minimizing nutrient runoff, soil erosion, and the use of synthetic inputs. For instance, elevated temperatures may induce heat stress, affecting enzyme activity and membrane integrity, while water scarcity can lead to stomatal closure and reduced photosynthesis. Nutrient deficiencies or excesses can likewise disrupt essential metabolic processes. Understanding these physiological changes is crucial for farmers and researchers, as it informs strategies to optimize crop performance, enhance resilience, and secure global food supplies in the face of evolving environmental challenges.

Physiological Responses in Conventional Farming

A. Synthetic inputs: Conventional Farming (CF) often involves the use of synthetic fertilizers, pesticides, and herbicides. These inputs can provide readily available nutrients, control pests, and manage weeds, promoting robust vegetative growth. These inputs can influence water use efficiency by affecting nutrient availability and crop health.

B. Monoculture: Large-scale monoculture in conventional farming can lead to specific challenges, such as increased vulnerability to pests and diseases, which may impact vegetative growth. Monoculture practices can lead to increased water stress on crops. This stress may affect physiological processes, potentially influencing water use efficiency.

C. Mechanization: Conventional farming typically involves regular tillage, which can impact soil structure and water retention. Excessive tillage may increase the risk of water runoff and reduce water use efficiency.

Overview of crop production systems: Crop production systems involve a combination of agricultural practices, technology, and management strategies designed to optimize yield, quality, and sustainability. The essential elements of crop production systems are concisely outlined in the table 1.

Table 1. Characteristics and aspects of crop production associated with physiological responses

Crop Production Systems	Characteristics	Advantages	Disadvantages
Conventional Agriculture	1. Relies on synthetic fertilizers and pesticides 2. Use of genetically modified organisms 3. Large-scale monoculture	1. High yields per acre. 2. High mechanization	1. Environmental concerns (soil degradation, water pollution). 2. Dependency on chemical inputs
Conservation Agriculture	1. Minimal soil disturbance 2. Permanent soil cover 3. Crop rotation.	1. Conservation of soil and water 2. Energy (fuel, labor & machinery) saving	1. Weed Management Challenges
Organic Farming	1. Emphasizes natural and organic inputs 2. Focuses on soil health (crop rotation and cover cropping	1. Reduced environmental impact 2. Promotes biodiversity and soil conservation	1. Lower yields compared to conventional farming 2. Higher labor and management requirements
Agroforestry	1. Combines agricultural crops with trees or shrubs 2. Enhances biodiversity and provides multiple products	1. Improved soil fertility and structure 2. Diversification of income sources	1. Longer time to establish compared to traditional systems

Physiological changes in conservation agriculture

Conservation agriculture (CA) involves sustainable farming practices that aim to minimize soil disturbance, maintain permanent soil cover, and diversify crop rotations. These practices promote long-term soil health and sustainability. Physiological adaptations in conservation agriculture are crucial for crops to thrive in these systems.

A. Minimal soil disturbance and root architecture: Minimal soil disturbance promotes better root development and increases nutrient uptake efficiency. It prevents disruption of nutrient-rich soil layers, providing a stable environment for roots to explore. No-till farming can moderate soil temperatures by preserving surface residues, reducing temperature extremes that may impact root growth and microbial activity. Reduced soil disturbance encourages deeper and more extensive root systems. Enhanced root development allows plants to access water from deeper soil layers, contributing to increased water use efficiency. Conservation agriculture encourages the development of extensive and deeper root systems. This enhances the plant's ability to access soil water, contributing to increased water use efficiency.

Minimal soil disturbance and soil cover in conservation agriculture reduce water evaporation. This leads to improved water use efficiency as more water is retained in the soil for plant uptake. Conservation agriculture minimizes surface runoff, reducing water losses. More water remains in the root zone, enhancing water availability for plants and improving overall water use efficiency. Increased mycorrhizal associations which form symbiotic relationships with plant roots, thrive in undisturbed soils, enhancing nutrient uptake and overall plant health.

B. Permanent soil cover and water use efficiency: Soil cover reduces water evaporation, maintains soil temperature, and improves microbial activity. This contributes to enhanced nutrient cycling, water use efficiency and availability for plant uptake. Conservation agriculture practices lead to improved soil structure, facilitating root penetration and nutrient absorption. Enhanced soil structure promotes efficient water infiltration and nutrient movement.

C. **Crop rotation and nutrient cycling:** No-till systems contribute to increased nutrient retention in the soil, reducing nutrient runoff. The presence of crop residues promotes nutrient cycling by providing a substrate for microbial activity, resulting in more available nutrients for plants. Diversified crop rotations break cycles of pests and diseases and promote nutrient diversification.

Physiological Changes in Organic Farming

A. Role of organic inputs (Organic fertilizers & amendments): Organic farming (OF) emphasizes soil health through practices like cover cropping, crop rotation, and organic matter incorporation. Healthy soils provide a favorable environment for germination. OF typically involves the use of organic fertilizers, which release nutrients more slowly than synthetic fertilizers and promotes diverse nutrient availability. This can affect nutrient availability during germination and patterns of nutrient uptake by plants. Organic amendments often result in a more balanced nutrient profile. This contributes to optimal physiological processes in plants, preventing nutrient imbalances that may occur in conventional systems. Organic farming practices, such as the use of organic amendments and cover crops, increase organic matter content in the soil. Higher organic matter enhances water retention and availability to plants, improving water use efficiency.

B. Soil health and microbial Activity: Organic farming encourages beneficial microbial activity in the soil. This can positively influence germination by promoting symbiotic relationships between plants and soil microorganisms. Organic farming fosters a diverse microbial community, contributing to nutrient cycling and improved soil structure. These factors positively impact water holding capacity and water use efficiency. Mulching is a common practice in organic farming. It reduces soil evaporation, suppresses weed growth, and helps maintain soil moisture, leading to enhanced water use efficiency. Organic farming promotes mycorrhizal fungi, forming symbiotic relationships with plant roots. These associations enhance nutrient absorption and utilization by increasing the effective root surface area.

C. **Crop rotation and polyculture:** The continuous addition of organic matter and crop residues supports nutrient cycling. This ensures a steady supply of nutrients for plant growth, influencing nutrient uptake patterns. Organic farming practices often result in reduced nutrient leaching. This helps maintain a stable nutrient environment in the root zone, promoting efficient nutrient utilization.

Physiological changes in agroforestry system

A. **Tree-crop interactions:** Agroforestry systems involve the integration of trees and crops. The presence of trees can influence light penetration, nutrient cycling, and microclimate, affecting the vegetative growth patterns of associated crops. The presence of trees in agroforestry systems influences light intensity, microclimate, and nutrient cycling. This can lead to changes in nutrient availability and uptake patterns in associated crops. Agroforestry systems with trees and crops may exhibit complex root interactions. Trees and crops may have different root depths and patterns, influencing nutrient uptake dynamics. Trees in agroforestry systems can regulate soil moisture by influencing water movement and evaporation. This regulation enhances water availability for both trees and associated crops.

B. **Biodiversity impact:** Agroforestry systems, by promoting biodiversity, can have positive effects on vegetative growth by creating a more balanced and resilient ecosystem. Agroforestry systems enhance biodiversity, supporting a range of plants and microbes. This diversity contributes to nutrient cycling and availability, impacting plant physiological processes.

C. **Microclimate and soil moisture regulation:** Trees in agroforestry systems regulate microclimate and soil moisture. This can affect nutrient availability and uptake by influencing root activity and microbial processes.

Effect of moisture & mulching on physiological traits under conventional and conservation agriculture

Water is a crucial resource to crop production and development. Soil moisture stress limits crop productivity in the rain-fed ecosystems. It is one of the major abiotic stresses, which adversely affects agricultural productivity in the majority of regions of the world, with devastating economical and sociological impact, particularly in the arid and semi-arid regions. The damaging effect of drought depend not only its severity but also the development stage at which it occurs. Conservation practices, such as cover crops and no-till farming, are highly valued in agricultural systems for nutrient and soil-water management. Zero tillage has proven to be superior to conventional practices, saving on inputs like irrigation water, fuel, and nutrients (Saharawat et al., 2010; Acharya et al., 2019). Mulch acts as an insulating agent, preventing sharp fluctuations in soil temperature and contributing to less evaporation of stored water, promoting better soil water use by plants (Sharma & Bhardwaj, 2017).

The no-tillage approach facilitates enhanced water retention, mitigates maximum temperature levels, and reduces temperature fluctuations, leading to increased leaf area accumulation (Yang et al., 2018). Moreover, increased soil water storage capacity enhances the overall dry matter content in the no-tillage system as compared to conventional system (Freitas et al., 2017). Long-term no-tillage with straw mulching (NTSM) improves soil structure, water infiltration, reduces soil water evaporation, and increases soil organic matter and fertility. NTSM also stabilizes soil temperature and regulates water requirements for wheat throughout various growth stages. Straw mulching contributes to higher net photosynthetic rate, stomatal conductance, maximum carboxylation rate, and maximum rate of photosynthetic electron transport in flag leaves. Leaves under no-tillage show a 3.7%–12.5% higher net photosynthetic rate than those under traditional tillage (Zhang et al., 2021).

Additionally, straw coverage inhibits chlorophyll degradation in flag leaves, delaying leaf senescence. This practice improves soil moisture status, optimizes soil root trails, and fosters dry matter accumulation, leading to increased wheat yield, particularly in drought years (Wu et al., 2015). The rise in wheat yield is linked to increased soil moisture and temperature (Cook et al., 2006) and alterations in soil structure and fertility (Zhang et al., 2021). Biological nitrogen fixation (BNF) is associated with reduced use of inorganic nitrogen fertilizers in field crops, contributing to savings of fossil energy resources and decreased CO_2 emissions (Carranca, 2012).

BNF exhibits varied responses under different tillage systems. No-till practices, characterized by minimal soil disturbance, have been associated with positive effects on BNF. The reduced disruption allows for the preservation of soil structure and organic matter, creating a favorable environment for nitrogen-fixing bacteria. Studies suggest that no-till systems can enhance biological nitrogen fixation due to improved soil conditions, including enhanced moisture retention and increased microbial activity. Conversely, conventional tillage systems, marked by intensive soil disturbance, may negatively impact BNF by disrupting the habitat of nitrogen-fixing microorganisms and accelerating the breakdown of organic matter.. Furthermore, the incorporation of cover crops in any tillage system can positively influence BNF by providing additional organic matter and root exudates that stimulate the activity of nitrogen-fixing bacteria, contributing to the overall sustainability of soil nitrogen levels.

Conclusion

In conclusion, water plays a vital role in crop production, with soil moisture stress being a significant constraint in rain-fed ecosystems. Conservation practices such as no-till farming and cover cropping are essential for nutrient and soil-water management. No-tillage, especially when combined with straw mulching, has proven superior to conventional practices, saving resources like irrigation water, fuel, and nutrients. It enhances water retention, mitigates temperature fluctuations, and improves soil structure, fostering increased dry matter content. Additionally, no-tillage systems contribute to higher yields by optimizing soil moisture, temperature, and root development. Conservation practices also positively influences biological nitrogen fixation (BNF), reducing the need for inorganic nitrogen fertilizers and promoting sustainability in agriculture. Overall, adopting these conservation practices can mitigate the impact of abiotic stresses, enhance soil fertility, and contribute to more resilient and productive agricultural systems.

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APPLICATION OF DIFFERENT ADDITIVES FOR QUALITY SILAGE PREPARATION AND CONSERVATION

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Silage can be defined as the plant material that has undergone anaerobic fermentation in controlled environment. It is produced due to the activities of various naturally-occurring bacteria that convert the plant sugars into organic acids that preserve nutritional qualities. The main purpose behind the idea of ensilage is to conserve the digestible fiber, protein, and energy in the forage, and to maintain the protein in a form that can be utilized efficiently by the ruminant animal. Ensiling also helps in managing the feed shortages during lean seasons and hence animals remain in good health throughout the year. The major objectives behind the process of ensiling are:

- to achieve anaerobic conditions under which natural fermentation can take place
- to discourage the activities of undesirable microorganisms such as clostridia and enterobacteria

In order to achieve these objectives, various silage additives are being used for ensilage purposes. There are four phases to the ensiling process, which begin as soon as the crop is cut:

Aerobic phase: This phase lasts until all oxygen is used up. It is the final stage of respiration, which began once the crop was harvested. Plant enzyme activity will continue while oxygen is present.

Fermentation (anaerobic) phase: This begins once the oxygen in the silage has been used up and anaerobic conditions have been achieved. Lactic acid dominates in a good fermentation. pH drops to 3.7 – 4.5.

Stable phase: Stable low pH is achieved in this phase, and the acidic conditions limit microbial activity. Micro-organism populations may gradually decline although some microbes can remain active if the pH is not low enough. Yeasts become dormant, and unwanted clostridia, bacilli, and moulds can survive as spores, ready to develop if conditions are suitable for them.

Feed-out phase: Aerobic spoilage will start on exposure to air. Any dormant yeasts and mould spores, can degrade the available lactic acid and plant sugars. Heat is generated as carbon dioxide and water, resulting in loss of dry matter. Moulds begin to grow and can produce harmful mycotoxins. Dry matter losses can also be significant in this stage.

	Day 1	Day 2	Day 3	Day 7 to 21	After Day 21
Chemical changes	Oxygen + Sugar ↓ CO_2 Heat water Proteins degraded	Sugar ↓ Acetic Acid	Sugar ↓ Lactic Acid, Acetic Acid, Ethanol, Mannitol, CO_2	Sugar ↓ Lactic Acid, Acetic Acid, Ethanol, Mannitol, CO_2	Stable state until silage is exposed to oxygen

Oxygen
Microbial Growth
Temperature
pH

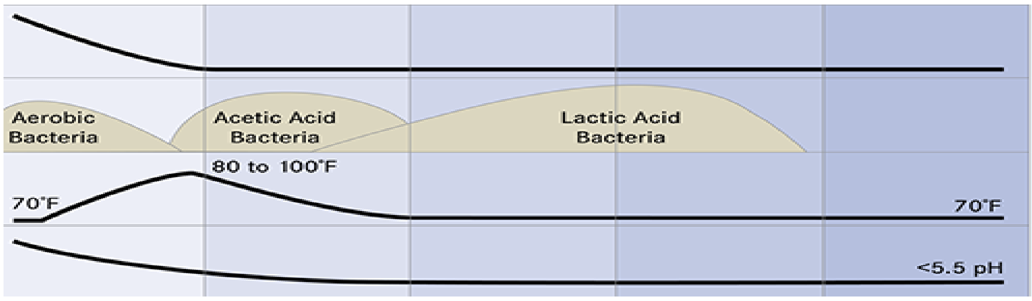

Figure 1: Phases of silage fermentation and storage

Silage additives

Silage additives can be defined as chemical or natural products (substances) added to the forage or grain mass to assist the fermentation process, improve crop preservation and its feeding value.

Addition of silage additives helps to control the preservation process so that by the time ensiling is completed, it still retains the nutritional value of original fresh forage. It also ensures that the growth of lactic bacteria predominates during the fermentation process, producing lactic acid in quantities high enough to ensure good silage (Oliveira, 1995). Additives are used to improve nutrient composition of silage, to reduce storage losses by promoting rapid fermentation, to reduce fermentation losses by limiting extent of fermentation, and to improve bunk life of silage (increase aerobic stability). It is widely accepted that silage additives can increase animal intake and animal performance through their effect on silage quality (Merry et al., 1993). The use of silage additives, however, does not make poor quality forage into good silage but can help convert good quality forage into excellent quality silage (Kenilworth and Warwickshire, 2012). Silage bacterial inoculants and chemical additives are known for their positive effects including improving fermentation, increasing DM and nutrient recovery, and extending aerobic stability. In addition to these effects, some commercial additives have demonstrated the capacity to mitigate the pathogenicity of silage, and thereby preventing the spread of pathogens on the farm.

Type of silage additives

Silage additives can be classified into 5 categories based on their mode of action:

Type of additive	Potential response*	Example
Fermentation stimulants		
a) Fermentable carbohydrates	A, B, C	Molasses, sucrose, glucose, citrus pulp, pineapple pulp, sugar beet pulp
b) Enzymes	A, B	Cellulases, hemicellulases, amylases
c) Inoculants	A, B, C	Lactic acid bacteria (LAB)

Fermentation inhibitors		
a) Acids and organic acid salts	A, B, C, D	Mineral acids (e.g. hydrochloric), formic acid, acetic acid, lactic acid, acrylic acid, calcium formate, propionic acid, propionates
b) Other chemical inhibitors	A, B, C, D	Formaldehyde, sodium nitrite, sodium metabisulphite
Aerobic spoilage inhibitors	B, C, D	Propionic acid, propionates, acetic acid, caproic acid, ammonia, some inoculants
Nutrients	C	Urea, ammonia, grain, minerals, sugar beet pulp
Absorbents	B	Grain, straw, bentonite, sugar beet pulp, polyacrylamide
***Potential response** A: Improve fermentation quality; B: Reduce in silo losses; C: Improve nutritive value; D: Reduce aerobic spoilage		

Figure 2: Classification of silage additives (Piltz and Kaiser, 2004)

Fermentation stimulants: promote the desired lactic acid fermentation and subsequently improve silage preservation quality by either increasing the population of beneficial lactic acid bacteria or by providing additional sugars used by silage bacteria

Fermentation inhibitors: inhibit the growth of all microorganisms or specific action targeted against harmful spoilage microorganisms

Aerobic deterioration inhibitors: are specifically designed to improve aerobic stability so as to reduce feedout losses due to aerobic exposure and inhibit the growth of lactate producing yeasts

Nutrients: when added to the forage at the time of ensiling, improve the nutrient value of silage

Absorbents: used to prevent effluent losses by raising the DM content of the silage and/or by absorbing moisture

Use of microbial inoculants as silage additives

In most cases, bacterial inoculants reduce pH, shift fermentation toward lactic acid, and reduce ammonia production. In general, inoculants are very useful on grasses, alfalfa, and clovers than in corn or small-grain silages but it also tends to be less-effective with a crop that is low in sugars. The ideal silage inoculant should have the following properties:

- It should grow vigorously and compete with other microorganisms
- It should tolerate low pH down at least 4.0
- It should be able to ferment glucose, fructose, sucrose, fructans, and pentose sugars

- It should not utilize organic acids in the silage
- It should grow at temperatures up to 120°F
- It should be able to grow in low-moisture environments

Lactic Acid Bacteria are commonly used as silage inoculant:

a) Fermentation of water soluble carbohydrates in forages

b) Production of organic acids

c) High palatability of fermented silages

d) Antimicrobial activity of lactic acid bacteria against undesirable bacteria

e) Improve ruminant gut health

Microbial silage inoculants can be classified into various categories based on their effect

Silage inoculant	**Mechanism**	**Example**	**Limitations/ Challenge**
First generation	Rapid decline in pH due to by increase in lactic acid production	Homolactic bacteria (LAB) such as *Lactobacillus plantarum*	Aerobically unstable
Second generation	Increased production of acetic or propionic acid, hence, improving the aerobic stability of silage	*Propionibacteria* spp. and *Lactobacillus buchneri*	Little impact on nutrient digestibility
Third generation	Hydrolyse ferulic acid-lignin linkages and increase the digestibility of fibre in the rumen (Nsereko *et al.,* 2008) and as a result may improve production	Lactic Acid Bacteria which produce Ferulic Acid Esterase	

Fourth-generation inoculants are presently under development with the focus on delivering silage with the properties of third-generation inoculants along with probiotic properties that could deliver performance or health benefits to the animal.

Conclusion

To improve silage quality, it is important to understand the biological and chemical processes that occur during ensiling, their effects on silage quality, and how these processes can be controlled. An effective additive may help make good silage better, but it will not make poor silage good. Especially, bacterial inoculants can increase the number of lactic acid bacteria in the silage. The desirable lactic acid bacteria use sugar to produce lactic acid, which results in a rapid decrease in pH to form a stable and high-quality silage.

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HARMONY WITH EARTH: EMBRACING ZERO-BUDGET NATURAL FARMING FOR SUSTAINABLE AGRICULTURE IN INDIA

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Undoubtedly, the technologies of the green revolution have significantly impacted the landscape of food production, bringing about a transformation in Indian agriculture from a subsistence-based approach to a surplus-generating enterprise. The reckless application of chemical inputs such as fertilizers, pesticides, and hormones, coupled with the over-exploitation of natural resources, has resulted in a deterioration of soil health and fertility. This has led to the depletion of natural resources and contamination of the environment, water, and food (Rakesh, 2022). These challenges emphasize the necessity to explore alternative agricultural systems that prioritize sustainability, environmental friendliness, non-degradation, and non-contamination. The objective is to provide enhanced income opportunities for farmers while ensuring the production of safe and nutritious food for the citizens. The approach of natural farming, besides being sustainable, non-degrading, non-depleting and resource-conserving is also cost-effective. It gives freedom to the farmers from purchased inputs, ensures comparable productivity, increased income and is safe for soil, environment and all life forms including humans and animals. The implementation of natural farming techniques in farmers' fields has been discovered to enhance soil fertility through the enrichment of organic carbon, heightened microbial activity, and increased earthworm activity, thereby facilitating the restoration of natural nutrient cycles. Furthermore, these practices contribute to improved water retention capacity and heightened overall biological activity in the soil. Fields practising natural farming with ample diversity have demonstrated reduced vulnerability to insect pest attacks.

Zero-Budget Natural Farming, championed by agriculturist Subash Palekar, stands as one of the various approaches to natural farming. In this method, a blend of natural inputs such as cow urine and dung, jaggery, lime, neem, and others are employed to enhance soil health, nutrient levels, and minimize input costs, among other advantages.

Natural farming provides a remedy for a range of issues, including food insecurity, the distress of farmers, and health concerns arising from pesticide and fertilizer residues in food and water. It addresses broader environmental challenges like global warming, climate change, and natural disasters. Furthermore, it holds promise in creating employment opportunities, thus preventing the migration of rural youth. True to its name, Natural Farming is both an art and practice, progressively recognized as a science, dedicated to collaborating with nature to achieve greater results with fewer resources.

Concept of NF

It represents a diversified farming approach that combines crops, trees, and livestock, facilitating the efficient utilization of functional biodiversity. When implemented effectively, Natural Farming not only boosts farmers' income but also brings about numerous advantages, including the restoration of soil fertility, improvement of environmental health, and the mitigation or reduction of greenhouse gas emissions. Natural Farming is grounded in the natural or ecological processes inherent in or around farms.

Features of Natural Farming

- According to natural farming principles, plants get 98% of their supply of nutrients from the air, water, and sunlight. And the remaining 2% can be fulfilled by good quality soil with plenty of friendly microorganisms. (Just like in forests and natural systems)
- The soil is always supposed to be covered with organic mulch, which creates humus and encourages the growth of friendly microorganisms.
- Farm made bio-cultures named Jeevamrit, Beejamrit etc. are added to the soil instead of any fertilizers to improve microflora of soil. Jeevamrit, Beejamrit are derived from very little cow dung and cow urine of desi cow breed.
- It holds the promise of enhancing farmers income while delivering many other benefits, such as restoration of soil fertility and environmental health, and mitigating and/or reducing greenhouse gas emissions.
- The system requires cow dung and cow urine (Gomutra) obtained from Indian breed cow only. Desi cow is apparently the purest as far as the microbial content of cow dung, and urine goes.
- In natural farming, neither chemical nor organic fertilizers are added to the soil. In fact, no external fertilizers are added to soil or given to plants whatsoever.
- In natural farming, decomposition of organic matter by microbes and earthworms is encouraged right on the soil surface itself, which gradually adds nutrition in the soil, over the period.
- In natural farming there is no ploughing, no tilting of soil and no fertilizers, and no weeding is done just the way it would be in natural ecosystems.
- Natural, farm-made pesticides like Dashparni Ark and Neem Astra are used to control pests and diseases.
- Weeds are considered essential and used as living or dead mulch layer.
- Multi-cropping is encouraged over single crop method.

Natural Farming Practices

The objective of natural farming is to rejuvenate soil health, preserve biodiversity, guarantee animal welfare, emphasize the judicious utilization of local resources, and advocate for ecological equity. This approach to farming is ecological in nature, as it collaborates with natural biodiversity, fostering the biological activity of the soil and effectively managing the intricate web of living organisms, encompassing both plants and animals, to coexist harmoniously with the food production system.

Important practices, essential for the adoption of natural farming include:

- No external inputs,
- Local seeds (use of local varieties),
- On-farm produced microbial formulation for seed treatment (such as bijamrita),
- On-farm made microbial inoculants (Jivamrita) for soil enrichment,
- Cover crops and mulching with green and dry organic matter for nutrient recycling and for creating a suitable micro-climate for maximum beneficial microbial activity in soil.
- Mixed cropping, ü Managing diversity on farm through integration of trees
- Management of pests through diversity and local on-farm made botanical concoctions (such as neemastra, agniastra, neem ark, dashparni ark etc);
- Integration of livestock, especially of native breed for cow dung and cow urine as essential inputs for several practices and ü Water and moisture conservation.

Objectives and Aims for Natural Farming Promotions

- Preserve natural flora and fauna
- Restore soil health and fertility and soil's biological life
- Maintain diversity in crop production
- Efficient utilization of land and natural resources (light, air, water)
- Promote natural beneficial insects, animals and microbes in soil for nutrient recycling and biological control of pests and diseases
- Promotion of local breeds for livestock integration
- Use of natural/local resource-based inputs
- Reduce input cost of agricultural production
- Improve economics of farmers

Principles for Natural Framing

- Adoption of diversified cropping system-based agriculture
- Recycling of naturally available nutrients in fields
- Recycling of on-farm generated biomass
- Use of locally developed and refined practices based on plant, animal and microbial source as raw materials
- Innovative practices continuously evolve on the field of farmers based on the cropping pattern, local climatic conditions, altitude, soil quality, severity and variability of insects and pests etc.

Scope of Natural Farming

Numerous operational models of natural farming exist globally, with zero-budget natural farming (ZBNF) emerging as the most widely adopted model in India. Natural farming contributes to the improvement of soil fertility and environmental health, facilitating a reduction in greenhouse gas emissions. Additionally, it holds the promise of augmenting farmers' income (Devarinti.,2016). In broader terms, Natural Farming can be seen as a significant strategy to safeguard the Earth for future generations. It possesses the potential to effectively manage various agricultural practices, thereby capturing atmospheric carbon in soils and plants for the benefit of plant life.

Importance of Natural Farming

Numerous research studies have highlighted the efficacy of natural farming, showcasing its positive impact on increased agricultural production, sustainability, conservation of water resources, enhanced soil health, and overall improvement in the farmland ecosystem. Recognized as a cost-effective agricultural practice, it also holds the potential to generate employment opportunities and contribute to rural development. Natural Farming addresses a spectrum of challenges, including food insecurity, agricultural distress, and health concerns arising from the residues of pesticides and fertilizers in food and water. Moreover, it offers a viable solution to global issues such as global warming, climate change, and natural disasters. Embracing the principles of Natural Farming, often regarded as an amalgamation of art, practice, and increasingly science, involves working harmoniously with nature to achieve more with fewer resources.

Benefits of Natural Farming

- Improve Yield-Farmers practicing Natural Farming reported similar yields to those following conventional farming. In several cases, higher yields per harvest were also reported.
- Ensures Better Health: - As Natural Farming does not use any synthetic chemicals, health risks and hazards are eliminated. The food has higher nutrition density and therefore offers better health benefits.
- Environment Conservation: -Natural Farming ensures better soil biology, improved agro-biodiversity and a more judicious usage of water with much smaller carbon and nitrogen footprints.
- Increased Farmers' Income: - Natural Farming aims to make farming viable and aspirational by increasing net incomes of farmers on account of cost reduction, reduced risks, similar yields, incomes from intercropping.
- Employment Generation

Current Scenario of Natural Farming in India

In India, several states are practicing Natural Farming. Prominent among them are Andhra Pradesh, Chhattisgarh, Kerala, Gujarat, Himachal Pradesh, Jharkhand, Odisha, Madhya Pradesh, Rajasthan, Uttar Pradesh and Tamil Nadu. Till now 6.5 lakh ha. area is covered under natural farming in India. Different State governments are promoting natural farming through various schemes. The state wise details of area and major crops covered under NF in India are given in Table 1.

Table 1. State-wise area Natural Farming in India

Sl. No.	States	Area in Ha
1.	Andhra Pradesh	100000
2.	Chhattisgarh	85000
3.	Kerala	84000
4.	Himachal Pradesh	12000
5	Jharkhand	3400
6.	Odisha	24000
7.	Madhya Pradesh	99000
8.	Tamil Nadu	2000
Total		**409400**

(Source: https://pib.gov.in/PressReleasePage.aspx?PRID=1813682)

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ADVANCING OF BIODYNAMIC AND NATURAL FARMING IN ACHIEVING SUSTAINABLE DEVELOPMENT GOALS

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Biodynamic and natural farming represents a paradigm shift in agricultural methodologies, emphasizing an ecologically harmonious approach to farming. Biodynamic agriculture, a concept initiated by Rudolf Steiner in 1924, is not merely an agricultural method but a profound understanding of the interplay between cosmic and earthly influences in agriculture (Koepf, 2005). Steiner introduced the concept of a farm as a single organism, where the interrelationship between soil, plants, animals, and the cosmos is crucial. Biodynamic farming relies on specific preparations made from fermented herbs, minerals, and manure to enhance soil biology and plant growth, reflecting a unique fusion of scientific insight and spiritual knowledge. In contrast, natural farming, as expounded by Masanobu Fukuoka in his seminal work, "The One-Straw Revolution," challenges the modern industrial agricultural paradigm with its minimalist, 'do-nothing' philosophy (Korn, 2015). Fukuoka's method, rooted in the principles of no tillage, no fertilizer, no pesticides, and no weeding, emphasizes the observance and imitation of natural ecosystems, thus reducing human labor and intervention in the farming process (Fukuoka, 2012).

The scientific rationale for these approaches in sustainable agriculture is grounded in their potential to create self-regulating agroecosystems. Sustainable agriculture, defined by the United Nations Food and Agriculture Organization, seeks to maintain and enhance environmental health, provide economic profitability, and foster social and economic equity (Allen et al., 1991). Research in sustainable agroecosystems has demonstrated that biodynamic and natural farming practices can lead to improved soil health, higher biodiversity, and reduced ecological footprints, thereby aligning closely with these goals (Hathaway, 2016). Studies have shown that biodynamic preparations can significantly affect soil properties, improving soil structure and fertility, and thereby enhancing crop yields and resilience to environmental stressors(Chaurasiya et al., 2023). Similarly, natural farming practices have been found to enhance soil biological activity and reduce the need for external inputs, leading to a more sustainable and cost-effective farming system (Padmavathy & Poyyamoli, 2011).

These farming methodologies are particularly relevant in the context of the Sustainable Development Goals (SDGs), specifically SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), and SDG 15 (Life on Land). Integrating biodynamic and natural farming into modern agricultural practices can contribute significantly to achieving these goals. For instance, by fostering biologically rich and self-sustaining farming systems, these methods can play a pivotal role in preserving biodiversity (Goal 15), ensuring sustainable food production systems (Goal 2), and promoting sustainable management of natural resources (Goal 12). The holistic and integrative nature of biodynamic and natural farming, which encompasses not only ecological but also socio-economic aspects, makes them a vital component in the quest for sustainable agriculture (Çakmakçı et al., 2023).

Historical Background and Evolution

1. *Global background*

Biodynamic and natural farming methodologies have emerged as significant responses to the challenges of conventional agriculture, with roots that delve into early 20th-century agricultural thought. Biodynamic farming, conceptualized by Rudolf Steiner in 1924, was one of the first systematic approaches to introduce ecological principles into agriculture. This method was developed in response to the decreasing soil fertility and degeneration of crop quality observed with the advent of chemical fertilizers. Steiner's lectures, known as the "Agricultural Course," proposed a farm as a self-sustaining ecosystem, emphasizing soil vitality, plant diversity, and ecological balance. His approach included unique soil preparations and an understanding of the farm about cosmic forces, concepts that were pioneering for the time and laid a foundational framework for what would later evolve into organic farming (Paull, 2011).

In a parallel development in Japan, Masanobu Fukuoka, a trained plant pathologist, began advocating for natural farming in the late 1930s. His approach, which gained prominence with the publication of "The One-Straw Revolution" in 1978, was rooted in the philosophy of minimal human intervention. Fukuoka's method involved no tillage, no fertilizers, and no pesticides, proposing that nature, left largely to its own devices, could sustainably produce crops. This method of farming challenged the prevalent agricultural paradigms of the time, emphasizing the need for harmony between farming practices and natural ecosystems (Devarinti, 2016).

The historical evolution of these farming practices reflects a growing recognition of the limitations and ecological costs of conventional, industrial agriculture. The late 20th century saw a surge in environmental awareness, leading to an increased interest in sustainable agricultural practices. Biodynamic and natural farming offered alternatives that were not only environmentally sustainable but also aimed at preserving the long-term fertility and health of the soil. These methodologies were among the precursors to the modern sustainable agriculture movement, contributing significantly to the development of organic farming standards and practices globally. Their evolution represents a shift from a focus on agricultural yield maximization to a broader consideration of ecological health, resource conservation, and long-term sustainability of farming systems.

2. *Indian background*

Natural farming in India is deeply rooted in its ancient agricultural traditions, reflecting a long-standing harmony between farming practices and the natural environment. Historically, Indian agriculture was characterized by its alignment with the rhythms of nature and a deep understanding of ecological principles, long before the advent of modern agricultural techniques.

Ancient Indian texts, such as the Rigveda and Atharvaveda, dating back to around 1500 BCE, provide evidence of a profound knowledge of agriculture and natural resource management (Patra, 2016). These texts highlight practices like crop rotation, soil fertility management through organic means, and the conservation of natural resources, principles that resonate strongly with modern natural farming methods. The traditional Indian farming system, known as 'Krishi,' was based on a holistic view of agriculture, where the interdependence of all life forms and natural elements was recognized and respected.

In the pre-industrial era, Indian farmers practised diverse cropping systems, utilized natural fertilizers like cow dung and compost, and employed biological pest control methods. These practices ensured sustainable yield while maintaining soil health and biodiversity. The reverence for nature inherent in these ancient methods is echoed in the contemporary natural farming movement in India, which advocates for a return to these sustainable and eco-friendly practices.

This historical continuum of natural farming in India represents not just a set of agricultural techniques, but a cultural and philosophical approach to farming that values ecological balance and sustainability. In recent times, there has been a resurgence of interest in these traditional methods, seen as viable alternatives to the environmentally damaging practices of modern industrial agriculture.

Principles of Biodynamic and Natural Farming

Biodynamic and natural farming are distinguished by their unique principles that emphasize ecological balance and sustainable agricultural practices. Biodynamic farming, conceived by Rudolf Steiner, is based on the idea of the farm as a self-sustaining ecosystem. Central to this approach are specialized preparations made from fermented herbs and minerals, used to enrich the soil and stimulate plant growth. These preparations, numbered 500 to 508, are applied according to specific cosmic rhythms, reflecting Steiner's belief in the interconnectedness of cosmic forces and terrestrial agriculture. Another key principle of biodynamic farming is the integration of livestock, which contributes to the farm's nutrient cycle, enhancing soil fertility and structure.

In contrast, natural farming, championed by Masanobu Fukuoka, is guided by the principles of no tillage, no fertilizer, no pesticides, and no weeding. This approach is predicated on the philosophy of 'do nothing' farming, where the goal is to intervene as little as possible in the natural processes. Fukuoka's method emphasizes the importance of observing and understanding nature's rhythms and patterns, allowing ecosystems to maintain their balance with minimal human interference. Crop diversity and polycultures are also integral to natural farming, ensuring a balanced and resilient agricultural ecosystem.

Both biodynamic and natural farming share a common objective of minimizing human impact on the environment while fostering a harmonious relationship between agriculture and the natural world. These principles reflect a profound respect for nature, aiming to create farming systems that are not only sustainable but also regenerative, contributing to the health of the earth and its inhabitants.

Biodynamic and Natural Farming in the Context of SDGs

Biodynamic and Natural Farming in the Context of Sustainable Development Goals (SDGs) represents a critical intersection of innovative agricultural practices and global sustainability targets. As the world confronts challenges such as climate change, food insecurity, and environmental degradation, the principles and methodologies of biodynamic and natural farming emerge as potent tools in addressing these issues. These farming approaches, deeply rooted in ecological and holistic principles, offer a unique lens through which to view and achieve several SDGs. This chapter delves into how biodynamic and natural farming practices align with and contribute to key SDGs, including Zero Hunger (SDG 2), Responsible Consumption and Production (SDG 12), Climate Action (SDG 13), and Life on Land (SDG 15), among others. By exploring this nexus, we can better understand the role of sustainable agriculture in fostering a more resilient and equitable world.

SDG 2: Zero Hunger

Biodynamic and natural farming practices directly contribute to SDG 2 by enhancing food security and nutritional quality. These methods prioritize soil health and biodiversity, which are critical for sustainable food production (Mrabet, 2023). Biodynamic farming, with its use of composts and biodynamic preparations, has been shown to improve soil structure and fertility, leading to higher yields and better crop resilience (Turinek et al., 2009). This improvement in yield is crucial for addressing hunger and food security. Furthermore, natural farming practices, such as polycultures and crop rotation, contribute to diversified and nutritious food production, thereby addressing the nutritional aspect of Zero Hunger. The emphasis on local, organic food production also reduces dependency on long supply chains, making food systems more resilient to global disruptions.

SDG 12: Responsible Consumption and Production

In the realm of SDG 12, biodynamic and natural farming exemplify sustainable production practices. These methods reduce dependence on synthetic chemicals and fossil fuels, thereby lowering the environmental footprint of agriculture. By focusing on local production and consumption, they also reduce the carbon emissions associated with long-distance transportation of food products. The principle of recycling and reuse in biodynamic farming, where waste products are turned into valuable inputs, aligns perfectly with the ideals of a circular economy. Moreover, natural farming's minimalist approach conserves resources and reduces waste, promoting more sustainable consumption patterns (Çakmakçı et al., 2023).

SDG 13: Climate Action

Both biodynamic and natural farming have significant roles in climate change mitigation and adaptation, aligning with SDG 13. The carbon sequestration potential of these farming methods is notable. Biodynamic farming practices, such as the use of green manures and cover crops, increase soil organic carbon, a key factor in carbon sequestration. Natural farming's no-tillage approach helps in maintaining soil carbon stocks and reduces greenhouse gas emissions (Krauss et al., 2022). Furthermore, the biodiversity inherent in these farming systems provides resilience against climate-related stresses, ensuring sustainable food production in the face of climate change.

SDG 15: Life on Land

SDG 15 focuses on protecting, restoring, and promoting sustainable use of terrestrial ecosystems (Bridgewater et al., 2015). Biodynamic and natural farming practices contribute to this goal through their promotion of biodiversity and ecological balance. The diverse habitats created in these farming systems support a wide range of species. Biodynamic farms often act as biodiversity hotspots, providing habitats for beneficial insects, birds, and other wildlife. Natural farming's approach of mimicking natural ecosystems contributes to the conservation of indigenous plant and animal species, thereby maintaining ecological balance and enhancing ecosystem services.

Other Relevant SDGs

Beyond the direct environmental impacts, these farming methods also contribute to SDGs like No Poverty (SDG 1) and Good Health and Well-being (SDG 3). The economic viability of biodynamic and natural farming can improve farmers' livelihoods, contributing to poverty reduction. Additionally, by avoiding hazardous agrochemicals, these farming practices protect farmers' and consumers' health, reducing the risk of diseases linked to chemical exposure and promoting overall well-being (Muhie, 2023).

Challenges

Globally, biodynamic and natural farming have been implemented with notable success across diverse geographies. In Europe, particularly in Germany and France, biodynamic farms have demonstrated resilience and profitability, even in challenging economic climates (Paull & Hennig, 2020). These farms often show enhanced soil quality and biodiversity compared to conventional farms. In India, the state of Kerala has seen a remarkable transformation with the adoption of natural farming methods, leading to improved livelihoods for smallholder farmers and a reduction in the use of chemical inputs (Khadse et al., 2018; Münster, 2018).

Challenges and Adaptations in Different Climates

Adapting these farming practices to different climates has been a challenge. In arid regions, water conservation and management are crucial. Techniques such as mulching and the use of drought-resistant crop varieties have been essential in these environments. In colder climates, the challenge lies in extending the growing season. Innovations like greenhouse farming and the use of biodynamic preparations that help improve soil warmth have been implemented.

Social and Economic Impacts

Socially, these farming methods have fostered community involvement and local food systems, enhancing food sovereignty. Economically, while initial transition costs can be high, long-term benefits include reduced input costs and premium pricing for organic produce. However, market access and consumer awareness remain challenges in many regions.

Scientific Basis and Research Findings

1. Soil Health and Biodiversity

Scientific research underpins the benefits of biodynamic and natural farming on soil health and biodiversity (Santoni et al., 2022). Studies have shown that these farming practices increase soil organic matter, enhance microbial activity, and improve overall soil structure (Carpenter-Boggs et al., 2000). This, in turn, supports a greater diversity of plant and animal life, contributing to healthier ecosystems.

2. Yield Comparisons and Nutritional Quality

Yield comparisons between biodynamic/natural and conventional farming have been mixed, with some studies showing comparable yields and others showing slight reductions. However, the nutritional quality of produce from biodynamic and natural farms often surpasses that of conventional farms, with higher levels of certain nutrients and antioxidants.

3. *Environmental Impact Assessments*

Environmental impact assessments of these farming practices indicate several benefits. Reduced chemical runoff, lower greenhouse gas emissions, and improved carbon sequestration are among the positive outcomes. These practices also contribute to higher water retention in the soil, reducing erosion and water pollution (Granstedt & Kjellenberg, 2005).

Challenges and Limitations

Economic Viability and Market Challenges

One of the primary challenges facing biodynamic and natural farming is economic viability. Transitioning from conventional to these sustainable farming methods often involves a significant initial investment in terms of both time and resources. Farmers may face decreased yields during the transition period, impacting their income (IFOAM, 2020). Moreover, the market for biodynamic and natural products is still developing. While there is a growing consumer base for organic and sustainably produced foods, the market share remains small compared to conventional products. Farmers also face challenges in terms of logistics and distribution, as the supply chains for organic products are not as well established as those for conventional products (Paciarotti & Torregiani, 2021)

Perceptions and Societal Acceptance

Societal acceptance and perceptions play a crucial role in the adoption of biodynamic and natural farming practices (Jaeger et al., 2023). Misconceptions and lack of awareness about the benefits of these methods can hinder their adoption. There is a prevalent belief in some circles that these methods are not as productive or scientific as conventional farming. This scepticism can be a barrier to consumer acceptance and may deter new farmers from adopting these practices.

Policy and Regulatory Hurdles

Policy and regulatory frameworks also present significant challenges. In many regions, agricultural policies are geared towards supporting conventional farming methods, with subsidies and research often focused on these practices. Biodynamic and natural farmers may not receive the same level of support, making it difficult for them to compete with conventional farms. Furthermore, certification and regulatory processes for organic and biodynamic products can be complex and costly, posing additional barriers for small-scale farmers.

Final Thoughts and Future Outlook

As we assess the current landscape and look towards the future, biodynamic and natural farming stand as pivotal elements in the quest for sustainable agriculture. These practices, rooted in ecological balance and respect for natural processes, offer a counter-narrative to the prevailing industrial agricultural model. They represent not just alternative farming techniques, but a fundamental shift in how we perceive and interact with our agricultural ecosystems.

The future of biodynamic and natural farming is intrinsically linked with the evolving global discourse on sustainable development. As the impacts of climate change and environmental degradation become more pronounced, there is a growing realization of the need for sustainable agricultural practices that can mitigate these effects. This is where biodynamic and natural farming, with their emphasis on carbon sequestration, biodiversity, and ecological harmony, can play a significant role.

Technological advancements are also set to play a crucial role in the evolution of these farming practices. Precision agriculture, data-driven farming techniques, and advancements in organic inputs could enhance the efficiency and appeal of biodynamic and natural farming. Additionally, the integration of these methods with innovative business models, such as community-supported agriculture (CSA) and direct-to-consumer sales platforms, could improve market access and economic viability.

Policy frameworks and educational initiatives will be key in facilitating the growth of biodynamic and natural farming. Governments and international organizations can support these practices through favorable policies, research funding, and by incorporating them into agricultural education and extension services. This will not only increase awareness but also equip the next generation of farmers with the knowledge and skills to implement these practices effectively.

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AGRICULTURAL WASTE RECYCLING METHODS

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Agricultural waste refers to undesirable or unsalable materials generated entirely from agricultural operations directly associated with crop cultivation (such as rice husk, wheat straw, sugarcane bagasse) or animal husbandry (including animal excreta, deceased animals), primarily for the purpose of profit or livelihood. India produces approximately 350 million tonnes of agricultural waste annually. As per projections by the Ministry of New and Renewable Energy, this significant volume of waste holds the potential to yield more than 18,000 megawatts (MW) of power annually, in addition to producing green fertilizer for agricultural purposes. With increasing population, there is a daunting challenge of food security in the coming years (Godfray *et al*., 2010). Meeting the demands of the growing population has led to a substantial increase in both livestock and crop production, consequently contributing to the generation of agricultural waste (Tripathi et *al*., 2019). These huge amounts of agricultural waste if not managed properly can pollute the environment like burning of rice straw causes environmental pollution through discharge of harmful gases such as CO_2 (70 %), CH_4 (0.66 %), CO (7 %), N_2O (2.09 %) and ash (Pathak *et al*., 2021) and uncontrolled disposal causes damage to the environment by contaminating soil, freshwater and polluting the air and creating public health risks (Duque-Acevedo *et al*., 2020). Recycling organic waste has benefits, such as utilization of nutrients, conservation of energy, reduction of fertilizers cost, reduction of soil pollution and sustainability of plant growth (Kowalska *et al*., 2020).

What is recycling

Recycling is the process of collection and conversion of waste into useful and new products. Recycling is done to minimize the pollution and the waste generated. Agricultural waste recycling is the process of properly disposing of organic waste from farmlands and agribusiness properties.

Methods of agricultural waste recycling:

1. Composting

Composting is the biological conversion of the solid waste of plant and animal organic materials into a fertile matrix through numerous micro-organisms, including actinomycetes, bacteria, and fungi, in the presence of oxygen. Composting processes undergo four stages: mesophilic, thermophilic, cooling, and finally ending with compost maturation, these stages can happen concomitantly rather than consequently (Belyaeva and Haynes, 2009). Over the past few decades, traditional composting methods such as vermicomposting, aerobic composting, and anaerobic composting have become widely adopted on a global scale. Numerous studies have demonstrated that the utilization of agricultural waste management through composting in the field improves soil texture and structure, resulting in various other positive impacts on agricultural fields (Muhammad *et al*., 2023).

2. Animal feed

One of the most common and efficient ways of recycling organic waste is by giving agricultural and food waste to cattle and other animals as food. Feeding organic waste to animals is a simple and easy method of waste recycling. However, the direct feeding of organic waste to animals might result in some health issues in such animals. Therefore, different countries like the US have made regulations on the extent of food and type of food given to the animals. Recycling of food through animal feed has many advantages like reduced pressure on landfills, reduced methane productions from fruits and vegetables, and the lack of need to convert organic waste into some other forms. This also helps the farmers as they do not have to buy extra animal feed and eventually, helps the economy.

3. Biogas production

Biogas is generated through a biochemical process where specific bacteria convert biological wastes into a valuable gas. This gas, deriving from a biological process, it has been named biogas. The production process of biogas is anaerobic, occurring in two distinct stages known as the acid formation stage and the methane formation stage. Methane gas constitutes the primary component of biogas. In the anaerobic digestion process, there is a recent trend of combining crop residues and animal manure to generate biogas. Co-digesting these materials enhances the biogas production rate compared to the digestion of individual feedstocks because of the better balance between carbon and nitrogen (El-Mashad and Zhang, 2010).

4. Rendering

Rendering is a procedure that transforms discarded animal tissue into stable, usable materials. During the rendering process, fatty tissues, bones, and animal carcass are exposed to a high temperature of about 130°C and then pressurized to destroy pathogens. Rendering can be carried out on both the kitchen and industrial scale.

5. Paper production

The paper industry, reliant on forests, has raised significant environmental concerns due to the depletion of forest cover (Vivek and Maheswari, 1998). A study by Ekhuemelo *et al*., (2012) identified giant bluestem, maize stalk, bahaman grass, peel from maize cob, banana leaf, bagasse, banana stalk, pineapple leaf and gamba grass as feasible non-wood raw materials for paper production. This study demonstrates the potential of utilizing waste materials in our environment as an alternative to timber, aiming to safeguard and conserve our environment from the detrimental impacts of deforestation.

6. Biomass conversion

It includes methods such as thermochemical and biochemical conversion, which convert agricultural waste into valuable products such as biofuels, biochemicals, and bioplastics.

Some of the widely recognized biomass conversion processes include:

- **Combustion:** Utilizing biomass combustion for heat and electricity generation stands as a sustainable alternative to fossil fuels. This energy source can be derived from renewable sources, such as plants and waste, which can be consistently replenished, making it an environmentally friendly option.

- **Fermentation:** Biofuels such as ethanol or biodiesel can be produced from fermented crops or sugarcane, offering a cleaner alternative to fossil fuels in transportation and various industries.
- **Pyrolysis:** Applying heat to biomass in the absence of oxygen results in the production of biochar, bio-oil, and syngas. Biochar can serve as a soil amendment, while bio-oil and syngas can undergo additional processing to yield biofuels and other valuable products.
- **Gasification:** The partial oxidation process transforms biomass into a gas mixture called syngas. Syngas has applications in power generation and can be subjected to additional processing to manufacture a range of chemicals and liquid fuels.

Benefits of agricultural waste recycling

- Recycling organic waste through composting or anaerobic digestion results in nutrient-rich fertilizers, safeguarding water quality and promoting large-scale sustainable food production.
- Farmers have the opportunity to increase their earnings and cut down on waste disposal expenses by utilizing waste for bioenergy or composting, simultaneously enhancing soil health and crop productivity.
- Organic waste recycling holds significant importance in minimizing air, water, and land pollution, addressing issues such as odorous emissions and gas generation.
- Treating waste as a valuable resource contributes to the establishment of a more sustainable and resilient agricultural sector, fostering long-term economic growth, and protecting the environment.

Conclusion

Agriculture operations produce a lot of waste from farms, slaughterhouses, and poultry houses. Mismanagement can lead to various problems like the emission of greenhouse gases, disease transmission, unpleasant odours, and water source contamination. Recycling agricultural waste has several benefits like reduced dependence on non-renewable resources, improved living environment, sustainable product creation, and bio-energy production.

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CROP- PLANNING FOR ROUNDS THE YEAR FODDER PRODUCTION IN NATURAL AND ORGANIC FARMING

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For food security in India livestock production and agriculture are complementary to each other and both are crucial for farmers with small and marginal holding. In mixed crop-livestock production system, dairy production contributes 20 to 50% of family income. The share of livestock for underprivileged marginal and landless livestock owner is as high as 70 to 80% during drought year. India is gifted with the largest livestock population in the world. It accounts for about 57.3 per cent of the world's buffalo population and 14.7 per cent of the cattle population. There are about 71.6 million sheep and 140.5 million goats in the country. Farmers of marginal, small and semi-medium operational holdings (area less than 4 ha) own about 87.7% of the livestock. Hence development of livestock sector would be more inclusive.

Livestock is symbolic to wealth and power across civilizations for centuries. India is blessed with diversified type of livestock. Its livestock sector is one of the largest in the world. It has 56.7% of world's buffaloes, 12.5% cattle, 20.4% small ruminants, 2.4% camel, 1.4% equine, 1.5% pigs and 3.1% poultry. The importance of livestock in Indian agriculture is well recognized. Livestock not only provides food and nutritional security through supply of milk, meat and self-employment but also plays an important role for poverty alleviation of smallholder livestock farmers. Natural farming is also dependent on livestock particularly cows for preparation of various inputs.

The average milk yield of cattle in the world and Europe is about 2040 kg and 4250 kg per lactation respectively, the average milk yield of Indian cattle is about 1000 kg. While genetic improvement and health care are the prerequisites for sustainability, efficient feeding and marketing will help in increasing the profitability, because 65-70% of the total cost of livestock farming is attributed to feeding. With feeding of good quality forage, particularly leguminous fodder, feeding of concentrate can be reduced significantly. At present, the country faces a net deficit of 35.6% green fodder, 10.95% dry crop residues and 44% concentrate feed ingredients. The demand of green and dry fodder will reach to 1012 and 631 million tonnes of by the year 2050 (Table-1).

Table 1. Demand and supply estimates* of dry and green forages (million tons)

Year	Demand		Supply		Deficit		Deficit as %	
	Dry	Green	Dry	Green	Dry	Green	Dry	Green
2010	508.9	816.8	453.2	525.5	55.72	291.3	10.95	35.66
2020	530.5	851.3	467.6	590.4	62.85	260.9	11.85	30.65
2030	568.1	911.6	500.0	687.4	68.07	224.2	11.98	24.59
2040	594.9	954.8	524.4	761.7	70.57	193.0	11.86	20.22
2050	631.0	1012.7	547.7	826.0	83.27	186.6	13.20	18.43

(Source- Vision,2050, IGFRI)

At the current level of growth in forage resources, there will be 18.4 % deficit in green fodder and 13.2% deficit in dry fodder in the year 2050. To meet out the deficit, green forage supply has to grow at 1.69% annually. The deficit and supply in crude protein (CP) and total digestible nutrients (TDN) are given in Table 2. The situation is further aggravated due to increasing growth of livestock particularly that of genetically upgraded animals. The available forages are poor in quality, being deficient in available energy, protein and minerals. To compensate for the low productivity of the livestock, farmers maintain a large herd of animals, which adds to the pressure on land and fodder resources.

Table 2. Demand and availability estimates of CP and TDN (million tons)

Year	Requirement		Availability		% Deficit	
	CP	TDN	CP	TDN	CP	TDN
2010	60.04	347.8	42.95	271.3	28.47	21.99
2020	62.58	362.5	47.18	290.5	24.60	19.87
2030	67.01	388.2	53.09	320.2	20.78	17.52
2040	70.19	406.6	57.61	342.8	17.92	15.69
2050	74.44	431.2	61.92	364.5	16.81	15.47

(Source- Vision, 2050, IGFRI)

Quality fodder production plays an important role in dairy industry. Green forage based economical feeding strategies are required to reduce the cost of quality livestock product as the feed alone constitutes 60-70% of the milk production cost. Thus any attempt towards enhancing feed availability and economizing the feed cost would result in increased margin of profits to livestock owners also. There is tremendous pressure of livestock on available total feed and fodder, as land available for fodder production has been decreasing. At present, the country faces a net deficit of 35.6% green fodder, 10.95% dry crop residues and 44% concentrate feed ingredients. In India the cropped area under fodder is only 4.2 to 4.4% of the total cultivated area and there is hardly any scope of expansion due to increasing pressure on agricultural land for food and cash crops. On the other hand maintaining green fodder availability round the year is also a challenge especially during the lean periods of summer (may-june) and winter (November-december).

Productivity and quality of forage crops will depend on the growing environment, which can be altered by various agronomic management practices, starting from sowing to harvesting viz. Sowing time, Planting densities, Cultivars, Crop Mixtures, Nutrient management, Water Management, Weed management, Harvesting management etc. Rapid industrialization and mining areas has caused shrinkage of grazing and fodder producing lands. Due to non availability of quality green fodder throughout the year, milk producers are forced to utilize extra concentrates for optimum milk production. On account of this cost of milk production is higher in such areas. The current milk production level can be sustained and enhanced by better feeding strategies and year round green fodder production through Intensive year round green production rotations.

Year-Round Forage Production Through Intensive Year Round Green Production Rotations

Overlapping cropping systems developed to fulfill the needs of dairy farmers for green fodder throughout the year and for small farmers requiring maximum forage from a piece of land. It consists of raising berseem, inter-planted with hybrid Napier in spring and intercropping the inter-row spaces of the grass with cowpea during summer after the final harvest of berseem (Table 3). This system was found superior to multiple crop sequences both in terms of production and economic returns. The hybrid Napier could be successfully replaced with relatively soft and palatable perennial grasses like *Setaria* and guinea grass and berseem with lucerne wherever required.

Table 1 Round-the-year fodder production systems

Crop sequence	Green fodder yield (tonnes/ha/year)
Napier x Bajra hybrid + Cowpea - Berseem	260
Maize + Cowpea – MP Chari + Cowpea – Berseem + Japanese rape	197
MP Chari + Cowpea – Berseem + Japanese rape	184
Cowpea – MP Chari + Cowpea – Berseem + Japanese rape	176
Napier x Bajra hybrid + Cowpea – Berseem – Cowpea	255

The intensive cropping systems when managed properly using modern techniques of soil and crop management are able to yield 180 - 300 tonnes of green fodder (30 - 55 tonnes dry fodder) per ha/year. Some of the intensive cropping systems have been suggested for different regions.

North Zone

Maize + Cowpea – Sorghum + Cowpea (two cuts) – Berseem + Mustard.

Sudan grass + Cowpea – Maize + Cowpea – Turnip – Oats (two cuts).

Hybrid Napier or *Setaria* inter-planted with cowpea in summer and Berseem in winter (9 -10 cuts/year).

Teosinte + Cowpea (two cuts) – Carrot – Oats + Mustard/*Senji* (two cuts).

Western and Central Zone

Bajra + *Guar* (Clusterbean) (two cuts) – Annual Lucerne (6 cuts).

MP Chari + Cowpea (2 cuts) – Maize + Cowpea - Teosinte + Cowpea (2 cuts).

Hybrid Napier or *Guinea* or *Setaria* grass inter-planted with Cowpea in summer + Berseem in winter (8-9 cuts/year).

Hybrid Napier or *Guinea* or *Setaria* grass interplanted with Lucerne (8-9 cuts/ year).

Southern Zone

Sorghum + Cowpea (3 cuts) – Maize + Cowpea – Maize + Cowpea.

Hybrid Napier or *Guinea* or *Setaria* grass inter-planted with Lucerne (8-9 cuts) or Hybrid Napier + *Subabul* / *Sesbania* (9-11 cuts/year).

Sudan grass + Cowpea (3 cuts) – M.P. *Chari* + Cowpea (three cuts).

Para grass + Centro (*Centrosema pubescens*) (9-11 cuts/year).

Eastern Zone

Maize + Cowpea – Teosinte + Rice bean (2 cuts) – Berseem + Mustard (3 cuts).

M.P. Chari + Cowpea – *Dinanath* grass (2 cuts) – Berseem + Mustard (3 cuts).

Para grass + *Centrosema pubescens* (8-9 cuts/year).

Hybrid Napier or Setaria grass inter-planted with *Subabul* or Common Sesban (*Sesbania sesban*) (9-10 cuts/year).

Conclusion

Under the scenario of non/limited availability of quality green fodder throughout the year, milk producers can be sustained and enhanced by better feeding strategies and year round green fodder production through natural farming and organic management practices. Since livestock and natural and organic farming practices are complementary to each other, there is vis-à-vis scope for development of each other.

SYNERGIES OF COW-BASED LIQUID FORMULATIONS IN NATURAL FARMING

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India's food production leapt to self-sufficiency following the Green Revolution era. The ship-to-mouth days are a thing of the past. The nation is now food self-sufficient and even exports numerous agricultural commodities thanks to technologies such as intensive cropping systems, the use of high-yielding seed types, chemical fertilisers, irrigation, and agricultural mechanisation. The burgeoning concerns regarding sustainability and environmental impact have propelled a collective consciousness within the agricultural community. As the need for sustainable practices becomes increasingly urgent, natural farming faces a crucial juncture. Questions about resource efficiency, carbon footprints, and the overall ecological footprint of traditional methods have sparked a quest for alternative, environmentally conscious approaches. Amidst these concerns, the concept of natural farming emerges as a beacon of hope. Natural farming, characterized by its emphasis on ecological balance, minimal external inputs, and harmonious coexistence with nature, is gaining remarkable traction in the context of dairy agriculture. Farmers and agricultural enthusiasts alike are exploring the potential of natural farming as a transformative solution that aligns with the principles of sustainability.

Natural Farming

Natural farming, often rooted in ancient agricultural practices, finds its resurgence in contemporary times as a response to the pitfalls of industrialized farming. Pioneered by visionaries who recognized the importance of working with nature rather than against it, this age-old wisdom is experiencing a renaissance, offering a promising path toward sustainable farming. It blends crops, trees, and livestock in an ecologically friendly, chemical-free, diversified farming method that promotes functional biodiversity (Rosset and Martínez-Torres, 2012). Its philosophy is based on the idea of collaborating with nature and natural cycles to produce food that is safer and healthier while preserving the wellbeing of the land, people, and cattle. Masanobu Fukuoka (1913–2008), a Japanese farmer and philosopher, introduced natural farming, which he extensively detailed in his well-known book "The One-Straw Revolution" (Fukuoka,1987). Natural farming offers numerous benefits, including eco-friendly practices, high-quality produce, and efficient preparation of farm inputs. A key aspect is the reliance on locally accessible natural resources for nutrient sources, soil conditioners, insect controllers, and disease cures. This eliminates the need to purchase materials from the market, aligning with the nutritional cycle idea. By minimizing external inputs, natural farming reduces costs and enhances overall profitability for farmers (Bana *et al*., 2022).

Role of cow in natural farming

Natural farming relies on natural manures and cow-based liquid organic biofertilizers to enhance soil health and preserve the environment. The symbiotic relationship between cows and natural farming is characterized by several key linkages. This approach aims to reduce contamination risks by utilizing animal wastes, green manure, and crop residue as nutrient sources (Mishra, 2018). Cows, integral to natural farming, contribute significantly to the sustainable agricultural system. Their essential inputs, such as nutrient-rich dung and urine, serve as potent fertilizers and biopesticides. Their grazing activities aid in weed control and pasture management, fostering a holistic and regenerative approach. The utilization of these natural by-products establishes a closed-loop nutrient cycle, promoting soil health and fertility in natural farming.

Liquid Formulations

The use of organic liquid formulations has a long history dating back to the Vedic age, as evidenced by references in Vrikshayurveda and its application in crop cultivation has demonstrated significant promise in enhancing plant well-being and yield, all the while decreasing dependence on traditional chemical fertilizers that pose risks to both human health and the environment. In the present day, there is a growing trend and increased demand for organic liquid formulations made from on-farm resources. These formulations contribute organic and mineral matter to the soil, enriching it with beneficial microflora, and gaining preference among farmers (Priya *et al*., 2019; Biswas and Das, 2022). The ingredients of these liquid formulations typically include cow dung, cow urine, legume flour, and jaggery, which are rich in both macronutrients and essential micronutrients. Additionally, they contain numerous vitamins, essential amino acids, and growth-promoting compounds such as indole acetic acid (IAA) and gibberlic acid (GA). This diverse composition is believed to be responsible for the positive impact on soil health and plant growth. Overall, the incorporation of these liquid formulations is seen as a beneficial practice, aligning with sustainable and organic agricultural approaches (Gore and Sreenivasa, 2011).

Table 1. Ingredients of Different Liquid Formulations

Formulations	Cow dung (kg)	Cow urine (L)	Water (L)	Jaggery	Additional ingredients	References
Jeevamruth	10	10	200	2kg	Pulse flour(1kg) and a handful of soil	Shaikh and Gachande, 2015
Beejamruth	5	5	50	-	handful of soil and 50g of calcium chloride	Sreenivasa *et al*., 2010
Amritpani	10	-	200	500g	Cow ghee(250g)	Shekh *et al*., 2018
Panchagavya	10	10	-	-	Cow ghee (1kg), Cow milk (2L), Curd(2L)	Kumar *et al*., 2019
Dashparni	3	5	-	-	Neem leaves, Jatropa leaves, Heart-leaved moonseed leaves, Custard apple leaves, Karanja leaves, Castor leaves, Nerium leaves, Aak leaves, green chilli, Garlic	Charapale *et al*., 2021
Neemastra	2	5	100	-	Neem leaves (5 kg)	Rameez and Ray, 2023

Brahmastra	-	10	-	-	Neem leaves (3kg) custard apple, papaya, pomegranate, and guava leaves	Devapatni *et al.*, 2023
Agneyastra	-	10	-	-	Tobacco leaves,green chilli, garlic, neem leaves	Devapatni *et al.*, 2023

Jeevamruth is a liquid fermented mixture that contains a lot of good microbes that stimulate the activity of both soil and phyllospheric microorganisms when applied to fields or foliage. Using additives like jaggery and pulse flour during the 48-hour fermentation process helps the aerobic and anaerobic bacteria found in desi cow dung and urine grow. The resulting solution contains beneficial microorganisms such as nitrogen-fixing and phosphorus-solubilizing bacteria, fungi, and protozoa. These microorganisms play a pivotal role in improving soil health by breaking down organic matter into nutrients that can be readily absorbed by plants. Jeevamruth exhibits acidity with a pH value of 4.93 and serves as a valuable reservoir of both macro and micro-nutrients, including nitrogen (1.97%), phosphorus (0.172%), potassium (0.29%), manganese (47 ppm), and copper (50 ppm) (Kumar *et al.*, 2021).

Application: Jeevamruth can be applied through both foliar and irrigation methods. For irrigation through drip irrigation, canal water, or sprinklers, the full 200 litres of Jeevamruth can be used. When spraying, the mixture needs to be diluted. The first spray should occur a month after seeding or seedling transplantation. For spraying, 5 litres of filtered Jeevamruth should be mixed with 100 litres of water. The second spray, 21 days later, involves a mixture of 10 litres of filtered Jeevamruth and 150 litres of water. The third dose, administered 21 days after the second, consists of 20 litres of filtered Jeevamruth mixed with 200 litres of water.

Beejamruth is a concoction of cow dung, urine, milk, lime, and water. 5 kilogrammes of cow dung wrapped in a cloth were submerged in 50 litres of water for the entire night. The tied dung is regularly squeezed and submerged in water in the morning of the following day. This extract was mixed with 5 litres of cow urine, a handful of soil, and 50 g of calcium chloride. It's applied to seeds to improve germination, establishment, growth, and yield. It comprises beneficial microorganisms that improve nitrogen-fixing abilities and provide protection to plants against detrimental pathogens found in both soil and seeds. Furthermore, the use of Beejamrita enhances the availability of essential nutrients in the soil, leading to a significant improvement in crop yield (Nirmale and Ulape in 2020). Applying beejamruth to seeds is said to protect the crop from harmful soil-borne illnesses and aid in the production of IAA and GA (Sreenivasa *et al.*, 2010).

Amritpani is renowned as a rejuvenating solution for depleted soil, containing a diverse range of nutrients that enhance soil's physical, chemical, and biological health. Additionally, it promotes plant growth, yield, and quality. The preparation of Amritpani primarily involves thoroughly mixing fresh cow dung and honey or jaggery to create a creamy paste. Subsequently, cow ghee is added and blended thoroughly. The resulting mixture is then poured into 200 litres of water and stirred to achieve a consistent suspension. The container's mouth is covered with cloth, and within 7-10 days, it is ready for use (Biswas and Das, 2022). Amritpani is frequently used as a bio-inoculant, which aids in the enriching and revitalization of soil. It is made from a concoction of jaggery, ghee, honey, and cow dung. It can be sprayed on leaves or used directly to the ground (Kumar and Singh, 2021).

Panchagavya is a concoction of five items made from the native cow. Cow dung, cow urine, cow milk, cow curd, and cow ghee are among these five items. To accelerate and improve the fermentation process, additional ingredients such as jaggery, sugarcane juice, soft coconut water, ripe bananas, and yeast are used in addition to these five goods (Kumar and Singh, 2021). According to Sudhakar *et al*. (2011), the use of panchagavya in foliar spraying has been observed to significantly impact the productivity of maize crops. Optimal maize yield was attained when the complete recommended fertilizer dose (RDF) was applied, along with three applications of 3% Panchagavya at distinct stages of the crop's development (20, 40, and 60 days after sowing).

Dashparni extract is made entirely of natural substances, it is incredibly effective at controlling a wide range of insect pests and diseases. It boosts the immune system of the plant. It has antifungal and antiviral properties. Neem leaves, Jatropa leaves, Heart-leaved moonseed leaves, Custard apple leaves, Karanja leaves, Castor leaves, Nerium leaves, Aak leaves, green chilli, Garlic, Cow dung, Cow urine are the ingredients (Charapale *et al*., 2021).

Neemastra is made by crushing 5 kg of neem leaves in water, adding 5 lit of cow urine and 2 kg of cow dung, and fermenting for 24 hours while stirring occasionally. The extract is filtered, diluted it to 100 lit, and can be applied as a foliar spray over an acre to combat mealy bugs and sucking pests (Charapale *et al*., 2021). Neemastra has demonstrated efficacy in managing various pests and diseases that affect crops, without causing harm to non-target organisms, the environment, or human health. Biopesticides such as Neemastra are crucial in agricultural production and are progressively embraced as integral components of integrated pest management systems, owing to their numerous benefits compared to synthetic pesticides (Thirumurthy and Mol, 2020). Apart from its abilities in pest control, it has been identified as a beneficial fertilizer and soil conditioner when utilized alongside other organic substances (Roshan and Verma, 2015).

Brahmastra is made by 3 kg of neem leaves are crushed and mixed with 10 litres of cow urine. Simultaneously, a mixture of 2 kg each of custard apple, papaya, pomegranate, and guava leaves is crushed in water. The two mixtures are combined and boiled five times at intervals until the volume reduces by half. After a 24-hour rest, the extract is filtered and squeezed, suitable for storage in bottles for up to 6 months. This concoction proves effective against sucking pests, as well as pod and fruit borers. For application, dilute 2-2.5 litres of this extract in 100 litres of water for use on one acre of farmland (Charapale *et al*., 2021). It is successful in managing pests in castor plants by maintaining elevated populations of beneficial organisms such as coccinellids, spiders, and Microplitis coccons (Kumar and Sarada, 2020)

Agneyastra's composition may vary based on the recipe or manufacturer, typically including organic elements like cow urine, cow dung, neem leaves, chili peppers, garlic, and onion. These components are renowned for their insecticidal and fungicidal properties, effectively combating pests and diseases in crops. To prepare agneyastra, mix 10 liters of local cow urine with crushed tobacco leaves, green chili, and garlic in an earthen pot. Add 5 kilograms of neem leaves pulp, boil the solution thoroughly five times, and let it ferment for approximately 24 hours before straining it through a muslin cloth. The resulting mixture is then diluted in water and applied as a spray on crops (Devapatni *et al*., 2023).

These liquid formulations can be used in almost all crops. Jeevamruth, Beejamruth, Panchgavya and Amritpani are employed to promote plant growth, improve soil fertility, and enhance overall crop health whereas Dashparni, Neemastra and Brahmastra are employed to manage pests like fruit, stem and pod borer, mealy bugs, sucking pests, leaf rollers, etc.

Conclusion

In natural farming, cows are integral partners in enhancing soil health, promoting biodiversity and maintaining the overall balance of the farming ecosystem. Natural farming emphasizes humane treatment of cows, prioritizing their well-being and disease prevention without relying on chemical interventions. This underscores the symbiotic relationship between cows and agriculture, establishing a regenerative and harmonious farming system.

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INSECT PEST MANAGEMENT IN ORGANIC FARMING

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The ensure of production of high-quality foods in modern agriculture, effective quality control is necessary. Agrochemicals, widely employed in agriculture, play a crucial role in managing weeds, diseases, and pests in crops. Agrochemicals serve various purposes such as insecticides, herbicides, fungicides, bactericides, miticides, nematicides, molluscicides, and rodenticides based on their desired functions. The use of agrochemicals increases crop yield however, non-judicious application leads to harmful effects like soil degradation, environmental pollution, residue accumulation, loss of biodiversity, human health concerns, groundwater contamination etc., Organic farming is a holistic system that works in harmony with nature, avoiding the use of synthetic chemicals, genetically modified organisms (GMOs), and other artificial inputs. Instead, organic farming relies on natural processes and traditional agricultural methods to cultivate crops and raise livestock (Costa, *et al.,* 2023).

Organic farming predominantly relies on preventive measures for pest management, emphasizing ecologically sound practices to preserve ecosystem health and enhance plant resistance to pests and diseases (El-Shafie, 2019). The first line of defence aims to create an environment less conducive to pest attacks. In the event of pest and disease threats, a secondary line of defence is implemented, employing curative methods like the introduction of predators, parasitoids, plant-based products, and environmentally friendly chemicals. The holistic approach of organic farming prioritizes the overall health of the ecosystem, promoting sustainable practices that contribute to long-term soil and crop well-being while minimizing the need for synthetic inputs.

Practices to manage Insect pests in organic Farming

1. Cultural measures

Cultural practices are the earliest methods employed for pest suppression. Even minor adjustments in cultural practices can significantly influence the entire ecosystem. Nevertheless, their effectiveness is limited as they require careful planning in advance and are primarily preventive, offering less assistance during severe outbreaks of insect pests (Haldhar, *et al.,* 2017).

- **Use of resistant cultivars:** Genetically modified crops (GMOs or transgenic crops) are prohibited in organic production systems. Selection of insect-resistant cultivars based on plant size, shape, colouration, leaf hairs, and natural chemicals (both attractants and repellents) significantly influence the outcome of insect crop colonization.
- **Crop rotation**: Growing different crops in sequential seasons with aim of disrupting life cycle of pests and diseases.
- **Time and method of planting**: Deciding stage and method of planting is complex. Early planting is recommended for some crops to reach a less susceptible stage, countering pest

issues. In endemic areas, avoiding off-season cultivation of late crops like cauliflower is advisable to manage pest problems effectively, Early plating reduces gall midge, leaf folder of rice, shoot fly and gram pod borer in chickpeas.

- **Fertilizer management**: Organic manures generate a temporary nitrogen stress in plants, without hampering crop growth. This induces the intrinsic production of defence compounds that discourage pest attacks. The lower nitrogen levels resulting from organic manures contribute to increased phenols, tannins, and lignin, enhancing leaf toughness and the production of cell wall-related structural compounds.
- **Water management**: Irrigation exerts both direct and indirect influences on pest insects and pathogens. The direct impact includes the potential reduction of insect populations as overhead sprinklers dislodge insects from plants or elevate microenvironment humidity, promoting diseases caused by bacteria or fungi. The effect varies based on the irrigation method employed, be it drip, overhead sprinkler, or flood irrigation. Lushness resulting from irrigation may attract more insect pests, while drought-stressed plants can become more susceptible. While irrigation is primarily driven by crop growth and weather, it can be considered a tool for pest control when scheduling allows for flexibility, suppressing pest insects as needed.
- **Tillage**: Tillage operations like summer ploughing can also destroy insects overwintering in the soil as eggs, pupae, or adults, and reduce pest infestation.
- **Mulches**: Compared to bare soil, mulching supress insects. Various plastic colours, including clear, white, yellow, or reflective aluminium, may offer additional suppression of aphids and whiteflies. Trash mulching reduces *Chilo partellus* in maize and sorghum.
- **Sanitation**: Effective farm sanitation plays a crucial role in preventing the introduction of pest insects from external sources, slowing their spread within the farm, and ultimately eliminating them. This is achieved by properly managing and disposing of crop materials that may serve as habitats for these pests (Linker, *et al.,* 2009).
- **Trap crops**: Trap crops serve as a strategy to divert pest species away from the main cash crop, drawing them into a designated area where they can be destroyed.

✓ Mustard is grown as a trap crop in cabbage and cauliflower fields (2:25) against DBM.

✓ Trap cropping of marigold for every 8 rows of tomato attracts *Helicoverpa armigera.*

1. **Physical measures**

- Flame throwers are used to control locusts.
- Yellow sticky traps are used to attract whiteflies and aphids.
- Light trap with large plate or vessel kerosene mixed water is kept near the light trap. The attracted moths fall in this water and die.
- Low temperature below 4°C makes insect inactive and prevent so cold storage of fruits and vegetables (1-2 °C for 12-20 days) kills fruit flies.

2. Mechanical measures

- Use of mechanical devices or manual forces for destruction or exclusion of pests is called mechanical control.
- Hand picking and destruction of large sized, conspicuous, immature or mature stages of insects Ex: Hand picking of hairy caterpillars, leaf rollers, beetles, grubs etc.
- Exclusion by screens and barriers in field to prevent insects reaching crops and agricultural produce.
- Digging trenches of about 30-60 cm to protect from moving bands of hairy caterpillar and locust.
- Scaring birds by creating noise.
- Use of hand nets and bag nets.
- Clipping, pruning and crushing of infested shoots and floral parts in checking further multiplication of insects (Adhikari, 2022).

3. Biological measures

The strategic release of biological control agents, including insect predators, parasitoids, and insect pathogens, through inundative and inoculative methods, becomes especially significant in environments where insecticides are not utilized. These agents play a vital role in controlling insect pests in an insecticide-free and can serve as curative measures during sudden outbreaks in insect populations.

- **Predators & parasitoids:**

Predators are the biological agents that hunt & kill the pests. Eg: Ladybird beetle, Mirid bug, Dragon fly etc. and parasitoids are friendly species that complete its life cycle within a host.

Table 1 Biocontrol agents to control pests of different crops

S.No.	Biological Agents	Pest	Crop
1.	*Trichogramma brassiliensis* - 1.0 cc/acre once in 10 lays, (Egg parasitoid)	Lepidopteran, *Heliothis spp.*	Cotton
2.	*Trichogramma chilonis* -2 cc/acre once in 15 days	Borers	Sugarcane, paddy, pulses
3.	*Verticillium lecanii* - 0.5 - 1.0% affects all stages	All sucking soft bodies insects	Sugarcane, groundnut, rice, potato, cereals
4.	*Beauveria bassiana* - 1.0% Affects the young stage	*Helicoperva, Spodoptera,* borers, hairy caterpillars, mites, scales, etc.	Vegetables, cereals

5.	*Chrysoperla spp*. @ 5000-10000 eggs /ha, 3 - 4 times in 15 days (Green lace wing)	Prudenia, Caterpillars, White flies, thrips, aphids	Vegetables
6.	*Phascilomycetes*	Nematodes	All crops
7.	*Metarhizium anisopliae*- 0.5 - 1.0 % affects all stages	White grubs, Beetle grubs, caterpillars, Semi-loopers, mealy bugs, BPH	Sugarcane, groundnut, rice, potato,
8.	*Bacillus thuringiensis* var. *Kustaki* 0.3 - 0.4%	Helicoverpa, Spodoptera, borers, hairy caterpillars, mites, scales, etc.	Vegetables, cereals, fruits
9.	Nuclear Polyhedrosis Virus (NPV) 100-200 LE/acre	*Spodoptera spp*. & *Heliothis spp*.	Vegetables
10	NPV - Nuclear Polyhedrosis Virus of *Helicoverpa armigera* 250500 ml/ ha, 2 - 3 time at 10 days interval	*Helicoverpa armigera*	Groundnut, pulses, cabbage, chillies, Cotton
11	NPV - Nuclear Polyhedrosis Virus of *Spodotera litura* 250-500 ml/ ha 2 - 3 time at 10 days interval	*Spodotera litura*	Cotton, groundnut, pulses,

Source: Mohan, *et al.,* 2013

4. Organic pesticides

In the past, traditional insecticides were not permitted in certified organic systems. However, a recent trend has emerged where certain companies producing agricultural chemicals incorporate active ingredients sourced from natural substances, signaling a shift towards more organic-friendly options within the agricultural chemical industry. (Haldhar, *et al.,* 2017).

➢ **Botanicals**

Botanicals and mineral-based insecticides are considered as a final resort in organic agriculture for controlling insect pests, employed only when prior methods have proven ineffective. The regulation of permissible chemicals for pest management in organic cultivation is rigorously overseen by organizations such as NPOP (National Programme for Organic Production) in India and equivalent entities in various countries. These botanicals in insect body act as poison in their digestive systems or repel with strong odours and tastes (Reddy and Chowdary 2021).

✓ **Neem:** Neem plants used as bio pesticide & found as very effective & ecofriendly. Every part of it useful control more than 100 diseases & 200 pests. Neem contains tetracycline, terpenes like limeroid, azadiractin, milianterl, salanin etc.

- ✓ **Ginger:** Extract of ginger has been traditionally used in agriculture for the treatment or prevention of tomato moth (*Tuta absoluta*) infestation.
- ✓ **Garlic:** Raw garlic straw extracts at 2% against root-knot nematodes (*Meloidogyne incognita*) in tomato crop, leads to inhibition of the nematodes and increasing the tomato yield (Duran-Lara, *et al*., 2020).
- ✓ **Pyrethrum:** Extracted from flowers of *Chrysanthemum cinerarifolium* acts as antifeedant at low doses against *Glossina sp*.
- ✓ **Apple factor**: Phlorizin is extracted from apple which is effective against *Myzus persicae.*
- ✓ **Solanum alkaloids:** Leptine, tomatine, solanine are alkaloids extracted from solanum plants has antifeedant property against leaf hopper.
- ✓ **Rotenone:** Extracted from roots of *Derris elliptica* kills flea beetles, cucumber beetle, etc.
- ✓ **Insecticidal soaps, or fatty acid salts**, are synthetic compounds derived from fatty acids. They are utilized to manage soft-bodied pests such as aphids and mites.
- ✓ **Horticultural oil/narrow range oil** consisting of light weight petroleum or vegetable oil used to smother insect pest.
- ✓ Pongamia, Jetropa, simaruba, *Madhuca indica* are also known to have pesticidal properties.

➢ **Inorganics**

Naturally occurring minerals are useful against the control of plant pests.

- ✓ **Kaolin clay** is finely ground to a consistent particle size and applied as a water suspension on plant surfaces. This protective measure acts as a deterrent, disrupting insects' ability to locate their host plants.
- ✓ **Copper** formulations like bordeaux mixture produced by copper sulfate and calcium hydroxide (lime) are used against fungi and bacteria.
- ✓ **Cryolite** contains sodium fluoaluminate, a mined mineral, which works as a stomach poison against beetles and caterpillars.
- ✓ **Lime sulfur** is made by boiling lime and sulfur together. It is used as a dormant spray on fruit trees for control of spider mites and thrips.

Conclusion

Organic pest management involves ecologically sustainable practices to prevent pests and diseases while minimizing curative solutions. Integrated Pest Management (IPM) utilizes information about the crop and its environment, focusing on maintaining a balanced ecosystem. This holistic approach cultivates plants with resistance to infections and insect feeding, reducing pest and disease severity.

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ROLE OF AGROFORESTRY IN NATURAL FARMING

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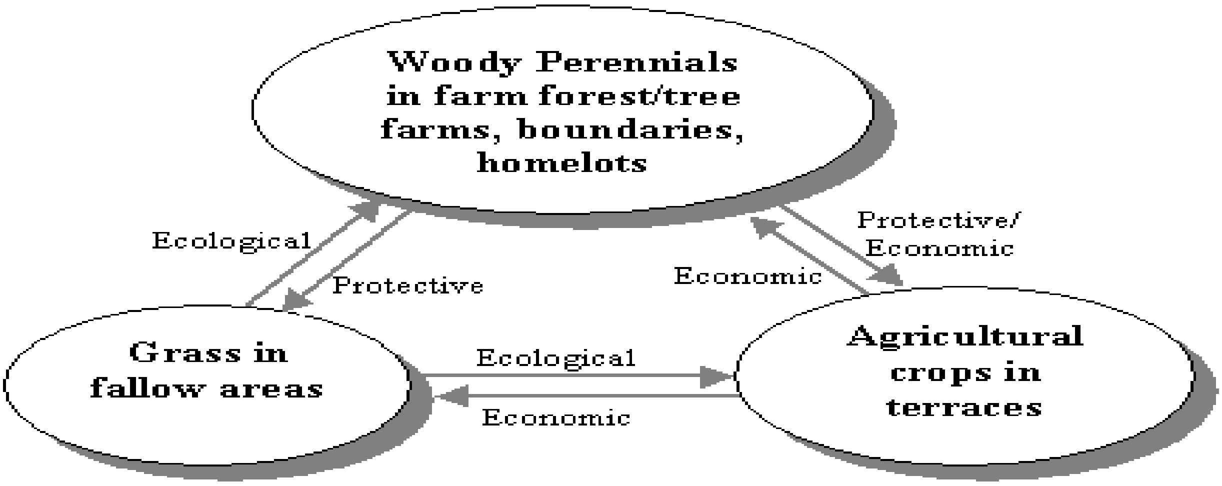
Agroforestry is an age-old land management practice, that involves the deliberate integration of trees, shrubs and crops in the same land area. This unique land use system has gained increasing recognition in recent years due to its various benefits, particularly in promoting soil conservation and ensuring sustainable crop production (Kaur, *et al.,* 2023). In this section, we explore the significance of agroforestry as a powerful tool in addressing environmental challenges and its pivotal role in sustainable agriculture through natural farming practices and it plays a crucial role in soil conservation through various mechanisms. In this chapter we included the benefits and mitigation strategies which affecting the environment and their mitigation through organic cum agroforestry systems. The strategic integration of trees and shrubs in agricultural landscapes helps control soil erosion by reducing the force of wind and water on the soil surface. Tree roots stabilize the soil, preventing erosion and protecting against landslides in hilly terrains. Moreover, agroforestry systems often include species with deep and extensive root systems enhancing soil structure and water infiltration capacity which further minimizes soil erosion.

Role of Agroforestry System:

Nutrient Cycling and Soil Fertility: The incorporation of nitrogen-fixing plants and shrubs into agroforestry systems improves the soil's nutrient availability. These leguminous species work in symbiotic interactions with bacteria that fix nitrogen from the atmosphere to produce different forms of nutrients that plants can use. Further, the variety of flora and organic matter supports a balanced nutrient cycling system, providing a consistent supply of nutrients for crops and enhancing soil fertility overall (Lin, B.B., 2011).

Decomposition of leaf litter cum organic matter: In agroforestry systems, trees and shrubs shed leaves and produce pruned branches, contributing to the continuous input of organic matter to the soil (Montagnini, F., & Nair, P. R., 2004). Soil microbes aid in the decomposition of organic matter and release nutrients. Organic matter gradually decomposes to provide the soil with nutrients and enhance soil structure, resulting in better soil fertility and crop yield.

Biological Nitrogen Fixation: Many agroforestry systems include nitrogen-fixing tree species, such as legumes, which form symbiotic associations with nitrogen-fixing bacteria in their root nodules (Nair *et al.,* 2009). These trees convert atmospheric nitrogen into plant-available forms, enriching the soil with nitrogen. As a result, nitrogen-fixing trees not only support their growth but also enhance nitrogen availability for associated crops, promoting healthier plant growth and reducing the need for external nitrogen fertilizers.



AGROFORESTRY SYSTEM

Carbon sequestration by agroforestry systems

The fundamental concept behind land-use system's potential to sequester carbon, particularly agroforestry systems, is quite easy to understand, it concentrates on the basic biological and ecological processes of photosynthesis, respiration, and decomposition. (Nair *et al.,* 2010). The manner in which agroforestry can potentially boost the amount of carbon stored in agricultural lands while permitting for the growth of food crops is by integrating trees into agricultural production systems. (Kursten, 2000). Earlier research have shown that agroforestry practices include.

1. The capacity of trees that are planted to sequester carbon may be limited by the fertility of the soil.
2. Mixed stand of plants might be more efficient than sole stands in carbon sequestration.
3. A comprehensive assessment of the system's overall constituent's ability to store carbon over the long term, including detritus, soil and forest products could act as the foundation for carbon sequestration estimates.

Agroforestry-based farming plays a prominent and important part in carbon sequestration, contributing to climate change mitigation and enhancing the sustainability of agricultural systems. Carbon sequestration refers to the capture and storage of carbon dioxide (CO_2) from the atmosphere preventing it's release into the air where it contributes to the greenhouse effect. Agroforestry practices leverage the capacity of trees to absorb and store carbon thereby reducing the concentration of CO_2 in the atmosphere. The majority of carbon enters the ecosystem through photosynthesis in the leaves and carbon buildup in aboveground biomass is most noticeable. Soils hold the majority of the carbon in the eco-system because over half of the digested carbon is eventually carried below ground by root growth and turnover, root exudates (of organic compounds) and litter deposition. Increases in net primary productivity (NPP) and/or the amount of plant material returned to the soil are inevitably going to increase the amount of carbon stored in the soil. Given that there is comparatively less research on carbon sequestration in agroforestry systems as opposed to tree-plantation systems the main factor influencing the potential for carbon sequestration in both plantations and agroforestry systems is the characteristics of the tree component.

Role of Agroforestry in adapting to climate change

Farmers have long used agroforestry or the integration of trees and shrubs with the production of annual crops as a management technique that provides shade, a consistent source of food and/or earnings all year around. This system reduces degradation and maintain soil fertility, diversify income sources, increases and stabilize income, enhance use efficiency of soil nutrients, water and radiation and provide regular employment. Noteworthy among such practices in tropical environments include the incorporation of fast-growing, nitrogen-fixing trees and shrubs in agricultural fields to increase the fertility of the soil and minimize erosion, improved management of fallows, domestication of new and underutilized tree species and intensification of agriculture on smallholder farms through use of appropriate tree and shrub species. A variety of agroforestry systems now exist with the potential to improve productivity, favourably influence microclimate, prevent soil degradation and restore soil productivity and diversify income-generating opportunities, recognizing the ability of agroforestry systems to address multiple problems and deliver multiple benefits. The IPCC third Assessment Report on Climate Change (IPCC, 2007) states that **"Agroforestry can both sequester carbon and produce a range of economic, environmental and socioeconomic benefits. As an example, trees on agroforestry farms boost soil fertility by preventing erosion, preserving the physical and organic matter of the soil, increasing N levels, drawing nutrients from deep soil layers, and encouraging better nutrient cycling.** We believe that agroforestry interventions provide the adaptation measures in making communities resilient to the impacts of climate change and do discuss the same in relation to the challenges posed by the changing and variable climate.

Environmental Challenges and the Need for Sustainable Solutions: The world faces numerous environmental challenges, including deforestation, soil erosion, loss of biodiversity and declining soil fertility. Conventional agricultural practices with their reliance on monoculture and extensive land use, often reduce these issues. To address these challenges sustainably, there is an increasing rate in adopting agroforestry practices that offer a promising solution.

Benefits of Agroforestry-Based Farming

Agroforestry-based farming offers a multitude of benefits that contribute to the sustainability, resilience, and productivity of agricultural systems. By integrating trees, crops, and livestock in a synergistic manner, agroforestry maximizes the potential for positive interactions and creates multifunctional landscapes. These benefits extend beyond individual farms, impacting ecosystems, communities, and global sustainability goals. Some benefits related to agroforestry-based farming systems are given below: -

1. Enhanced Soil Health and Fertility
2. Increased Biodiversity
3. Climate Change Mitigation
4. Diversified Income Streams
5. Sustainable Livelihoods
6. Nutritional security

7. Erosion Control and Watershed Protection
8. Aesthetic and Recreational Value
9. Long-Term Sustainability
10. Reduced Land Degradation
11. Root Exudates and Mycorrhizal Associations

Economic and Environmental Benefits of Agroforestry

Agroforestry systems offer economic benefits for farmers along with promoting carbon sequestration. Trees provide valuable products such as timber, fruits, nuts, and non-timber forest products, which can generate income while supporting carbon storage. Agroforestry's role in carbon sequestration underscores its potential to contribute to global efforts to mitigate climate change. By enhancing carbon storage in both above-ground and below-ground biomass, along with soil organic matter, agroforestry-based farming offers a holistic approach to sustainable land use that benefits both ecosystems and communities. (Rao *et al.,* 2007). As part of comprehensive climate change mitigation strategies, the promotion and adoption of agroforestry systems can decrease carbon emissions and promote more resilient and sustainable agricultural systems.

Combining agroforestry with organic farming

The combination of agroforestry in organic farming represents therefore among the most promising improvements as it could help reduce the yield gap with conventional agriculture, while further improving sustainability. In fact, among the most important goals of modern agroforestry is to produce more per unit area and more sustainably known as sustainable intensification or Eco intensification.

Challenges of Agroforestry-Based Farming

The adoption of agroforestry-based farming, despite its numerous benefits, is often constrained by a variety of challenges and obstacles that may hinder its widespread implementation. These constraints stem from factors related to knowledge, socioeconomic dynamics, policy frameworks, and practical limitations. It is essential to understand these limitations to create strategies that work to promote and support the adoption of agroforestry-based farming systems. Here we delve into some of the key constraints that can impede the adaptation of agroforestry-based farming they are given below. (Sinha, A., & Pal, B. 2023).

Limited Awareness and Knowledge: Lack of awareness and knowledge about the possible benefits of agroforestry and how to implement it effectively can hinder adoption among them Farmers, extension workers, and policymakers may be unaware of the various agroforestry practices their ecological benefits and their relevance to local conditions.

Perceived Risks: Farmers often perceive agroforestry as a more complex and risky farming system compared to conventional monoculture. Concerns about possible encounters between trees and crops uncertainty about tree growth and maintenance and unfamiliarity with multi-component systems can deter farmers from adopting agroforestry.

Access to Resources: The establishment of agroforestry systems often requires initial investments in tree planting, labour and inputs. Limited access to financial resources, technical support, and appropriate tree germplasm can constrain farmer's ability to adopt agroforestry practices.

Market Access and Value Chains: Lack of established markets and value chains for tree products such as timber, fruits and non-timber forest products can discourage farmers from integrating trees into their farming systems. The absence of reliable markets can limit the economic incentives for adopting agroforestry.

Conclusion

Agroforestry-based farming is a sustainable approach that harmonizes the relationships between trees, crops, and livestock. It offers a holistic solution to the challenges of our time by improving biodiversity, soil health, and carbon sequestration. The integration of trees into agricultural systems can lead to resilient landscapes, improved livelihoods, and a sustainable future for both humanity and the planet.

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Chapter-20

HOLISTIC APPROACH OF WEED MANAGEMENT IN ORGANIC PRODUCTION

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Dairy farming plays a pivotal role in fulfilling global demands for nutritious food. In recent years, the shift toward organic practices has gained momentum, and organic fodder production has become a cornerstone of sustainable dairy farming. The significance of organic fodder production in modern dairy farming lies in its commitment to sustainability, environmental well-being, and the creation of high-quality, chemical-free feed for dairy animals. Worldwide, areas dedicated to organic farming and organic food markets are expanding. The converting of conventional to organic production poses significant challenges, with weed control being a prominent issue. In organic fodder production, managing diseases, pests, and weeds is particularly critical due to the prohibition of synthetic chemical preparations used in conventional agriculture. Alternative control methods involve physical, cultural, or biological approaches. Soil health in organic farming relies on a dynamic microbial population. Misuse of manure disrupts soil balance, leading to increased weed growth. The adopting organic fodder practices align with sustainability, emphasizing a holistic approach to weed management and the intricate balance within the farming ecosystem.

Organic production and animal husbandry

Animal husbandry plays a fundamental role in the realm of organic farming. In bio-dynamic farming, the maintenance of ruminants is a compulsory practice. Beyond its role in producing food, animal raw materials, and intangible services provided by animals, the services rendered by animal husbandry within a farm hold significant value for organic farming. Animal husbandry harnesses the growth generated by green manure crops in fields, utilizes crop by-products, and generates manure, serving as a crucial fertilizer. Consequently, it constitutes an essential component of the organic management cycle (Figure 1.).

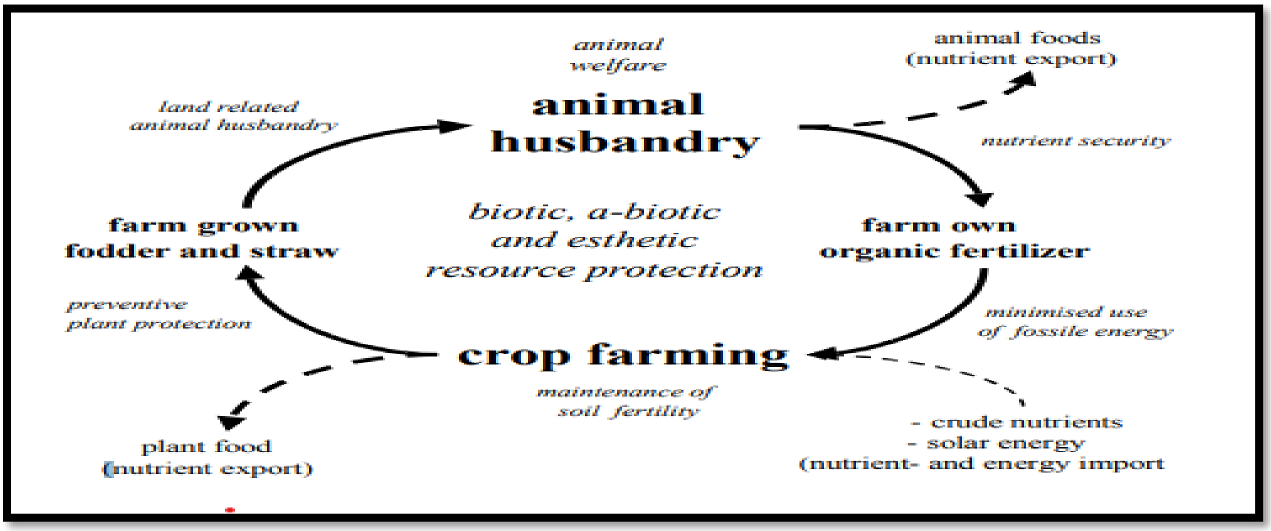

Figure 1. Ideal model of the correlation between the cultivation of plants and animal husbandry within the system of organic farming (Rahmann and Böhm, 2005)

Importance of holistic weed management in organic production

Weeds are considered the most significant challenge in organic crop production. The apprehension of ineffective weed control is a major concern for farmers contemplating converting from conventional to organic farming (Beveridge and Naylor, 1999). Despite this, researchers have given limited attention to weed management issues in organic agriculture. The conventional approach overlooks the systemic (holistic) nature of organic agriculture, recognized as a cornerstone in designing effective organic crop production systems. Holistic weed management is vital in organic production for overall sustainability, profitability and productivity. Key reasons include preserving soil health through practices like cover cropping, promoting biodiversity by encouraging diverse plant species, and reducing reliance on synthetic inputs, aligning with organic principles. Improved nutrient cycling, water conservation, and natural pest control are additional benefits, enhancing the ecological balance. The high-quality organic fodder produced through holistic weed management contributes to livestock welfare, providing a nutrient-rich diet. Integrating livestock, such as targeted grazing, controls weed growth and supports sustainable land use. Furthermore, holistic weed management facilitates organic certification, aligning with organic farming principles and ensuring compliance with standards.

Sustainable Practices for weed control in organic farming

Under organic farming, weed control strategies encompass: 1) Preventive 2) Cultural 3) Physical and Mechanical 4) Biological approaches.

1. Preventive methods

The adage 'Prevention is better than cure' is highly relevant in weed management. Prevention strategies target: (i) preventing initial introduction, (ii) halting infestation development, and (iii) curbing the dispersal of weeds and their propagules. Formulating successful prevention plans may involve individual, group, and governmental efforts, including laws to control weed propagule dissemination.

2. Cultural methods

2.1 Cover crops- Cover crops play a crucial role in soil protection, mitigating erosion and enhancing soil health during periods between crop cultivation or among orchard trees and vineyards. Utilizing cover crops before or between full-season crops enhances soil physical, chemical, and biological properties, ultimately enhancing the soil health and valuable crop yields. In organic farming, where synthetic chemicals are prohibited, cover crops are pivotal. Legume cover crops contribute to nitrogen fixation, reducing the need for nitrogen fertilizers in subsequent crops. Bio cultures of grass and legumes demonstrate reduced nitrogen release compared to continuous legume cropping.

2.2 Stale seedbed (SSB)- Using this approach, weed seeds in the topsoil are induced to germinate and appear before planting, allowing pre-plant shallow tillage to eliminate a portion of the weed population. Sanbagavalli (2010) observed approximately 30% reduction in the weed seed bank in cotton fields. In two consecutive years, adopting the Stimulated Seedbed (SSB) technique resulted in a 15-20% increase in seed cotton yield compared to traditional seedbed preparation methods.

2.3 Mulching- Various studies indicate that organic mulch materials enhance soil nutrient levels, maintain optimal soil temperature, reduce evaporation, hinder weed growth, promote soil health, and prevent erosion. Materials like weed-free straw, thick leaf mulch, well-composted manure, and natural or synthetic mulches, including wood bark and grass clippings, are commonly used. An 8-10 cm hay or straw mulch can successfully decrease the emergence of broadleaf weed seedlings. Living mulch, covering an area throughout the season, suppresses early weed germination, maintains a crop-weed balance, and ensures crop access to light, water, and nutrients. Successful living mulch requires rapid establishment, wear tolerance, drought resistance, low maintenance, and precise timing for effective weed suppression and soil erosion prevention (Paine and Harrison, 1993).

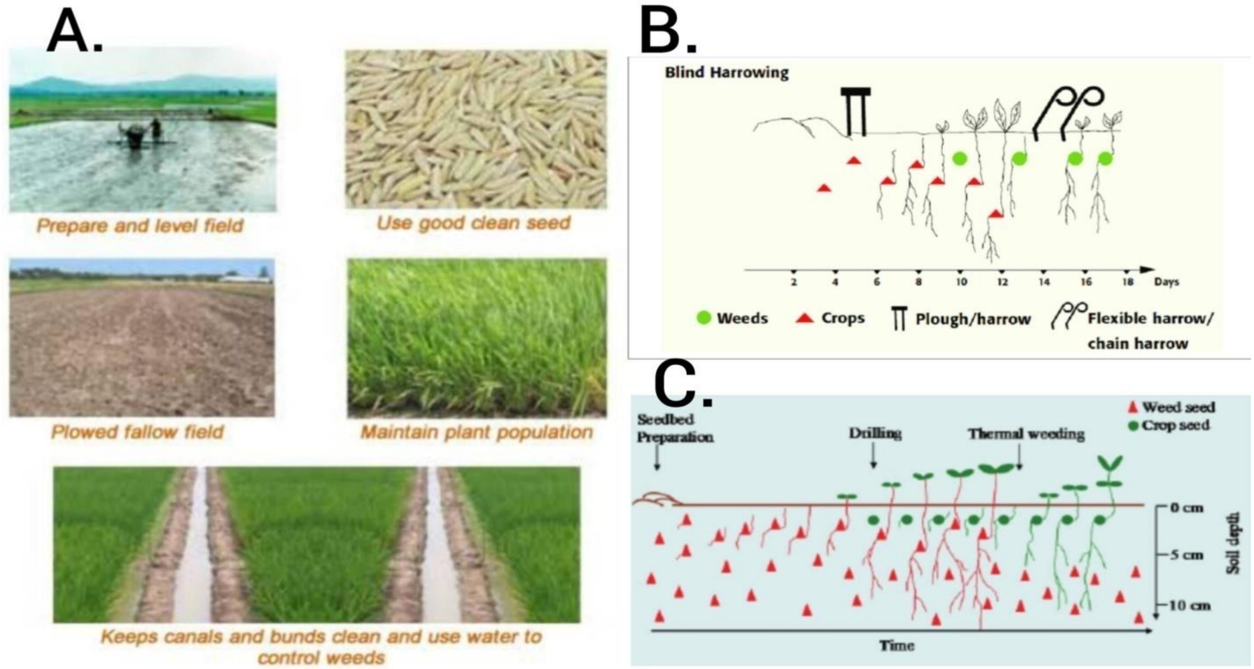

Figure 2. A. Cultural method of Weed management B. Blind Harrowing C. Stale seedbed (Johnson and Mullinex 1995)

2.4 Crop rotation- Crop rotation stands as an enduring and effective method for managing pathogens in both soil and plant hosts, preserving soil fertility and texture. Organic weed control is contingent on a robust crop rotation. In organic farming, crop rotation plays a pivotal role in minimizing damage from insects, pathogens, weeds, and diseases. Continuous cropping of the same plant family should be avoided, emphasizing the importance of rotation length based on the survival period of soil-transmitted pathogens. A four-year rotation, involving diverse crops to deter specific causative organisms, generally mitigates troubles caused by soil-borne diseases, provided preventive measures are taken against susceptible weeds and volunteer plants in the field.

3. Physical and Mechanical methods

Physical weed control refers to weed removal by hand, machinery and equipment, or thermal methods.

3.1 Hand weeding- Hand weeding is the oldest weed management method; it remains a viable and effective approach for eradicating annual and biennial weeds in both cropped and non-cropped environments.

3.2 Tillage- Tillage is often necessary to eliminate well-established weeds, especially perennial ones that propagate from vegetative parts like storage roots or rhizomes. Its involves uprooting weeds, cutting their shoots and roots, and burying both the weeds and their seeds, depending on the tool used. Optimal weed control is achieved when tillage is performed on a hot, sunny day, allowing the removal and desiccation of noxious weeds like couch grass with long underground rhizomes. Soil aeration is crucial, especially in organic production, relying on microbial activity for sustainable crop growth. Introducing new oxygen enables soil microbes to transform organic matter into stable humus, reproducing and releasing readily available nutrients into the soil solution for crop utilization.

3.3 Blind cultivation- Blind cultivation, the most straightforward and efficient mechanical weed control technique, disregards the arrangement of field rows, taking advantage of the height disparity between the crop and weeds. This method involves cultivating fields without considering the placement of rows, breaking the soil crust and facilitating the emergence of crop seedlings.

3.4 Thermal weeding methods- Thermal weeding techniques can be categorized into two groups: high-temperature and low-temperature methods. High-temperature methods encompass hot water or steam (HW), infrared radiation (IR), open flame (OF), and microwave radiation, while low-temperature methods involve liquid nitrogen. In applications like crop cultivation, glasshouses, public gardens, and schoolyards, HW, IR, and OF are commonly utilized. HW, applied directly to weeds, poses no fire risk as there is no flame. For crop protection during flame weeding between rows, heatproof shields are installed. Flaming serves as a cost-effective pre-emergence strategy for suppressing broadleaf weeds, more efficient than hand pulling. Open flame is particularly effective against broadleaf species and is generally applicable to various crops, excluding shallow-rooted ones (Bond and Grundy, 2001). Thermal weeding methods also include steam weeders, hot water, and infrared heaters.

4. Biological methods-The biological control of weeds entails intentionally utilizing host-specific phytophagous insects and plant pathogens to decrease the population density of a specific target species below its economic injury level.

Table 1: Commercial Myco-herbicides (Sanbagavalli and Somasundaram, 2020)

Trade Name	**Pathogen**	**Weed controlled**
Devine	*Phytophthora palmivora*	Strangle vine in citrus
Collego	*Colletotrichum gloeosporioides*	Joint vetch in rice and soybean
Biopolaris	*Bipolaris sorghicola*	Johnson grass
Biolophos	*Streptomyces hygroscopicus*	General vegetation (Non-Specific)
LUBAO 11	*Colletotrichum gloeosporioides f.sp.*	*Cuscutta spp.*
ABG 5003	*Cercospora rodmanii*	*Eichhornea crassipes*
Biochon	*Chondrostereum purpureum*	*Prunus serotina*

4.1 Bio- herbicides- Fungi are most often mentioned as Bio-herbicides, but numerous plant extracts are exhibiting Bio-herbicides activity. These Bio-herbicides are successfully used in small weed control and short annuals. The effects of all of these products are similar: leaf cuticles are damaged and leaf cells are destroyed, resulting in leaf death. These so-called burn-down herbicides act very quickly, but their effects depend on good coverage. Most commonly the micro-organism used is fungus and its prologues are spores or fragments of mycelia; in this case Bio-herbicides is also called a Myco-herbicide (Table 1.).

Table 2 Pre and Post-emergence organic herbicides (Pantović and Sečanski, 2023)

Pre-emergence organic herbicides	**Post-emergence, post-directed, and burn down organic herbicides**
Maize gluten meal (MGM)	Ammonium nonanoate
Mustard seed meal (MSM)	Vinegar (acetic acid)
	Clove oil
	D-limonene

Table 3 Common Weeds and Their Biological Control Agents (Afaq, 2023)

Weed	**Common Name**	**Biological Control Agents**	**Common Name**
Parthenium hysterophorus	Gajar Ghas, Carrot Grass	*Zygogramma bicolorata*	Mexican beetle
Lantana camara	Lantana	*Crocidosema lantana, Octotoma scabripennis*	Lantana flower-cluster moth or Lantana tortricid moth, Lantana leaf beetle, Leaf-mining chrysomelids
Opuntia spp.	Prickly pear	*Cactoblastis cactorum, Dactylopius spp.*	The cactus moth, cochineals
Alternanthera	Alligator weed	*philoxeroides Agasicles hygrophila, Disonycha argentinensis Jacob*	Alligator weed Flea beetle
Cyperus rotundus	Cocograss, Java grass, Nut grass	*Bactra verutana*	Javelin moth
Eichhornia crassipes (Mart.)	Water hyacinth	*Neochetina eichhorniae Warner*	Water hyacinth weevil
Cirsium arvense	Canada thistle	*Cassida rubiginosa Muller*	Thistle tortoise beetle

4.2 Weed Bio-Control Agents- Insects are commonly used as Bio-control agents for weeds, and this approach has extended from its primary application in rangelands and aquatic systems to diverse environments. Occasionally, non-native plants that have become weeds in new regions can be managed by introducing host-specific Bio-control agents from the weed's native range. This practice is termed Classical Bio-control and draws parallels with the Classical Bio-control strategies applied against insect pests.

Conclusion

The growing environmental consciousness among the public, increased interest in organic farming and concerns surrounding herbicide use have prompted the development of sustainable, non-chemical weed control methods. Effectively managing weeds in organic systems is an intricate and lengthy process crucial for the success of organic farming. It involves maintaining a comprehensive weed database for each farm and comprehending effective management techniques. Organic weed control primarily relies on preventive and direct methods, ensuring the well-being of crops, soil, and the environment.

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LOW BUDGET NATURAL FARMING PRACTICES FOR CULTIVATION OF RAPESEED AND MUSTARD

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Rapeseed and mustard are a group of crops belonging to the genera, *Brassica, Eruca* and *Sinapsis* of tribe *Brassiceae,* within the family Brassicaceae (Cruciferae). Rapeseed-mustard comprises eight different species. Of these, *toria* (*Brassica rapa* L. var. toria), brown *sarson* (*Brassica rapa* L. brown sarson), yellow *sarson* (*Brassica rapa* L. var. yellow sarson), *gobhi sarson* (*Brassica napus* L. ssp. *oleifera* DC var. annua L.) and *taramira* (*Eruca sativa*/vesicaria Mill.) are together termed as rapeseed; and Indian mustard (*Brassica juncea* (L.) Czern. & Coss.); black mustard (*Brassica nigra* [L.] Koch) and Ethiopian mustard or *karan rai* (*Brassica carinata* A. Braun) are collectively called mustard. They are grown under diverse agroclimatic conditions ranging from north-eastern/ north western hills and plains to down south under irrigated/rainfed, timely/late sown, saline soils and mixed/inter-cropping situations. Indian mustard is a popularly grown brassica crop in India, accounting for more than 90% of total rapeseed-mustard cultivated area. It is predominantly grown in Rajasthan, Madhya Pradesh, Uttar Pradesh, Haryana and Gujarat. It is also grown in some non-traditional areas of southern states like Karnataka, Tamil Nadu, Andhra Pradesh and Telangana. *Toria* is a short duration crop cultivated largely in Odisha, Assam, West Bengal and Bihar as a main crop while as a catch crop in Haryana, Madhya Pradesh, Punjab, Himachal Pradesh, Uttarakhand and western Uttar Pradesh. Yellow *sarson* is grown in Odisha, Assam, West Bengal, Bihar and eastern Uttar Pradesh. *Taramira* is mainly cultivated in drier parts of north-western India including the states of Rajasthan, Haryana and Uttar Pradesh. *Gobhi sarson* and *karan rai* are the new emerging oilseed crops having limited area of cultivation. *Gobhi sarson* is a long-duration crop confined to Haryana, Himachal Pradesh and Punjab. Brown *sarson* is cultivated on a limited scale in colder regions of the country like Jammu & Kashmir and Himachal Pradesh (Chauhan et al., 2020).

Rapeseed-mustard crops are basically cultivated in temperate region; however, it is also grown in certain tropical and sub-tropical regions as a winter crop. In general, these crops require high temperature during early growth stages and cool weather and clear sky during reproductive phase for better development of oil. Well drained sandy loam soil with pH 6.0-7.5 is the best suited for the proper growth and development of the rapeseed-mustard. However, these crops can be grown on a wide variety of soils.

Area, Production and Distribution

India is the fourth largest vegetable oil economy in the world next to USA, China and Brazil. Oilseeds are the second largest contributor in Indian agricultural economy after the cereals. Rapeseed-mustard comprise a group of important oilseed crops that are grown in more than 70 countries globally on an area of 35.50 million hectare with a production of 72.38 million tonnes of seed and a productivity of 2039 kg/ha during 2020 (FAOSTAT, 2022). Being second largest grower (21.1 %) after Canada, and third largest producer (12.6 %) after Canada and China, India plays a key role in global rapeseed–mustard industry (FAOSTAT, 2022).

In India, rapeseed-mustard group of crops stands next to soybean in terms of area and production among the nine oilseed crops. Normal estimates (average of 2015-16 to 2019-20) of area, production and productivity of major oilseed crops in India are presented in Table 1. During 2020-21, rapeseed–mustard occupies around 23.3 % area (6.69 million ha) and 26.8 % (10.11 million tonnes) production of total oilseeds in the country and contributes around 24.4 % of total vegetable oil production through nine oilseed crops, thus it is playing a pivotal role in meeting the edible oil requirements of the country (Anonymous, 2021). Rajasthan, Madhya Pradesh, Haryana, Uttar Pradesh and West Bengal are the major grower and producer states of rapeseed-mustard in the India (Table 2). Rajasthan, Madhya Pradesh, Haryana and Uttar Pradesh had occupied for 72 % of total area and accounts for 80 % of production of the rapeseed-mustard during the 2020-21 (Anonymous, 2021). Further, Rajasthan alone accounts for 41 % of area and 45 % of production of the rapeseed-mustard in the country, followed by Madhya Pradesh (Table 2). While Haryana had the highest productivity (2027 kg/ha), followed by Gujrat, Madhya Pradesh and Rajasthan during the 2020-21 (Table 2). Irrigated area under rapeseed-mustard crops is around 83 %, which is very high when compared to other oilseed crops. Gujrat, Rajasthan and West Bengal are having 93-95 % irrigated area under these crops (Table 2).

Table 1 Normal estimates (average of 2015-16 to 2019-20) of area, production and productivity of major oilseed crops in India

Crop	Area (Million ha)	Production (Million tonnes)	Productivity (Kg/ha)
Soybean	11.29	11.43	1013
Rapeseed & Mustard	6.46	8.30	1349
Groundnut	4.88	8.03	1646
Sunflower	0.33	0.24	730
Nine oilseeds*	25.74	30.55	1187

* Includes groundnut, rapeseed & mustard, sesamum, linseed, castor seed, niger seed, safflower, sunflower and soyabean

Source: Agricultural Statistics at a Glance 2021.

Table 2 Area, production and productivity of rapeseed-mustard during 2020-21$ in major producing states along with coverage under irrigation

State	Area (Million ha)	% to All-India	Production (Million tonnes)	% to All-India	Productivity (Kg/ha)	Area under irrigation (%) 2018-19*
Rajasthan	2.72	40.60	4.51	44.57	1659	95.0
Madhya Pradesh	0.77	11.65	1.31	12.98	1713	70.3
Haryana	0.63	9.42	1.28	12.64	2027	84.6
Uttar Pradesh	0.70	10.48	0.99	9.79	1412	83.3
West Bengal	0.59	8.86	0.72	7.12	1215	93.0
Gujarat	0.21	3.18	0.42	4.16	1976	95.3
Jharkhand	0.43	6.44	0.35	3.51	823	63.2
Assam	0.29	4.30	0.18	1.80	633	16.4
Others	0.35	5.28	0.35	3.44	986	-
All India	6.69	100.00	10.11	100.00	1511	83.2

Source: Agricultural Statistics at a Glance 2021.

Low Budget Natural Farming Practices for Cultivation of Rapeseed-Mustard

The agronomic management practices to be followed for the cultivation of rapeseed-mustard under the natural farming system are described in this chapter. These practices are based on the basic principles of the natural farming or zero budget natural farming (ZBNF) as propagated by Subhas Palekar and other workers (Kumar et al., 2020). The basic principles natural farming should be remained same for all the crops and enterprises, but these can be modified/ customized as per the availability of inputs and other local conditions as done under the Andhra Pradesh Zero Budget Natural Farming (APZBNF), earlier known as Climate Resilient ZBNF (CRZBNF).

Land and seedbed preparation

Soil should not be disturbed or disturbance of the soil should be minimal under natural farming system. Turning the soil or deep ploughing is completely prohibited. Further, retention of the residue of the previous crop as a mulch is also integral component of the natural farming. Therefore, zero/conservation tillage practices should be adopted for sowing of the rapeseed-mustard under the natural farming systems. The zero tillage consisted minimum soil disturbance, which accompanied by just opening the furrow, putting the seeds into furrow and covering the seeds in one operation. Rapeseed-mustard grown with zero tillage/conservation tillage has several advantages of over the conventional tillage practices (repeated tillage practices to prepare fine seed-and root-bed for sowing to ensure proper germination and initial vigour, improve moisture conservation, control weeds and other pests, mixing of fertilizers and organic manures) e.g., it moderates the soil temperature, conserve soil moisture, add organic matter, improve the nutrient-water interactions, reduce the production cost, energy use and GHGs emission, improve the soil health, productivity and profitability etc. However, the advantages of zero tillage/conservation tillage practices with rapeseed-mustard under natural farming systems are need to be realized.

Sowing time

Optimum sowing time is the most vital non-monetary input; thus, it should be considered as one of the important components of the natural farming. In general, rapeseed-mustard can be sown from the mid-September to the end of October according to temperature, crop rotation and variety. However, 10 to 25th October is the most appropriate time of sowing for the mustard. The middle of October, when the mean temperature in the north Indian plains is 24-26°C, is considered optimum for sowing rapeseed/mustard. Sowing of the crop should not be done if the day temperature exceeds 33 ^{0}C.

Selection of cultivar/ variety

Adoption of local cultivars of the crops have been advocated in the natural farming systems. Since, there is a great variability in the climatic and edaphic conditions in the rapeseed-mustard growing areas of India, the selection of appropriate cultivars is important in order to achieve the maximum yield. Therefore, prevailing local cultivars should be selected in a particular rapeseed-mustard growing area under the natural farming systems. However, either availability of local cultivars of rapeseed-mustard or their poor yield performance could be limitations of the natural farming practices in rapeseed-mustard. Therefore, local/regional climatic and edaphic conditions specific screening of the improved varieties of rapeseed-mustard under natural farming system is required in order to identifying the best performing cultivars. The improved varieties of rapeseed-mustard recommended for specific growing conditions are given in Table 3.

Table 3 The improved varieties of rapeseed-mustard recommended for specific growing conditions

Sr. No.	Specific growing conditions	Suitable varieties
1.	Irrigated early sown	PM-25, PM-27, PM-28, Pant Rai-19, Pusa Tarak
2.	Irrigated timely sown	DRMR IJ-31, RH-749, NRCDR-601, Pusa Vijay, NRCDR-2, GRN-73, Urvashi, Maya, RVM-2, PM-29, Pm-30, GDM-4
3.	Irrigated late sown	Brijraj, Radhika, RGN-145, NRCHB-101, CS-56, PM-26, Ashirwad, RGN-236
4.	Rainfed	DRMR-150-35, DRMR-1165-40, RH-406, RB-50, RH-725, RGN-229, RGN-298, RGN-48, PM-1, RVM-2, Pant Rai-20, PBR- 378,

5.	High temperature tolerant	PM-25, PM-27, Azad Mahak, Pant Rai-18, PM-2, Pant Rai-19, Pusa Vijay, Pusa Tarak, RH-0119, RH-406, RGN-229, RGN-236
6.	Salinity tolerant	CS-54, CS-58, CS-60
7.	Frost tolerant	RGN-13, RH-819, Swaranjyoti, RH-781, RGN-48, RGN-73
8.	White rust resistant	Basanti, JM-1, JM-2, NRCDR-2
9.	*Alternaria* blight tolerant	Jawahar Mustard 3, Him Sarson 1, Ashirwad
10.	Non-traditional areas	NRCHB-101, PM-25
11.	Low erucic acid	PM-24, PM-9, PM-30, PM-32, RLC-2
12.	Double zero ('00')	Pusa Double Zero Mustard-1 (PDZ-1), PM -31, PM-33
13.	*Toria* (*B. rapa* var. toria)	Azad Chetna, RSPT-2, Uttara , Tripura Toria-1, Tapeshwari, Sushree
14.	Yellow *sarson* (*B. rapa* var. yellow sarson)	Pitambari, NRCYS-05-02, YSH-401, Pant Shweta, Pant Pili Sarson-1
15.	Brown *sarson* (*B. rapa* var. brown sarson)	Shalimar Sarson-1, Shalimar Sarson-2, Shalimar Sarson-3
16.	*Gobhi sarson* (*B. napus*)	GSC-5, GSC-6, GSC-7, RSPN-25, ONK-1
17.	Ethiopian mustard (*B. carinata*)	Pusa Aditya, Pusa Swarnim, PC 5-17, JTC-1, Kiran, Pusa Gaurav
18.	Black mustard (*B. nigra*)	Surya (LBM 428)
19.	*Taramira* (*E. sativa*)	Jobner Tara, Jwala Tara, Vallabh Tara-1, Vallabh Tara-2, Narendra Tara

Seed treatment

Seed treatment with *beejamritham/ beejamriha/ beejamrita* is one of the main components and mandatory practices of the natural farming. *Beejamritha* is prepared by mixing the local cow dung (considered as natural fungicide), *and* cow urine (as anti-bacterial liquid), lime and soil. The dung is tied in a cloth and is kept in urine for about 12 hours. The dung is removed from cow urine, cow dung is squeezed and urine is added with about 50 grams of lime. *Beejamritha* prepared by this way can be used for seed treatment of rapeseed-mustard. For seed treatment, mix the mustard seeds with *beejamritha* by hand in such a way that every seed should have a layer of coat of *beejamritha*. After coating the seeds with *beejamritha,* dry them well and use them for sowing. *Beejamritha* is effective in protecting seed from soil-borne and seed-borne diseases. Seed treatment also should be done with biofertilizers like *Azotobacter, Azospirillum*, Phosphobacteria @ 200 g each per 10-15 kg seed. Soil application of these biofertilizers also can be done @ 5 kg each/ ha. Liquid formulations of these biofertilizers should be applied @ 500 ml/ha.

Crop establishment techniques

Since soil should be least disturbed in natural farming systems, hence only options for sowing of the rapeseed-mustard either through broadcasting of the seed or with the use of zero-till drill machine. Rapeseed-mustard can be successfully established without disturbing the soil much with a zero-till drill machine or zero-till planters. Zero-till drill machine is used for sowing of crop in lines under zero-till conditions, while zero-till planter is used for sowing of the crop in lines on raised beds under zero till conditions. However, initially the raised beds are prepared by a bed maker after tilling the soil as per conventional tillage practices (one deep ploughing followed by multiple (4-7) passes of cultivator and planking operations). Seed should not be sown more than 4-5 cm deep in soil.

Seed rate, planting geometry and plant population

A seed rate of 4-5 kg/ha is sufficient to achieve the optimum plant population (2.2-3.3 lakh plants/ha) for the rapeseed-mustard. However, the optimum plant population varies with the environment, the genotype, the seeding time and the season. A planting geometry of 45 cm × 10-15 cm gives optimum plant population of Indian mustard in most of the growing areas. For *toria*, brown *sarson*, yellow *sarson*, and *taramira* the desired plant population is obtained by following the planting geometry of 30 cm × 10 cm. Thinning operation for removing the excessive plants should be done at 15-20 days after sowing to maintain the optimum plant population.

Cropping systems

In natural farming systems, emphasis has been given on the crop diversification rather than sole crops and mono-cropping systems. Adoption of extensive inter-cropping/ mixed cropping/ poly-crops and crop rotations are the recommended practices of the natural farming systems. The predominant conventional cropping systems of the major mustard growing states in India are listed in Table 4. Intercropping of rapeseed-mustard can be done with many local crops because of its wider adaptability and high remuneration. The popular conventional intercropping systems are: mustard+potato (1:3), mustard+wheat/barley (1:5), mustard+chickpea/lentil/linseed (1:2/3/4), *karan rai*+chickpea (2:8), *toria*/mustard+autum sugarcane (1:2), *toria*+ *gobhi sarson* and *karan rai* and Indian mustard (1:1) and *karan rai*+ winter vegetables and spices e.g., garden pea, radish, coriander and fenugreek etc. However, performances of these intercropping systems in natural farming systems are need to be realized and validated.

- Poly-cropping: 5-layer cropping in which different layers of crops comprising of trees, fruits, vegetables, pulses and cereals are grown. These have different levels of canopies and maturity period, thus are harvested at different point of time. Among these crops, some may act as border crop, other as trap crop or pulses, vegetables, cereals, etc. It thus helps in providing one or other produce to the farmer at regular interval.

Table 4 Cropping sequences in major rapeseed-mustard growing states of India

State	Rainfed	Irrigated
Rajasthan	Fallow-*toria*/mustard Pearl millet/cowpea-mustard	Maize/green gram/pearl millet/ cowpea – mustard *Toria*-wheat
Madhya Pradesh	Fallow-*toria*/mustard	Fallow-*toria*-wheat/summer moong-field pea Fallow-*toria*-gram
Haryana	Pearl millet-mustard Fallow-mustard/brown *sarson*	Maize-*toria*-wheat Groundnut-mustard Fallow-*toria*-wheat Early fodder-mustard
Uttar Pradesh	Maize/pearl millet/green gram/sesame-mustard/yellow *sarson* Early rice-*toria*/mustard Fallow-*toria*/mustard	Maize-mustard-green gram/ Fodder-mustard Black gram/maize-mustard Maize-*toria*/mustard Upland rice-toria- spring green gram/sugarcane
West Bengal	Jute-*toria*/mustard-spring green gram Maize-*toria*/mustard Upland rice/jute-mustard/yellow *sarson* Cowpea-mustard (fodder) Maize (fodder)-sorghum/ cowpea – yellow s*arson*/mustard	Rice-*toria*-summer rice Rice-mustard/jute-yellow *sarson* Rice-mustard-rice Aman rice-toria-boro rice Rice-mustard/yellow *sarson*-jute

Nutrient management

Application of chemical fertilizers for supply of nutrients are completely restricted in natural farming systems. Application of farm yard manure (FYM) is also not advocated in natural farming systems. Even though, a small quantity of FYM (1-4 t/ha) is applied by the natural farming farmers in sugarcane, rice, turmeric, finger millet, soybean etc. Crop yields also got improved significantly with the application of FYM under natural farming (Kumar et al., 2020). Natural farming/ ZBNF aims to improve the soil health through improving the soil biological activity by addition of microbial cultures/ inoculants (to enhance decomposition and nutrient recycling) and organic matter. Therefore, following practices should be adopted for crop nourishment in natural farming systems (adapted from Kumar et al., 2020).

1. Application of *jeevamrutha:* To ensure the proper crop nutrition, application of *jeevamrutha* to the crop is the integral component of the natural farming. Around 200 litres of *jeevamritha* is required for one acre of land. It should be applied to the crops at 15 days interval in the irrigation water or as a 10% foliar spray. In mustard, it can be applied at 25, 40, 55, 70 and 85 days after sowing (schedule being followed in present experiment at DRMR, Bharatpur). Basically, it is a fermented microbial culture that not only provides nutrients, but most importantly, acts as a catalytic agent that promotes the activity of microorganisms in the soil, and also increases population of native earthworms (Kumar et al., 2020). In brief, it is prepared by using 10 kg fresh local cow dung, 5 to 10 liters aged cow urine, 2 kg jaggery, 2 kg pulses flour and a handful of native soil of the field (acts as inoculate of native species of microbes and organisms). All these ingredients are added in a barrel containing 200 liters of water. The solution is mixed and stirred well and put it in hold for fermentation for 48 hours in shade. It can be stored up to a maximum of 15 days.
2. Application of *ghanajeevamritha: Jeevmaritha* preparation requires plenty of water. Therefore, it is an alternative option of *jeevmaritha*, and usually practiced in areas where the water availability is scarce. *Ghanajeevamritha* can be applied (0.5-1.0 t/ha) in rainfed mustard cultivated areas. However, *ghanajeevamritha* also can be applied as an additional input in addition to the *jeevmaritha.* Basically, it is a solid form of *jeevmaritha*, and prepared in the form of ball like structures by mixing the cow dung, urine, pulse flour and jaggery. These balls are then dried under the shade. The dried product is stored in gunny bags and finely powdered before applying in the field. It is applied by broadcasting method before sowing of the crop.
3. Mulching (*Acchadana*)*:* Mulching is also an integral component of the natural farming systems. Three types of mulching practices have been suggested under the natural farming/ ZBNF:
   i. Soil mulch: This protects topsoil during cultivation and does not destroy it by tilling. It promotes aeration and water retention in the soil. Therefore, deep ploughing should be avoided.
   ii. Straw mulch: Keeping the soil covered with the crop residues or cover crops or any other organic materials is also essential in natural farming systems. In mustard-based cropping systems, surface of the soil can be covered with in-situ recycling/ retention of crop residues of previous crops in the cycle. For example, in cluster bean/green gram/maize/pearl millet/sesame-mustard based cropping systems, the mustard, cluster bean, green gram, maize, pearl millet and sesame crops can be harvested from above the soil surface by leaving 30, 10, 100, 30, 30 and 20% crop portion as anchored stubbles in the field (Jat et al., 2021); these leftover stubbles would serve as straw mulch in these cropping systems. It adds the organic matter and increase the microbial activity and strengthen the nutrient cycling mechanisms.

iii. Live mulch: The development of multiple cropping patterns with inclusion of monocotyledons and dicotyledons in order to ensure the supply all essential nutrients to the soil and crops is essential in natural farming systems. Dicot fix the atmospheric N (legumes crops) and monocot add the potash, phosphate and sulphur in the soil. Therefore, leguminous crop like chickpea, lentil etc. in inter-cropping and guar, mungbean, cowpea, soybean, groundnut etc. in sequence with rapeseed-mustard should be adopted. *Sesbania* also can be grown in sequence with rapeseed-mustard based cropping systems for green manuring and mulching. Mulching of *Sesbania* grown in intercropping with kharif crops should be done at 30 DAS.

Water management

In natural farming system fields are maintained in *whapasa-moisture* condition. *Whapasa* is the condition where there are both air molecules and water molecules present in the soil. Thus, irrigating only at noon, in alternate furrows, may fulfil the moisture requirement of the crops. Creating of soil mulch after first irrigation may also help in retaining more water in soil pores by disconnecting the soil capillaries. Therefore, the irrigation water requirement of the rapeseed-mustard under natural farming system may significantly decreased over the normal irrigated conventional production system. Further, *acchadana – mulching* is the integral component of the natural farming systems which promotes the water conservation by reducing the evaporation through creating the physical barrier between soil surface and sunlight. Though, water requirement of the rapeseed-mustard is low (240-400 mm), but it is sensitive to moisture stress at critical stages of crop growth and development. In general mustard requires two irrigations, first at pre-flowering stage (35-40 days after sowing) and second at siliqua formation stage (65-70 days after sowing) for optimum crop performances. However, irrigation requirement of the crop in different growing areas is ranged between 1 to 6 irrigations due to variation in soil and climatic conditions of the region.

Weed management

Weeds may reduce 20-70% seed yield of the rapeseed-mustard. The most common weeds of the rapeseed-mustard are *Chenopodium album* (*bathua*), *Chenopodium murale* (*khartua*), *Melilotus indica* (*senji*), *Lathyrus* spp. (*chatrimatri*), *Cirsium arvense* (*kateli*), *Cyperus rotundus* (*motha*) and *Fumaria parviflora* (*gajri*), *Orobanche (broom rape)* etc. Initial 45-60 DAS is critical period for crop weed competition. The traditional method of the weed control such as uprooting/manual weeding/weeding by animal drawn weeder have been adopted by the natural farming farmers. Chemical methods of weed control are completely restricted in natural farming systems. Under rainfed conditions, one hand weeding at 25 days after sowing, while under irrigated conditions, two hand weedings at 25 and 40 days after sowing are necessary for effective weed control. Orobanche is a major devastating parasitic weed of rapeseed-mustard. For reducing infestation of orobanche avoid continuous cropping of toria/mustard on the same field. Follow crop rotation with cereals and legumes. Cowpea/ black gram/ moth bean/ sunnhemp/ clusterbean/ sesame-mustard sequence significantly reduces orobanche infestation. The infestation of *Orobanche* can be effectively controlled with the application of two drops of soybean oil per young shoot. Further, the menace of the weeds in natural farming system is observed less because mulching has the smothering effect and prevent the weed growth.

Insect-pest and diseases management

The oilseed brassica is highly vulnerable to a large number of insect-pests and diseases. The important insects of the rapeseed-mustard are mustard aphid *(Lipaphis erysimi),* saw fly *(Athalia proxima)* and painted bug *(Bagrada cruciferarum*). Other minor insects of the rapeseed-mustard are pea leaf miner (*Chromatomyia horticola*), bihar hairy caterpillar (*Spilosoma obliqua)* etc. The important diseases of the rapeseed-mustard are *Alternaria* blight (*Alternaria brassicae*), white rust (*Albugo candida*), downy mildew (*Peronospora parasitica*), powdery mildew (*Erysiphe cruciferarum),* stem rot or blight *(Sclerotinia sclerotiorum),* club root *(Plasmodiophora brassicae)* and phyllody.

The chemical methods of diseases and pest control measures are not recommended in natural farming systems. The following management strategies can be adopted to reduce the infestation of insect-pest and diseases in rapeseed-mustard:

- To escape the crop from aphid infestation, it should be sown early at optimum time recommended for particular area. The mustard sown before 15 October in north India often escapes aphid damage. Plucking and destruction of infested twigs is very useful. It should be done 2-3 times at 10 days interval early in the crop season. Release of *Coccinella septempunctata* @ 5000 beetles/ha helps in reducing the aphid population. Use of 2 % neem oil and 5 % neem seed kernel extract (NSKE) reduces the aphid infestation. Whenever, aphid population crosses the economic threshold level, two foliar sprays of Azadirachtin 3000 ppm @ 5 ml/ litre water at 10 days interval provides the effective control of aphids in rapeseed-mustard.
- Timely irrigation helps in killing larvae of mustard saw fly through drowning.
- Apply the first irrigation 3-4 weeks after sowing wherever possible to reduce the painted bug infestation. Thresh the crop as early as possible to avoid further losses and dispose off plant material immediately.
- If infestation of pea leaf miner is observed, then pluck all the infested leaves and burn them to kill the larvae and pupae resting inside.
- If infestation of bihar hairy caterpillar is observed, then pluck all the infested leaves containing first/second instar gregarious phase larvae and dip them in kerosenized water.
- Seed treatment with biocontrol agents like *Trichoderma harzianum* @ 10 g/kg seed, soil application of *Trichoderma* (1 kg/50 kg FYM), recommended spacing and proper drainage to avoid water stagnation helps in reducing disease infestation.
- Seed treatment with botanicals like garlic (*Allium sativum* L), bulb extract (2%) followed by garlic bulb extract foliar spray (2%) at 45 and 75 DAS reduce the infestation of Alternaria blight and stem rot.
- Early sowing in first fortnight of October enables the crop to escape severe development of white rust, downey mildew and *Alternaria* blight.

- Use the seed from stag head free plants to avoid carry-over of oospores of *Albugo candida* and *Peronospora parasitica* through seeds.

The natural farming farmers are using the following formulations (*kashyam*) made up of locally available plant materials to control the pests:

1. *Neemastra: Neemastra* is the most popular and commonly used pest controlling solution. It is prepared by adding 2-3 kg cow dung, 10-20 litres cow urine, 5 kg of neem leaves paste and handful of soil in 100-200 litres water. Then, the solution is kept for fermentation for about 48 hours. After this, the solution can be directly applied to the infested plants without any further dilution.

2. *Brahmastra: Brahmastra* is prepared from five types of bitter leaves (5 kg). Neem leaves are used along with the other bitter tasting leaves, like datura, custard apple, chillies, etc. Th bitter leaves are added in 20-30 litres of cow urine and then the solution is boiled for about 2-3 hours. The solution is cooled for about 12 hours and is filtered using fine cloths. The solution should be further diluted with about 15 litres of water for every 1 litre of *brahamastra*.

3. *Agniastra: Agniastra* is prepared by adding 5 kg of neem paste with around 1 kg of tobacco leaves, 0.5 kg of chillies and 0.5 kilo of garlic paste. These are added in about 25- 30 litres of cow urine and is cooled down for about 24 hours. The solution is then filtered and used. The solution should be diluted with about 15 litres of water for every 0.5 litre of *agniastra* before applying in the field.

Jeevamritha also helps to prevent fungal and bacterial plant diseases. *Beejamritha* is effective in protecting young roots from fungus as well as from soil-borne and seed-borne disease.

Harvesting and threshing

The harvesting and threshing practices are same as followed under conventional rapeseed-mustard production system. The rapeseed-mustard crops are harvested whenever 75 % of the siliquae turn yellow in colour and moisture content in seed is around 30-40%. Moisture content in seed should be ranged between 12 to 20 % before the threshing and it must be less than 8 % at the storage time.

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EXPLORING THE PRINCIPLES OF NATURAL FARMING FOR SUSTAINABLE AGRICULTURE

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Natural farming is a general word that stems from fundamental ecological concepts. Globally, the term "natural way of farming"—which eschewed chemicals and embraced an ecological farming approach—was coined by Japanese farmer and philosopher Masanobu Fukuoka in 1935 for his book "One-straw Revolution," and by Mokichi Okada in 1936 for his book "Nature Farming." The government of India's Mission LiFE-2022 and the zero carbon economy, which are in response to a clear call to battle climate change and meet the SDGs-17 targets by 2030, are the national priorities for promoting environmentally friendly agricultural technologies (Mission Life, 2023). This has led to put more emphasis on concept of environment friendly, chemical free agriculture and the classical ecological economics. Natural farming, also known as zero-budget farming, has gained significant traction in India in recent years. As the world grapples with environmental challenges and the need for sustainable agricultural practices, India is making strides in adopting natural farming methods. This chapter explores the natural farming scenario in India, examining the principles, challenges, success stories, and potential impact on the agricultural landscape.

Indian Perspective of Natural Farming

Besides the Masanobu Fukuoka and Mokichi Okada in Japan, broad tradition of ‘natural farming’ in India is propounded by advocates such as Shri Narayana Reddy (Karnataka), Shri Shripad Dabholkar (Maharashtra), Shri G Nammalvar (Tamil Nadu), Shri Deepak Suchde (Madhya Pradesh) and Shri Bhaskar Save (popularly referred to as the ‘Gandhi of Natural Farming’, working in Gujarat). Natural Farming based on ‘Zero-Budget’ input cost, is a system developed in the 1980s by Shri Subhash Palekar and number of its variants are available in ancient Indian literature and Vedic agriculture (Bharucha *et al*., 2020; Sharma *et al*., 2022).

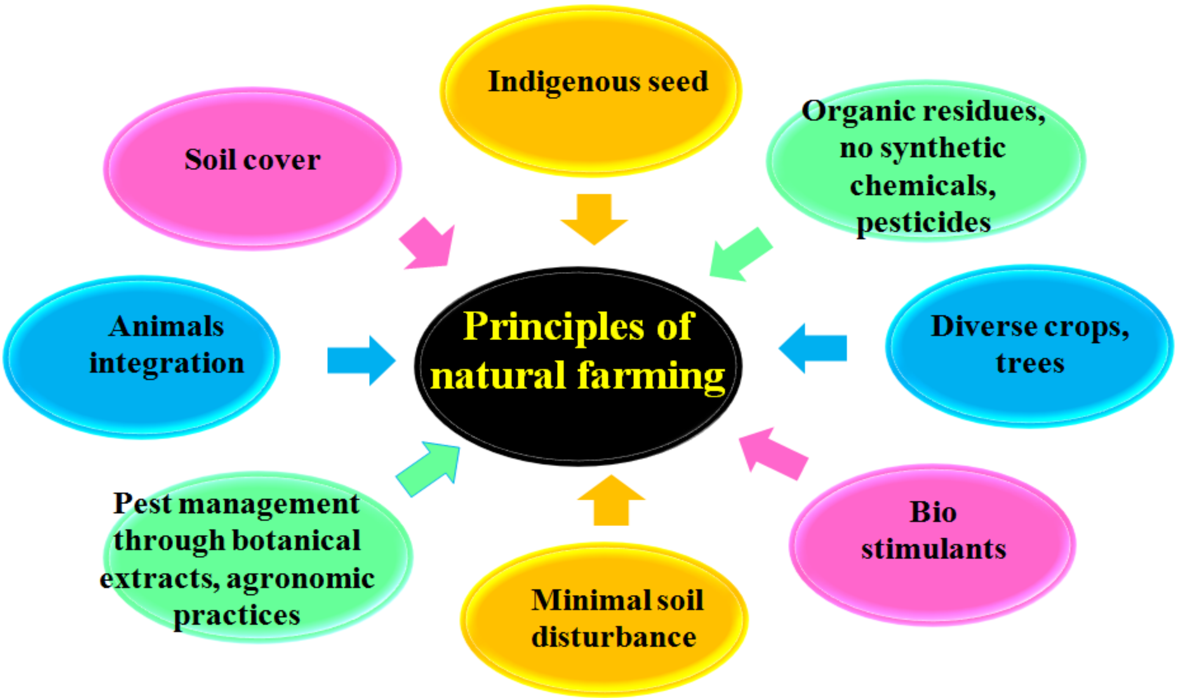
Table 1. Types of natural farming

Method	Associated Workers	Constituents
Natuecoculture	Dabhokar, 1967	Mulching-no ploughing, Amrit mitti, Amrut jal-fermented cow dung and urine with jaggery
Rishi krishi	Deshpande, 1970	4 steps: Angara- soil from banyan tree trunk Amrit pani-ghee, honey,cow dung in water Beej sanskar-seed dressing Achhadana-mulch

Krishi suktis and vriksharyurveda	Parashara (400 BCE) Kashyapa (800BCE) Surapala (1000BCE)	Animal dung manure to field crops Kunapajala for perennialcrops (prepared from-animal and plant wastes and cow products).
Panchgavya	K natarajan, 2003	Mixing 5 products of cow, Cane jiggery, Coconut water. Ferment for 30 days. Seed dip, soil drench and foliar paste.
Homa farming	Potdar	Grains, milk, dried cow dung burned in copper pyramid. Smoke purifies the air around.
Zero budget natural farming	Subhash palekar 2005-06	4 key elements: Beejamrita-seed treatment Jeevamrita-fermented microbial culture Achhadana -mulching Waaphasa-no irrigations
Biodynamic farming	Stenier, 1924	Cow horn manure Cow horn quartz (silica)

Source: Nene (2017)

Principles of Natural Farming:



Benefits of natural farming

Improved Yield

a) Increased Farmers' income

b) Minimize cost of production and increase farmer's income

c) Ensures better health

d) Employment Generation

e) Eliminate the application of chemical inputs

f) Environment Conservation

g) Reduce Water Consumption

h) Rejuvenate Soil Health

i) Livestock sustainability

j) Women's agency and community ownership for scaling up of Natural Farming

k) Resilience.

Success Stories

a) **Subhash Palekar's Zero-Budget Natural Farming:** Subhash Palekar, an agricultural scientist, has been a pioneer in promoting zero-budget natural farming in India. His techniques, such as the use of jeevamrutha (microbial culture), have been widely adopted, particularly in states like Maharashtra and Karnataka.

b) **Sikkim's Organic Mission:** Sikkim, a small state in north eastern India, has successfully transitioned to 100% organic farming. The state government's commitment to supporting farmers in adopting organic practices has made Sikkim a role model for other regions.

c) **Farmers' Collectives:** Many farmers across India are forming collectives and cooperatives to share resources, knowledge, and market access. These collaborative efforts help in overcoming individual challenges and create a supportive community for natural farming enthusiasts.

Table 2 Yield and economics under natural farming and conventional farming

Parameters	Natural farming (0.75 Ha)	Conventional farming (0.75 Ha)
Crop	Papaya	Papaya
Cost of cultivation	Rs 41500/-	Rs 70000/-
Production	16 t	15.5 t
Gross return	Rs 320000/-	Rs 310000/-
Net return	Rs 278500/-	Rs 240000/-
BC ratio	6.71	3.42

Source: Sharma *et al*., 2023

Potential Impact

a) **Environmental Sustainability:** Natural farming promotes soil health, biodiversity, and water conservation. The reduction in chemical inputs helps mitigate environmental pollution and contributes to sustainable agricultural practices.

b) **Economic Resilience:** By eliminating the need for expensive external inputs, natural farming can enhance the economic resilience of farmers. The reduced production costs and access to premium organic markets can improve the financial well-being of farming communities.

c) **Food Security:** Diversification of crops and resilient farming systems contribute to increased food security. Natural farming methods are better equipped to adapt to changing climatic conditions, ensuring a more reliable food supply.

Major government schemes and initiatives to promote natural farming

a) Paramparagat krishi vikas yojana

b) Prakritik kheti khushaal kisan yojana

c) Zero budget natural farming

d) Bharatiya prakritik krishi paddhati

e) National mission on natural farming

f) National committee on natural farming

Challenges Faced

a) **Awareness and Education:** Despite the benefits, there is a need for increased awareness and education about natural farming practices. Many farmers still lack knowledge about the principles and techniques involved.

b) **Transition Period:** Shifting from conventional to natural farming practices requires a transition period. During this time, farmers may experience yield fluctuations and financial challenges, which can deter widespread adoption.

c) **Market Access:** The demand for organically grown produce is on the rise, but challenges in accessing organic markets persist. Strengthening the supply chain and creating market linkages is crucial for the success of natural farming.

Conclusion

Natural farming has advantages linked to environmental sustainability, health benefits, market demand, technological innovation, and supportive policies. It is likely to play a significant role in shaping the future of agriculture, and India can lead the way by investing in education, infrastructure, and market support.

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ORGANIC FARMING: A PRESENT NEED FOR FUTURE

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Organic Farming is the best-known farming that primarily avoids the use of synthetic conventional agricultural knowledge. Organic production is a system that sustains soil, ecosystem and people's health. It can counteract the negative impacts of the adoption of chemical farming. The goals of organic farming are to maintain consumer health by offering organic products and the environment by utilizing organic management techniques that do not have the negative impacts of conventional practices. In addition, organic farming requires a lot of labour, which raises rural employment and improves resource quality over time. During the Green Revolution, new techniques and technologies were adopted to transform Indian agriculture into an industrial system. The productivity and production of all crops in India increased dramatically as a result. But this was only a brief era of success and it eventually had negative repercussions on the environment. Organic farming is a method of production that primarily avoids the use of synthetic compounded fertilizers and pesticides. Sustainable use of natural resources, lowering cultivation costs, producing nutritious food, increasing farm income, and enhancing environment and soil health are the primary objectives of organic farming. (Rani *et al*., 022).

An organic farming system's ability to sustain soil productivity, provide plant nutrients and manage weeds, insects and other pests. Crop rotation, crop residues, animal manures, green manures, and natural insecticides are the major components of an organic farming system that helps to sustain soil productivity and provide essential nutrients. (Devi *et al*.,2019), The field of agriculture greatly benefits from organic farming. India is ideally positioned to produce enough organic food to fulfil both domestic and international demand since it has an abundance of natural resources that include a variety of organic factors. Organic farming provides solutions for most problems faced by contemporary issues in agriculture and food Production.

The principles of health, ecology, fairness and care are the roots from which organic agriculture grows and develops. Organic products are richer in nutrients and largely free of pesticide residues and additives (Hammed *et al*., 2019). Organic farmers are aware of health by avoiding chemical pesticides and fertilizers commonly used in farming (Pandiselvi *et al.,* 2017). Organic farming depends upon crop rotations, crop residues, animal manures, off-farm organic waste, mineral-grade rock additives, and biological systems of nutrient mobilization, ensuring plant protection optimally. "Organic agriculture is a production system that sustains the health of soils, ecosystems, and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects.

History of Organic Farming

Organic farming is a holistic system designed to optimize the productivity and fitness of diverse communities within the agro-ecosystem, including soil organisms, plants, livestock and people. The principal goal of organic production is to develop enterprises that are sustainable and harmonious with the environment." (Source: Omafra). Organic farming in 1900, a British colonial officer Albert Howard in India with the title of Imperial Chemical Botanist, carried out agricultural experiments. He found that the factor most important in soil management was a regular supply of compost prepared from animal and vegetable wastes and concluded that crops have a natural power of resistance to infection. Returning to England in 1931, Albert became known as the pioneer of the organic movement. Organic farming was a definable production system in the 1930s and 1940s. The organic philosophy suggests that natural products for food production are desirable and synthetic ones are not; and healthy soils lead to healthy plants that resist pest attack, while healthy plants lead to healthy animals, including people. The environmental awareness of the 1970s led to increased demand for organic foods. This also led to the development of early organic certification systems. In 1972, the International Federation of Organic Agriculture Movements (IFOAM) was founded in Versailles, France. Roland Chevriot, the former president of Nature and Progress and several other persons led the initiative.

Need of organic farming

A significant portion of India's economy is derived from agriculture, and most people are either directly or indirectly dependent on it and its related industries. The Green Revolution in India was a time of transition when the country's agricultural system was transformed into an industrial one through the use of modern techniques and tools. All of India's crops produced significantly more and were more productive as a result. However, that short period of growth was followed by unfavourable effects on natural resources, including soil, water, biodiversity and human health. The depletion of soil has been caused by factors such as salinization, soil erosion and heavy use of agrochemicals. These practices have also resulted in the exploitation and pollution of water resources. Fig. 1: shows the Advantages of Organic Farming. India is the second most populous country in the world after China. According to the Census of India 2011, the population of India was 1210.19 million. At the time of independence, the country's population was 342 million. The number has multiplied fourfold in around five decades. The increasing rate of population increase is placing greater strain on food production. Higher food insecurity, greenhouse gas emissions and extensive environmental deterioration result through this. (Narayanan *et al*., (2005), The extensive use of chemical fertilizers in agriculture deteriorates soil quality and has a negative impact on the environment and public health. Due to the deleterious effect that inorganic fertilizers and agrochemical have on the environment and on people, there is an urgent need to switch from the current inorganic agriculture to organic agriculture.

India is the country with the highest number of producers worldwide and the ninth largest in terms of organic agricultural land. Thirty per cent of the world's organic producers reside in India, which also accounts for 2.59 per cent, or 1.5 million hectares, of the 57.8 million hectares of total organic farming area. (V. Kumari *et al*., 2020), The entire area certified as organic was 3.566 million hectares in 2018-19 in India. Madhya Pradesh leads all other states with 9.18 lakh hectares, followed by Rajasthan with 6.32 lakh hectares, Maharashtra with 2.61 lakh hectares odisha with 1.28 lakh hectares, Karnataka with 1.05 lakh hectares, Gujrat with 0.94 lakh hectares, Telangana with 0.88 lakh Hectares and Sikkim with 0.76 lakh hectares. In 2018-19, the total percentage of these states of total certified organic area was 90 percent. (Bas *et al*., 2023), With the use of certified organic products, farmers cultivate organic food while adhering to rigorous government-approved guidelines, conserving water and land for the benefit of future generations and using renewable resources (*Xu, et al.,2006)*.

Features of organic farming

- Decreased use of chemicals, which contributes to protecting the long-term fertility of the soil by maintaining organic matter level, enhancing soil biological activity and avoiding water contamination.
- Organic foods don't include artificial pesticides or herbicides, the health hazards related to chemical residues are decreased.
- The outstanding aspect of organic farming is mix cropping, which involves growing a range of crops on the same area of land at the same time or at various times. Mix crops prevent competition for nutrients by promoting photosynthesis and allowing various plants to obtain their nutrients from different soil depths. The legume stores atmospheric nitrogen, which it then releases for use by companion or future crops.
- Crop rotation uses various kinds of root systems to improve the structure of the soil.
- Organic farming requires a lot of labour, it improves the quality of the resources over time and creates employment opportunities in rural areas.
- Achieve ecological balance, organic farming has to establish habitats, maintain genetic and agricultural diversity and implement a well-designed farming system.

Types of Organic Farming

Pure Organic Farming- Pure Organic Farming avoidance of use of any inorganic/artificial chemicals. Natural resources are the source of all fertilizers and pesticides.

Integrated Organic Farming- To fulfil ecological demands and requirements, integrated organic farming integrates pest and nutrient management. It has complete nutritive value and also manages to prevent the crop or plants.

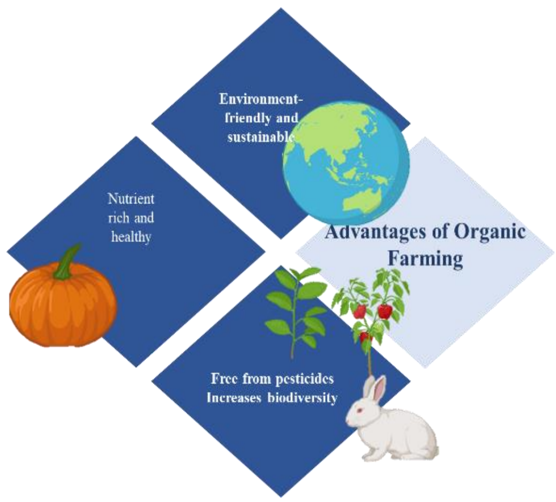

Fig. 1 - Advantages of Organic Farming

Constraints of organic farming

- Degradation of the soil, deficiencies in several nutrients, low level of organic farming and a decrease in total factor productivity have all been noted.

- Farmers' capacity to turn a profit is limited by their ignorance of modern technologies and government initiatives.
- Due to the lower output per acre when compared to conventional agricultural practices, organic food costs are typically higher.
- With the smaller production levels, the organic food supply chain may be less efficient.

Conclusion

The overuse of chemical fertilizers in agriculture deteriorates soil quality and negative impact on the environment and public health. it is imperative to switch from the current inorganic agriculture to organic agriculture. Organic farming methods will boost agricultural output and production in an agricultural sustainable way without disrupting the ecosystem's balance to accommodate the expanding population. In the future, it is envisaged that organic farming will play a significant role in both sustainable agriculture and a friendly environment.

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CARBON FARMING: AN APPROACH TOWARDS SUSTAINABLE AGRICULTURE

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According to UN forecasts, the global population is anticipated to reach 9.7 billion by the year 2050. Simultaneously, the Food and Agriculture Organization (FAO) predicts that world food demand would rise by 70% by the year 2050. Furthermore, the global community is currently confronted with a climate change crisis that poses a significant threat to food security on a global scale. As per the International Panel of Climate Change (IPCC, 2019), agricultural, forestry, and land-use change (AFOLU) are responsible for 25% of greenhouse gas (GHG) emissions. Specifically, agriculture alone contributes to around 14% of GHG emissions. In relation to croplands, they have the potential to capture and store approximately 0.90 to 1.85 billion metric tons of carbon annually. This would contribute to 26-53% of the objective established by the '4p1000 Initiative: Soils for Food Security and Climate', which is a worldwide approach to utilize soil for mitigating climate change (Zomer*et al*., 2017). The UN announced the 4 per 1000 project in 2015, which is ainitiative designed to annually improve carbon storage in agricultural soils by 0.4%. A soil carbon stock growth rate of "4‰" per year would effectively halt the current rise in atmospheric CO2 levels, as stated by the UNFCCC. Hence, agriculture serves as both a source and a means of reducing greenhouse gas emissions. Although agriculture contributes to the problem, it has the potential to be part of the solution through the implementation of scientific knowledge, raising awareness among various stakeholders (including farmers, policy makers, and government assistance), and taking responsible actions.

Carbon farming is a system of agricultural management that helps the land store more carbon and reduce the amount of GHG that it releases into the atmosphere (Tang *et al*., 2016). It is one of strategy to lessen atmospheric carbon dioxide that is released from agricultural landscape, in an effort to slow down the rate of climate change. Carbon sequestration is the fundamental principle in carbon farming.According to the UNFCCC, carbon sequestration is the process of removing carbon from the atmosphere and storing it in a reservoir. Soil Organic Carbon (SOC) is the most important of indicator of soil carbon sequestration efficiency and overall soil health.Farming practices, soil management, and land usage all affect SOC. Agroecosystems' soils have significantly decreased in SOC and are degrading. Increasing SOC concentration through the use of best management practices that result in a positive C budget is necessary to restore soil quality (Lal *et al*., 2015).

Carbon farming helps both mitigate and adapt to climate change in agriculture.Mitigation involves reducing the emission of GHGs from various sources by practicing climate smart agriculture whereas adaptation includes practices that help adjust to the effects of climate changeby adopting various climate resilient practices. Carbon farming is a sustainable agriculture approach which ensures food security while conserving natural resource base and environmental quality.

Carbon farming can include a number of sustainable agricultural practices that improve sequestration of carbon from atmosphere into soil. Agroforestry, Conservation Agriculture (CA), Biochar application, Direct Seeded Rice (DSR) & Alternate Wetting and Drying (AWD) in rice cultivation, crop residue management, etc. These methods not only sequester more carbon in soil but also reduces the carbon emissions in the form of CO2 & CH4 and help retain more soil carbon.

Agroforestry

Agroforestry as the purposeful growing or deliberate retention of trees with crops and/or animals in interacting combinations for multiple products or benefits from the same management unit Agroforestry practices contribute to carbon sequestration through several mechanisms: tree biomass (via photosynthesis), below ground carbon (as roots and organic matter), litter and mulch and agroforestry interactions (Nair *et al*., 2010). The majority of the carbon stored in land use systems based on trees is thought to be held by the soil and aboveground components, which account for around 60% and 30% of the total, respectively (Lal, 2008). Nair *et al*. (2021) stated the general trend of increased soil carbon sequestration in agroforestry relative to other land-use strategies in terms of their SOC content: forests > agroforests > tree plantations > arable crops.

Pathak *et al*. (2011) collected data on the capacity of various cropping systems in Indian agriculture to sequester carbon through a variety of long-term experiments (LTEs) conducted in the country's various agroclimatic zones. They found that the rate of sequestration of carbon varied from 0.02 mg C/ha/yr to 1.2 mg C/ha/yr. The global scenario of carbon stored in agroforestry systems, according to P. R. Nair *et al.* (2010), ranged from 0.29 to 15.21 Mg C/ha/yr above ground and 30–300 Mg C/ha down to a depth of 1 m in the soil (the age of trees varied from 4 to 35 years).

Conservation Agriculture

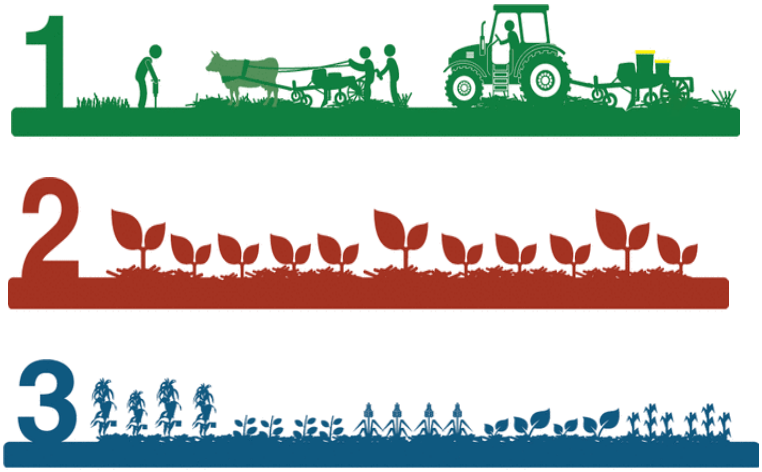
Conservation Agriculture (CA), as defined by the United Nations' Food and Agriculture Organization (FAO), is “a farming system that promotes maintenance of a permanent soil cover, minimum soil disturbance, and diversification of plant species. According to Jat *et al*. (2019), the combination of CA and well-balanced nutrition management increased SOC stability as well as concentration.

Adoption of conservation agriculture resulted in annual increases in SOC stock in IGP of 0.16 to 0.49 Mg C ha1 yr1 as compared to conventional practice (Powlson*et al.,* 2016). As per field experiment done by Dendooven*et al*., (2012), the net global warming potential (GWP) of CA was − 7729 kg CO2 ha/yrin 2008–2009 and − 7892 kg CO2 ha/yr in 2010–2011, whereas that of Conventional Tillage (CT) was 1327 and 1156 kg CO2 ha/yri.e. the share of CA to GWP was small compared to that of CT. No-Tillage (NT) soils under dryland farming and rice (Oryza sativa L.) paddy soils have the potential to contain higher concentrations of SOC (Zhang *et al.,* 2014).

Minimum mechanical soil disturbance

Permanent soil organic cover

Species diversification



Source : FAO (2022)

Direct Seeded Rice (DSR)

Direct Seeded Rice (DSR) reduces the water use and the GHG emissions created by methane emitting bacteria that thrive in the standing water. DSR is reducing the methane emissions by 30–38% in India (Pathak *et al*., 2013). According to Kumar and Ladha (2011), DSR can save labor expenses by up to 50% and reduce water use by up to 40%. According to a two-year field experiment conducted in China by Xu *et al*. (2023), DSR reduced the GWP by an average of 28.9–53.2% over the course of the two years. This suggests that direct seeded rather thantransplanted rice will significantly lessen the climatic impact caused by GHG emissions. There exists a platform named 'Direct Seeded Rice Consortium (DSRC)' on direct seeded rice (DSR), convened by the International Rice Research Institute (IRRI) to promote, and enhance the area under DSR across Asia and Pacific.

Biochar Application

Biochar, a carbon (C)-rich material obtained from the thermochemical conversion of biomass under oxygen-limited environments, has been proposed as one of the most promising materials for C sequestration and climate mitigation in soil. (Luo *et al.*, 2023). The maximum sustainable technical potential of biochar to considerably reduce climate change was estimated by Woolf *et al*. (2010) on a global scale. Since this process is a true contribution to mitigating climate change, adding biochar to the soil may result in "SOC sequestration" by creating a net additional long-term removal of CO_2 from the atmosphere and C storage in the SOC pool (Stockmann*et al*., 2013).

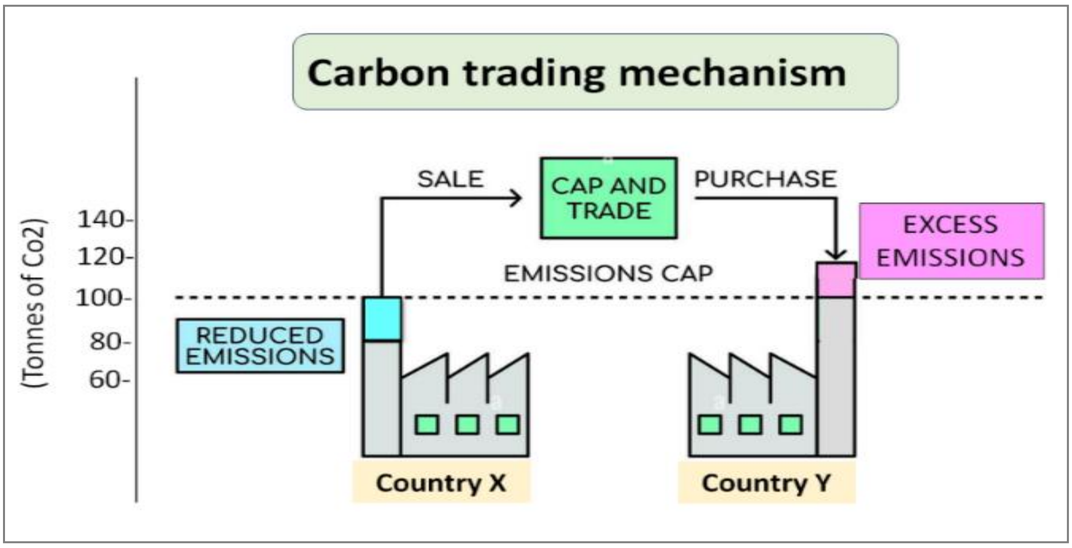
Crop Residue Management (CRM)

India produces 550 million tonnes (Mt) of crop residue from agriculture each year. About 90–140 Mt of it is burned annually on fields to clear the area for the following crop (Bhuvaneshwari*et al*., 2019). Presently, more than 80% of the total rice straw produced annually is burnt by farmers in 3–4 weeks during October–November in India (Singh *et al*., 2010). Burning rice straw releases gases that include 70% CO_2, 7% CO, 0.66% CH_4, and 2.09% N_2O (Gupta *et al*.,2004).

According to Gadi *et al*. (2003), burning one tonne of rice straw releases roughly 3 kg of Particulate Matter (PM), 60 kg of CO, 1460 kg of CO2, 199 kg of ash, and 2 kg of SO2. Therefore, managing crop residue by using different methods other than burning would limit the amount of carbon released as greenhouse gases into the atmosphere. Crop residue management alternatives include composting, calf feeding, soil mulching, in-situ residue retention under conservation agriculture, biogas generation, etc.

Carbon trading

Carbon Credit' means a value assigned to a reduction or removal of greenhouse gas emissions achieved & is equivalent to one ton of carbon dioxide equivalent (tCO2e).(Lokuge & Anders, 2022)Carbon trading in the agricultural sector refers to the buying and selling of carbon credits that are generated by practices that reduce greenhouse gas emissions or increase carbon sequestration on farms and other agricultural lands.(Johnson *et al*., 2014). As for example, there exists two countries X & Y and X produced 80 tonnes of CO2 and Y produced 120 tonnes. The maximum emission cap is set 100 tonnes. X can now sell it's 20 tonnes (not emitted CO2) in the form of carbon credits to Y so that Y also has net emission as 100 tonnes.



(Elkerbout, 2020)

In the recent times, different governments and national &international bodies have identified the potential benefits of carbon farming. India's Ministry of Power announced the "Carbon Credit Trading Scheme (CCTS) 2023" to help grow the country's carbon market. This is part of the country's plan to decarbonize its economy and meet its promise to cut emissions by 45% from 2005 levels by 2030. As Uttar Pradesh becomes the first state in India to finalize a "agroforestry policy," farmers there will soon receive additional revenue from the carbon credits produced by the trees growing within their farm boundaries. By 2027, the state wants to raise its percentage of green space from the current 9.23% to 15%.

Startups in Carbon Farming

Various agri-startups have taken up carbon trading as their business idea. They are helping farmers to adopt sustainable agricultural practices that aid in more carbon sequestration in the field.

Nurture farm: Working with farmers in Punjab & Haryana states, aims to generate 1 Million carbon credits in coming one year through promotion of AWD & DSR in rice cultivation. Also focusing on crop residue management.

Varaha Climate Ag pvt. Ltd : Based in New Delhi and coversareas of Indo-Gangetic Plain (IGP), Madhya Pradesh & Haryana, en route to sequester 1 Billion Tonnes of carbon by 2030.

Boomitra: Boomitra uses satellite and AI technology to measure, report, and verify soil carbon credits across the globe viz. Asia, Africa and Mexico.

Opportunities of Carbon Farming in Agriculture

Carbon farming provides many opportunities in all terms; social, economic and environmental.Participating in carbon markets and selling carbon credits.Creation of agri-products needed for carbon farming, like biopesticides.Business prospects from technology development required for credit certification.Developing complete value chain, linking farmers who practice carbon farming with customers, who can pay more.Mechanisms that reduce methane emissions and positive public image (Mitsui & Co. Global Report, 2023).

Conclusion

Carbon farming is asustainable approach for ensuring food security, conserving natural resource base and mitigating climate change effects on agriculture.Several promising technologies supporting carbon sequestration have evolved with time viz. agroforestry, conservation agriculture, AWD & DSR,etc. and more extensive research need to be done to strengthen the associated benefits.Carbon trading via carbon credits offers a new source of income for farmers adopting sustainable practices.Awareness regarding carbon farming needs more scaling, from policy makers to scientists and extension workers.

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