CLIMATE-SMART AGRICULTURE AND FOOD SECURITY

Chief Editor
Dr. Aarti Kamboj

Editors
Dr. Gonchikari Lokesh
Dr. Rajat Sharma
G. Manisankar
Dr. Jyotika Bhati
Dr. P. Malathi
Rahul Sharma

Kripa Drishti Publications, Pune.

CLIMATE-SMART AGRICULTURE AND FOOD SECURITY

Chief Editor
Dr. Aarti Kamboj
Research Scholar,
Department of Molecular Biology & Biotechnology,
College of Biotechnology,
CCS HAU, Hisar.

Editors
Dr. Gonchikari Lokesh
Assistant Professor,
(Horticulture) at Sri Krishna Devaraya college of Agricultural Sciences
at Ananthapuramu AP.

Dr. Rajat Sharma
Ph.D. Horticulture, GBPUAT Pantnagar.

G. Manisankar
Ph.D. Research scholar, Department of Agronomy,
Visva Bharati Central University, Bolpur, West Bengal.

Dr. Jyotika Bhati
PhD- Bioinformatics,
ICAR-Indian Agricultural Statistics Research Institute,
New Delhi.

Dr. P. Malathi
Associate Professor (SS&AC),
Department of Soil Science and Agricultural Chemistry,
Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu.

Rahul Sharma
PhD Scholar,
Dept. of Agronomy CSK HPKV Palampur HP.

Kripa-Drishti Publications, Pune.

Book Title: **Climate-Smart Agriculture and Food Security**

Editors By: **Dr. Gonchikari Lokesh, Dr. Rajat Sharma,**
G. Manisankar, Dr. Jyotika Bhati,
Dr. P. Malathi, Rahul Sharma

1st Edition

ISBN: **978-81-19149-59-9**

Published: **August 2023**

Publisher:

Kripa-Drishti Publications
A/ 503, Poorva Height, SNO 148/1A/1/1A,
Sus Road, Pashan- 411021, Pune, Maharashtra, India.
Mob: +91-8007068686
Email: editor@kdpublications.in
Web: https://www.kdpublications.in

PREFACE

Climate change is one of the most pressing challenges of our time, and its impact on agriculture and food security cannot be overstated. As we stand at the crossroads of environmental and agricultural crises, the need for innovative, sustainable solutions has never been more critical. "Climate Smart Agriculture and Food Security" seeks to address this urgent issue by delving into the intricate relationship between agriculture, climate change, and the quest for food security. This book is a comprehensive exploration of climate-smart agriculture, a concept that aims to harness the power of innovation, technology, and sustainable practices to adapt to climate change while mitigating its impact. It provides a roadmap for creating resilient agricultural systems that can thrive in the face of adversity, reduce greenhouse gas emissions, and contribute to the broader goal of achieving food security for a growing global population. Within these pages, you will find a wealth of knowledge and insights from leading experts in the fields of agriculture, climate science, and policy. They will guide you through the key principles of climate-smart agriculture, from the integration of traditional and modern farming practices to the adoption of cutting-edge technologies such as precision agriculture, agroforestry, and climate-resilient crop varieties. But this book is not just about theory; it is also about action. It showcases real-world examples of climate-smart agriculture in practice, highlighting success stories from around the world where farmers, scientists, and policymakers have come together to implement innovative solutions. These stories serve as both inspiration and a call to action, illustrating what can be achieved when we work collaboratively to address the challenges of our changing climate. We hope that this book will serve as a valuable resource for researchers, policymakers, farmers, students, and anyone who is passionate about creating a more resilient and sustainable future. It is our collective responsibility to confront the challenges of climate change head-on and to ensure that no one goes hungry in a world where the climate is changing faster than our agriculture practices. "Climate Smart Agriculture and Food Security" is a step in that direction, offering knowledge, inspiration, and a roadmap for a more sustainable and secure future.

About the Editors

Dr. Aarti Kamboj, a dedicated researcher who has journeyed through the fascinating realms of Molecular Biology and Biotechnology. Her academic prowess shines through her notable educational milestones. She embarked on her scientific journey with a B.Sc. in Life Science from KU, followed by a remarkable M.Sc. in Molecular Biology & Biotechnology from CCSHAU. Her academic journey culminated in a Ph.D. in the same field, where she focused on tackling foliar blast disease in pearl millet. Moreover, her commitment to education was evident during her tenure teaching courses on Plant Biochemistry, Biotechnology, and Bioinformatics to undergraduates during her Ph.D. Her M.Sc. thesis delved into the genetic diversity of kiwifruit, and her Ph.D. research focused on molecular characterization for targeting foliar blast disease in pearl millet. Her skill set is a testament to her comprehensive understanding of the field. From technical proficiency in molecular biology techniques, to hands-on fieldwork, and crop raising, she's a versatile researcher. A strong believer in continuous learning, she has participated in numerous workshops and conferences, showcasing her research findings and staying at the forefront of her field. Her published papers and articles further solidify her contributions to the scientific community.

Dr. Gonchikari Lokesh was born on 10th June 1995 at Thumukunta village in Ananthapuramu District of Andhra Pradesh. He did his Ph.D. Horticulture (Specialization in Fruit Science) from Dr. Y. S. R. Horticultural University, Venkataramannagudem, Andhra Pradesh in 2023. He was awarded B.Sc. (Hons) Horticulture in 2016 and M.Sc. Horticulture specialization in fruit science in 2018 by Dr. Y. S. R. Horticultural University, Venkataramannagudem. He also qualifies ICAR NET in fruit science. He has published 05 research papers in national and international journals, 05 abstracts, 06 popular articles and 02 book chapters. Presently he was working as an Assistant Professor (Horticulture) at Sri Krishna Devaraya College of Agricultural Sciences (Affiliated to ANGRAU), Ananthapuramu, and Andhra Pradesh.

Dr. Rajat Sharma was born in Village-Kharmasa, Kashipur, District Udham Singh Nagar, Uttarakhand in 1994. He completed his graduation in Horticulture in 2016 from Veer Chandra Singh Garhwali, Uttarakhand University of Horticulture and Forestry, Bharsar, Pauri Garhwal, Uttarakhand. He pursued his Masters degree in Horticulture in 2018 from Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, District Udham Singh Nagar, Uttarakhand in propagation aspect of peach Cv. Shan-e-Punjab. After that he completed his doctoral degree in Horticulture in 2023 from Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, District Udham Singh Nagar, Uttarakhand in which he worked on irrigation, mulching and micronutrient aspect in litchi Cv. Rose Scented. During his academics period, he wrote around 15 popular articles, 3 research papers in NAAS rated Journals. He also cleared National Eligibility Test in Horticulture conducted by ASRB in 2018. He also participated in around 10 conferences/workshop/trainings. Now, he is working as District Horticulture Officer or equivalent in Department of Horticulture, Govt. of Haryana.

Mr. G. Manisankar completed his Bachelor's degree in Agriculture from Annamalai University, Chidambaram and his Master's degree in Agronomy from Tamil Nadu Agricultural University, Coimbatore. He is currently pursuing his third year of Ph.D. (Ag.) Agronomy at Visva Bharati (A Central University and an Institution of National Importance), West Bengal. His area of specialization is Weed Management and Rice Agronomy. He has published many original research articles, as well as review articles and book chapters for the benefit of the scientific community. He has also published popular articles for the benefit of the farming community. He has presented his research findings at various national and international conferences and has received many awards for the best paper presentation which includes the M.S. Swaminathan Young Scientist Award, Young Agronomist Award, Shri Jay Lal Singh Solanki Memorial All India Best M.Sc. Thesis Award and ISWS Student Travel Grant Award. His attitude towards research and innovation has led him to become a member of the Indian Science Congress Association, Indian Society of

Weed Science, Indian Society of Agronomy and the Center for Advanced Research in Agricultural Sciences. His teaching capability was exhibited through his successful clearance of the National Eligibility Test conducted by the Agricultural Scientists Recruitment Board, New Delhi in 2021.

Dr. Jyotika Bhati, Ph.D. Bioinformatics is a Research Associate (Bioinformatics) at ICAR-Indian Agricultural Statistics Research Institute, New Delhi. She is a passionate researcher with extensive interests on multi-disciplinary "omics" methods and having ten or more years' research experience. She is proficient in aspects of bioinformatics, comparative genomics and metagenomics. With Masters in Bioinformatics from Chaudhary Charan Singh Haryana Agricultural University, Hisar (India) and defended her PhD thesis in Bioinformatics at Banasthali Vidyapith, Rajasthan. Currently she is working on identification of differentially expressed genes from high-throughput transcriptome data using NGS data analysis tools. She is also assisting molecular biologist with bioinformatics support. She is a prolific bioinformatics researcher and have published high-quality research articles in high impact research journals. Some of these peer-reviewed journals include International Journal of Genomics, Frontiers in Genetics, Frontiers in Veterinary, Genomics, MDPI Genes, Ecological Indicators, PLOS One etc. She has also been awarded with reputed **Prof. Nils Lagerlof Award Best Publication award 2020-21**.

Dr. P. Malathi is an Associate Professor in All India Coordinated Research Project on Soil Test Crop Response, Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore. She obtained her Ph.D. from TNAU, Coimbatore in 2002. She has 13 years of service in teaching, research and extension activities. She is specialised in soil fertility, soil nutrient extractants, developing new fertilizer formulations and micronutrients. She guided four PG scholars as chairperson. She participated in about 30 trainings/conferences and acted as resource person in many trainings. She is the recipient of best M.Sc(Ag) and PhD student awards at TNAU and many prestigious awards and recognitions. She authored and coauthored 5 books, 17 book chapters, 24 research articles, 31 conference papers, 23 teaching manuals and 18 popular articles/leaflet.

Rahul Sharma, Obtained his degree in B.Sc. (Hons), M.Sc. (Agronomy-Gold medal list- University Merit scholarship) and Ph.D. pursuing from CSK Himachal Pradesh Krishi Vishwavidyalaya, Palampur in 2018 and 2020 and onwards. He has attended 6+ National and International Conferences with 1 “Best Poster Award” in an international conference received several awards such as “Best M.Sc. Thesis Award” and “Best Research Scholar Award” during his academic career. He has also published 2 research papers, 8 popular articles and 2 book chapters.

CONTENT

ISBN: 978-81-19149-59-9

1. Climate Smart Agriculture: Technology and Impact

Osman Ali, Sunil Kr. Gunri, Biswapriya Mallick

Department of Agronomy,
Bidhan Chandra Krishi Viswavidyalaya (SAU), Mohanpur,
Nadia, West Bengal, India.

Abstract:

The text discusses Climate Smart Agriculture (CSA), which is an integrated approach to landscape management. CSA aims to adapt farming methods, livestock, and crops to the current anthropogenic climate change. Additionally, it aims to reduce greenhouse gas emissions and ensure food security while considering the growth of the world's population. The emphasis is on enhancing agricultural productivity alongside sustainable agriculture. Climate smart agriculture (CSA) is an approach that aims to transform and reorient agricultural systems to support development and ensure food security in a changing climate. The goals of CSA include enhancing agricultural productivity and income sustainability, fostering resilience to climate change, and minimizing greenhouse gas emissions. The CSA proposes examining three objectives across various levels and timeframes while considering regional and national differences and preferences. These goals encompass the farm-to-landscape continuum and range from local to global perspectives. CSA is context-specific and involves a range of integrated elements rather than universal practices. CSA involves the integration of various technologies, policies, institutions, and investments to address both on-farm and off-farm actions.

1.1 Introduction:

Education is an unquestionable privilege. It helps to form opinions and makes people less The agricultural sector in India is highly susceptible to weather and climate conditions, which are exacerbated by extreme weather events and distinctive meteorological factors. Consequently, the country has encountered a substantial decline in crop yield.

The Global Circulation Model Climate Change experiments predict that future agricultural production in the nation will be significantly affected by variations in weather and climatic characteristics. According to the assessment conducted by the Food and Agriculture Organization (FAO) and the Intergovernmental Panel on Climate Change (IPCC), it is projected that there will be a significant reduction in agricultural productivity in India in the coming years. Specifically, it is estimated that by 2020, there will be a reduction of 2.5-10%, and by 2050, a reduction of 5-30%. The country's food security may be jeopardized due to the effects of a shifting climate. In order to enhance resilience to climate change, crops must adapt to heightened weather variability, extreme occurrences, and shifting climate patterns that occur during the entirety of the growth period. Therefore, it is now more crucial than ever to implement integrated adaptation and mitigation interventions that comprehensively address the numerous challenges confronting agriculture.

The implementation of "climate-smart agriculture" is a pragmatic approach to ensuring food security amidst a dynamic environmental landscape. The implementation of adaptation strategies based on the principles of climate-smart agriculture, including the advocacy of conservation agriculture, sustainable resource management, and climate-smart crops, can serve as a means of alleviating the impacts of climate change.

Climate-smart agriculture (CSA) has been implemented with the aim of supporting smallholder farmers in adapting to the effects of climate change through the improvement or expansion of their livelihood strategies. The concept of climate-smart agriculture was introduced by the Food and Agriculture Organization (FAO) during the Hague Conference on Agriculture, Food Security, and Climate Change in 2010. It pertains to agricultural practices that promote sustainable production, enhances resilience, mitigates greenhouse gas emissions, and facilitate the attainment of national food security goals. This approach is considered a viable means of achieving sustainable development objectives. The simultaneous addressing of food security and climate concerns serves to integrate the three fundamental components of sustainable development, namely the economic, social, and environmental dimensions. The construct comprises three primary pillars.

a. **Sustainability**: Sustainably increasing and intensifying agricultural productivity and incomes;
b. **Adoption**: Adapting and building resilience to climate change;
c. **Mitigation**: Reduction and/or mitigation of greenhouse gases emissions, where and when possible;

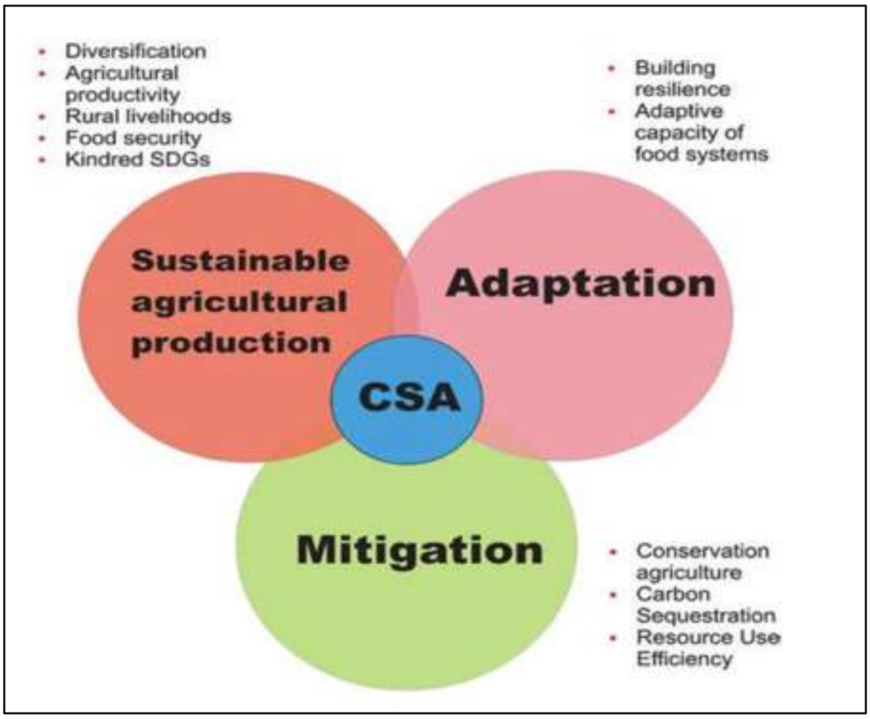


Figure 1.1: Climate-Smart Agriculture (CSA)

Overall, Climate-smart agriculture primarily focuses on addressing both nutrition security and food security as well for rural and smallholder farmers. In addition, CSA uses a comprehensive strategy to safeguard or replenish the resource base.

1.2 Technology for Climate-Smart Agriculture:

Natural resource management requires coordinated, scientific, multidisciplinary, and varied approaches. It is the main paradigm shift that will modernize conventional agriculture under CSA. Thus, climate-smart agriculture requires multiple interventions in the land, water, soil, energy, cattle, etc. The time has come to adopt these approaches holistically and with site-specific resources.

1.2.1 Land Use Management:

In addition to its extraordinary function in the cycling of substances between the ground and the air, the land also serves as a repository for greenhouse gases. In varying degrees, land bio-networks are the most vulnerable to the effects of ongoing Climate Change (CC) and Extreme Weather Events (EWE). This necessitates environmentally sustainable land management, which helps lessen the negative consequences of CC and unpredictability. The following are a few examples of actions that will aid in sustainable productivity increases and also contribute to CC mitigation and adaptation:

- The practice of carbon sequestration (CS) in soil or vegetation, along with the moderating influence of climate change (CC), is reinforced by various land use management alternatives. These include afforestation, agroforestry, reforestation, soil organic carbon (SOC) management, and the introduction of biochar into the soil.
- The preservation and rehabilitation of natural ecosystems, such as wetlands and coastal regions, is of paramount importance. The implementation of sustainable land use management practices such as green manuring, cover crop production, crop residue retention, minimum/zero tillage, and enhanced grazing management can effectively mitigate soil degradation resulting from agricultural activities. These practices also offer supplementary advantages for climate change adaptation. The cultivation of forage legumes such as lablab, cowpea, pigeon pea, lucerne, and sesbania on a large scale to enhance feed conversion efficiency resulted in a reduction of methane emissions by 25-33%.
- The implementation of diverse forest and crop systems, coupled with appropriately diversified crop rotations and effective range and pasture management, has the potential to maintain or even improve forest carbon stocks. This approach can effectively mitigate greenhouse gas emissions and contribute to climate change adaptation efforts. The consumption of a diverse range of foods can enhance the nutritional value of one's diet.
- Incorporating soil organic matter (SOM), implementing measures to prevent soil erosion, utilizing enhanced fertilizers, adopting crop management techniques such as fallow rice management, cultivating drought- and flood-tolerant varieties, and other similar farming practices are widely recognized as effective strategies for achieving both climate change adaptation and mitigation. Spatial and interdisciplinary methodologies hold significant importance.

- Mitigating the hazards of climate change on agroecosystems can be facilitated through alterations in land use practices, including adjustments to cropping patterns, animal production, and the relocation of crop or livestock production from vulnerable areas, as well as modifications to the frequency of application of inorganic fertilizers and chemical pesticides, as well as the allocation of capital and labour. The planting of trees in fields for purposes such as windbreaks, live fences, fodder banks, alley cropping, or enhanced fallows has the potential to sequester carbon dioxide from the atmosphere in both biomass and soil. Additionally, this practice can provide a source of firewood and other forest-based products. According to Awazi and Tchamba (2019), the preservation of natural forests is supported by this, and it also facilitates adaptation and mitigation efforts under CC.

1.2.2 Crop Production Management:

In order to achieve sustainability in CC scenarios, agricultural crop production (ACP) that is managed effectively is crucial. In this respect, SCPI (sustainable crop production intensification) is crucial. SCPI is a type of ACP that makes use of natural biological inputs and processes to preserve and improve natural resources while lessening their negative effects on the environment. It helps make agricultural systems less vulnerable to the effects of climate change. Maintaining healthy soil, avoiding monoculture, and growing high-yielding, well-adapted varieties through the use of high-quality seeds and planting materials, integrated pest, weed, and disease management, and careful water management are the foundation of the Sustainable Crop Production System (SCPI). As a result, climate-smart ACP refers to the sustainable cultivation of crops in the face of CC, with the goal of making them more resistant to Climate Variability (CV).

- Adopting the tenets of conservation agriculture (CA), such as reduced tillage, crop rotation, and residue retention, is strongly recommended. With zero tillage, farmers can plant wheat immediately after reaping other crops like rice or cotton. In the final stages of grain development, this method protects the wheat crop from fatal heat stress (Pathak, 2009). GHG emissions are cut and soil organic carbon is stored when farmers practise no-till. Techniques that improve the efficiency with which resources are managed or inputs are applied are examples of resource conservation technologies (RCTs), which have direct, measurable, and all-encompassing economic benefits like lower production costs, less need for energy, labour, and water, and better seeding timing, which leads to higher crop yields (Amin *et al.*, 2015).
- Physical, chemical, and biological methods, including biocontrol agents, traps, mulches, soil sterilisation, pesticides, resistant cultivars, etc., should be used in the context of integrated pest management.
- Integrated weed management is a strategy for controlling weeds that makes use of cultural, mechanical, biological, and chemical techniques to lessen the impact of weedicides on the environment and boost CSA.
- Sprinkler or drip irrigation should be used to efficiently manage water and irrigation, eliminate water conveyance losses, reduce water losses due to evaporation, runoff, and drainage, apply water based on crop needs, and so on.
- Organic farming is another option because it forgoes the use of synthetic fertilisers and pesticides in favour of natural methods of crop nutrition.

- Nutrient-use-efficient crop varieties should be grown to reduce the amount of fertilisers used on farms and, by extension, greenhouse gas emissions.
- A preferable choice for CSA and livelihood sustainability, especially for small and marginal farmers, is an integrated farming system that includes crops, poultry, dairy animals, and fishing. This method of farming is crucial to ensuring people have access to adequate nutrition because it utilises a wide variety of food sources.
- The cultivation of energy crops necessary for the development of biofuels tends to eliminate the need for Fossil Fuels (FF).
- Reducing fuel use in agricultural machinery operations is an effective strategy for lowering greenhouse gas emissions.

1.2.3 Soil Management:

The utilisation of soil as a fundamental natural resource is essential in attaining sustainability via CSA. The soil functions as a substrate for the growth of plants, facilitating the absorption of essential nutrients and water. The aforementioned phenomenon aids in the sustenance of soil biodiversity and the regulation of various nutrient cycles, including carbon and oxygen. Effective soil management is an essential practice within the context of Community Supported Agriculture (CSA).

The soil management techniques for Climate Smart Agriculture (CSA) may include the following approaches:

- Prior to implementing any CSA soil management technique, it is imperative to evaluate the physical, chemical, and biological attributes of the soil that have an impact on soil health and the sequestration of soil organic carbon (SOC). This can be accomplished through an in-situ examination using soil testing kits or by obtaining soil samples and conducting laboratory analyses. The utilization of CSA is recommended for the incorporation of these attributes, as suggested by Faurès *et al*. (2013).
- Minimum or no-tillage reduces runoff, enhances soil water infiltration, and prevents subsurface plough pans. CA increases SOM and inhibits SOC mineralization, which aids SOC sequestration. Thus, CA reduces GHG emissions.
- Soil erosion can be prevented by planting vegetation across steep slopes or by building soil and water conservation structures like tied ridges, bunds, terraces, trenches, etc. Grassed rivers, chute spillways, drop-inlet spillways, etc. can securely dispose of runoff water on slopes.
- The implementation of agroforestry, mixed cropping, cover cropping, contouring, strip cropping, and other similar practices have been shown to effectively mitigate soil erosion and enhance the sequestration of soil organic carbon (SOC).
- The phenomenon of wind erosion in arid and semi-arid regions has the potential to cause the depletion of nutrient-rich topsoil or the formation of sand dunes on agriculturally productive land. The implementation of drought-resistant plant species, rotational grazing practices, and perpendicular windbreaks in relation to the prevailing wind direction can effectively mitigate this issue. The practice of mulching with crop residues has been found to have several benefits for soil management. These include the buffering of soil temperature, reduction of soil water evaporation and nutrient loss, and an increase in soil organic matter (SOM). The resulting improvement in soil moisture

content, biodiversity, structure, and infiltration are also noteworthy. Preventing soil erosion can be achieved by avoiding runoff and rainfall. According to Faurès *et al*. (2013), it has been observed to decrease soil salinity and alleviate waterlogging.

- Improper agricultural nutrient management increases soil GHG emissions, making it crucial in CSA. Nitrogenous fertiliser can convert to nitrous oxide gas under anaerobic conditions, which has a global warming potential of 300. Nitrogenous fertiliser mineralization releases nitrate ions into soil water, which promotes drainage. Nitrous oxide emissions are lowered by nitrogenous fertilisers in the reduced zone. Apply these fertilisers to the root zone. To maximise crop efficiency and minimise waste in CSA, fertilisers and manures should be administered at the right time and amount.
- Integrated soil fertility management is a crucial component of CSA, which aims to deliver optimal levels of nutrients to plants through a combination of compost, organic manure, green manure, crop rotations, intercropping, and inorganic fertilisers. This approach is designed to minimise nutrient losses, soil erosion, greenhouse gas emissions, and enhance nutrient use efficiency, while simultaneously preserving soil and water resources.
- Applying fertilisers in the right form, amount, timing, and position can improve fertiliser use efficiency. Leaf Colour Charts, chlorophyll metres, and optical sensors like Green Seeker can help farmers manage nitrogenous fertilisers precisely (Purba *et al*., 2015). Computer or Android-based decision support systems like Nutrient Expert and Crop Manager can also help.
- Leguminous agroforestry can also be used. Site-specific and integrated nutrient management minimise GHG emissions and stores SOC. Preventing input waste enhances soil and water quality.

1.2.4 Water Management:

Water is a limited resource that is being used up too quickly due to reckless and dishonest use patterns. The ever-increasing demand placed on the world's water supply by a growing human population highlights the importance of conserving this precious commodity. At the present time, 70% of all removed water is used by agriculture, mostly for irrigation. Inadequate access to water supplies makes irrigation impossible. Reducing losses due to percolation, evaporation, seepage, etc. is essential for irrigation development, especially in water-scarce countries. Climate change is expected to affect agricultural water in the form of more extreme weather events (EWE) including floods and droughts, as well as higher average temperatures. In this case, sustainable water management is crucial for reducing the effects of climate change. Improved irrigation scheduling, precision irrigation, effective drainage systems, in-situ moisture conservation, and rainfall harvesting structures are prioritised as water management practices that support the three pillars of CSA. The following are the CC adaption options for efficient water management:

- Micro-irrigation systems (micro-sprayer, trickle, or drip irrigation) are effective ways to water crops since water is supplied to the roots rather than the soil. In addition to increasing ACP by 20–38 per cent, micro-irrigation systems reduce irrigation water use by 20–48%, energy use by 10–17%, labour cost by 30–40%, and fertiliser use by 11–19 %.

- The utilization of pressurized micro-irrigation systems with sensor-based irrigation scheduling can significantly assist in the maintenance of soil moisture content at field capacity within the crop root zone, as well as in the resolution of challenges related to manual irrigation.
- Recent advancements in information and communication technology (ICT) have facilitated the development of irrigation scheduling and soil water balance software tools such as BEWARE (Chartzoulakis *et al*., 2008), IrriSatSMS (John *et al*., 2009), PILOTE (Khaledian *et al*., 2009), etc. These software tools are designed to aid in the irrigation scheduling of various crops. Furthermore, Regulated Deficit Irrigation (RDI) and Sub Surface Irrigation (SSI) are feasible alternatives that can be implemented in water-scarce regions under a climate change scenario.
- In CSA, cutting-edge technology like telemetry systems, RS, and GIS are crucial for reducing water loss across the supply chain.
- If in a region where groundwater is readily available at a shallow depth, solar pumps may be a great way to get the most out of this resource while reducing the carbon footprint. However, there is another option for reducing diesel use and carbon emissions: micro-irrigation systems that use solar power to pump water from the ground.
- The utilization of remote sensing and geographic information systems (GIS) has proven to be advantageous in multiple aspects of water management. These include command area planning and management, crop mapping and yield projection, flood monitoring and hazard mapping, and environmental impact assessment in the interlinking river project.
- The modern method of surveying is remote sensing, which may also be used to learn about groundwater's presence, growth, storage, and flow direction. This method is also useful for mapping aquifers and pinpointing places where groundwater could be refilled. Farmers can also benefit from automated irrigation systems, crop and agro-meteorology alerts, and insurances for crops and animals that are enabled by information and communication technologies (ICTs) (Altieri and Nicholls, 2017; Mittal, 2012) to help mitigate the negative impacts of CC and CV.
- The implementation of various agricultural techniques such as land levelling, minimum or no tillage, System of Rice Intensification (SRI), direct-seeded rice, crop diversification, appropriate irrigation scheduling, rainwater harvesting, site-specific soil and water conservation structures, and improved agronomic practises have been identified as potential measures to enhance the efficiency of on-farm irrigation and mitigate the depletion of groundwater resources.
- Rainwater collecting is a great way to prevent drought and should be encouraged in rainfed areas. Alternative adaptation strategies for reducing CC include integrated watershed management and the development of artificial recharge infrastructure.
- Many high-pressure drip irrigation systems use more energy to deliver the same amount of water as gravity-based systems. Therefore, changes must be made to strike a balance between enhanced energy efficiency and water efficiency if sustainability is to be achieved.

1.2.5 Livestock Management:

Figure 1.2: Livestock Management

Both livestock producers and consumers are affected by climate change (FAO, 2006). Livestock accounts for 18% of greenhouse gas emissions (Steinfeld *et al*., 2006). Methane gas, produced primarily from enteric fermentation in livestock, has a heat-trapping potential 25 times greater than carbon dioxides. Changing the diets of animals is one way to reduce their methane emissions. Feeding high-digestibility feeds instead of low-digestibility feeds and adding high-quality feed additives can both improve the diet. Adaptation and mitigation to CC can be aided by including more fats and proteins in the livestock feed and supplementing with antioxidants, vitamins, and minerals (Hristov *et al*., 2013; Havlik *et al.*, 2013). Restoration of degraded grasslands, better soil health, and increased climate resilience are all benefits of rotational grazing as a method of managing livestock. Cattle grazing on grasslands necessitates the cultivation of improved pasture variety. Vaccines against methanogens found in the rumen of livestock are now in development, which might eventually reduce methane gas emissions (Wright and Klieve, 2011). Greenhouse gases are also released into the air from manure. As a result, composting and other improved methods of manure management should be implemented. Thornton and Herrero (2010) and Herrero *et al.* (2016) estimate a total mitigation potential of 417,000 Gg CO_2 eq from the implementation of these strategies.

The CSA practice of livestock diversification has been shown to increase tolerance to pests and diseases linked to climate change (Batima *et al*., 2005). Rearing should focus on breeds with improved heat and humidity tolerance, disease resistance, and adaptability to low-input environments (Pankaj et al., 2013). There are a variety of management practices that can aid in the development of livestock's capacity to adjust to CC (Pankaj *et al.*, 2013). One such method is providing animals with a steady supply of fresh, chilled water. Reducing heat stress in animals during hot periods can be as simple as splashing them with cool water at regular intervals. During the warm season, it's best to keep fewer animals in a given space. Animals should be housed in areas with adequate shade since this can lower the heat burden by as much as 30–40 per cent. Cattle shelters with roofs made of hay or corrugated steel sheets provide welcome shade. Fans and open housing systems, or taller buildings, can be used to improve ventilation and air circulation in animal shelters. Long-term cooling can be provided by planting trees around livestock sheds (Das, 2017).

1.2.6 Climate Resilience through Genetic Approaches:

The crop's genetic composition plays a crucial role in determining its response to external environmental factors and its ability to withstand various abiotic and biotic stresses, such as extreme temperatures, floods, droughts, pest and disease attacks, among others. The crop's Length of growing period (LGP) and phenology are regulated by its genetic makeup, which also impacts its ability to efficiently utilize inputs such as fertilizers and water. The preservation of genetic resources across multiple crop varieties is crucial in facilitating their potential to enhance the breeding of crops that exhibit greater adaptability in the face of climate change. According to Faurès *et al*. (2013), in order to adapt to climate change, crops must possess certain traits, including tolerance to water and temperature stress, resistance to pests and diseases, efficient utilization of limited nutrient supply, and the ability to grow in unfavourable soil conditions.

- Phenotypic plasticity is a phenomenon that refers to the ability of an organism to alter its physical and behavioural traits in response to changes
- The preservation of genetic resources can be achieved through in-situ and ex-situ methods. On the other hand, the utilization of gene banks and botanical gardens for ex-situ conservation purposes is deemed to be a more economically viable and readily available option for its users. The process of creating genetically modified organisms involves the introduction of foreign genes or the removal of existing genes through the use of targeted enzymes.
- According to Nagargade *et al*. (2017), the emission of methane gas from rice cultivation can be reduced by cultivating varieties with increased root oxidative activity, fewer unproductive tillers, and a higher harvest index.
- It is imperative to cultivate crop varieties that possess the ability to mitigate greenhouse gas (GHG) emissions, as suggested by Barfoot and Brookes in 2014. According to Nagargade *et al*. (2017), the implementation of genetically modified crops has the potential to mitigate greenhouse gas emissions through the reduction of fuel consumption during farming activities and the enhancement of atmospheric CO_2 absorption and conversion into oxygen. The Nitrogen Use Efficiency (NUE) of crops can be enhanced through the application of genetic engineering techniques or traditional breeding methods. Improving the nitrogen use efficiency of crops can lead to a reduction in the application of nitrogenous fertilizers, resulting in a decrease in greenhouse gas emissions. The objective of enhancing nitrogen use efficiency (NUE) in crops for breeding purposes involves targeting the alanine aminotransferase gene, which has been identified in barley by Shrawat and Good (2008). Certain plant genes, such as those found in *Brachiaria humidicola* and *Leymus racemosus*, have been observed to produce compounds that impede the nitrification process in soil by suppressing the activity of Nitrosomonas bacteria, as noted by Subbarao *et al*. (2007).

According to Lutz's (2013) research findings, the transfer of nitrogen-fixing genes from leguminous plants that fix atmospheric nitrogen to non-nitrogenous fixing plants has the potential to facilitate autonomous nitrogen fixation without the need for synthetic nitrogenous fertilizers.

1.2.7 Energy Management:

The agriculture sector is heavily reliant on energy, with non-renewable sources such as fossil fuels being a primary contributor to greenhouse gas emissions, which are closely linked to climate change. Consequently, it is imperative to tackle these obstacles through the implementation of sustainable energy alternatives. The significant need and extensive utilization of energy within the agricultural sector necessitate the careful administration of both sustainable and non-sustainable energy resources. The primary objective of energy management is to optimize energy usage while considering the principles of sustainability. Energy management primarily centres on the optimization of energy conservation and energy efficiency. The following activities are recommended for effectively managing energy in a sustainable manner within the context of climate change:

- There exists a necessity to augment the stock of bio-derived commodities as a substitute for those derived from petroleum, with the aim of mitigating greenhouse gas emissions. Anaerobic microorganisms can decompose biomass such as wood, animal dung, and agricultural waste to generate biogas. The biogas has the potential to be utilized for both heating and lighting applications. The residual substance resulting from biogas production, commonly referred to as slurry, is a valuable source of nitrogen and phosphorous that can be utilized as a fertilizer for crops. Additionally, laser-assisted land levelling has demonstrated potential as an effective method for addressing climate change. This technology has been shown to conserve water resources by up to 40%, optimize the utilization of fertilizers, and increase crop productivity. This methodology reduces greenhouse gas (GHG) emissions across various agricultural activities, primarily by mitigating the requirement for irrigation water, thereby decreasing the energy consumption for water pumping.
- The promotion of micro-irrigation systems, which have been shown to decrease the amount of energy required for pumping, is recommended as a means of conserving energy. It is advisable to refrain from irrigating during days characterized by high temperatures, intense sunlight, and strong winds.
- The promotion of conservation agriculture (CA) machinery, such as zero till, raised bed planter, seed-cum fertilizer drill, happy seeder, and laser-guided land leveller, is crucial as they have demonstrated their efficacy in conserving energy during diverse farming operations.
- Selecting the appropriate pump capacity and corresponding pump sets that align with the water source, whether it be a canal or well, is imperative for energy conservation in a climate change context.
- The implementation of variable speed drives (VSDs) on pumps is a significant energy-conservation strategy that enables pumps to function at the most efficient rate by offering variable speeds. According to reports, a reduction in motor speed by a mere 20% can result in a significant energy conservation of up to 50%.

- Performing routine maintenance on pumps not only extends their lifespan but also maximizes the energy efficiency of the pumping apparatus.
- The implementation of an Internet of Things (IoT) enabled smart irrigation system has the potential to facilitate optimal irrigation of fields, while also serving as a beneficial measure for climate change adaptation.
- The implementation of on-site renewable energy generation has the potential to facilitate sustainable income growth for farmers through the sale of solar power to electricity grids or biogas to regional markets while minimizing reliance on fossil fuels.
- The on-site production of biogas has the potential to facilitate the utilization of its resulting substances as a form of fluid organic fertilizer, thereby enhancing agricultural productivity while mitigating ecological harm.
- Considering the context of Creative Commons licensing, it is imperative to foster the adoption of energy-efficient technologies that can effectively curtail energy consumption in agricultural practices and mitigate crop water demands.

Impact:

Considering the diverse circumstances of climate fluctuations and their consequences on agricultural output, sustenance, and dietary welfare at the domestic level, it is apparent that climate change will significantly impact food production. The impact of climate change extends beyond the availability of food and nutrition for human consumption and encompasses the sustainability of crop production, livestock production standards, and socioeconomic stability.

The imperative of enhancing agricultural production, productivity, and profitability in the future cannot be overstated, as it is crucial for fostering harmonious relationships among diverse stakeholders at the village, district, state, national, and international levels. In consideration of the sustainability of food production, several strategies can be recommended. These include the efficient and prudent utilization of resources, as well as the judicious application of pesticides, herbicides, and fertilizers.

Additionally, adapting to climate change through ecological, genetic, and socioeconomic approaches is crucial. Furthermore, minimizing the emission of greenhouse gases such as methane, nitrous oxide, and carbon dioxide (CO_2) is essential. Strengthening resilience, reducing environmental impact, and protecting soil moisture and natural enemies of pests are also important measures to be taken. By implementing appropriate strategies, regulations, and financial resources, the agricultural industry can transition towards Climate-Smart Agriculture (CSA) approaches. This shift can lead to a reduction in immediate food insecurity and poverty, while also contributing to the mitigation of climate change as a potential threat to food security in the long run.

1.3 Conclusion:

Climate-smart agriculture has the potential to mitigate the effects of climate change and contribute to global sustainability efforts. According to the Food and Agriculture Organization (FAO), meeting the food requirements of the global population would necessitate a 60% increase in agricultural production by 2050, assuming present production and consumption patterns persist. In order to achieve the objectives of food security and agricultural development while adapting to climate change, it will be imperative to reduce emission intensities per production. Improving food safety can be achieved by implementing a slight shift in climate conditions, responsibly utilizing natural resources, enhancing the efficiency of resource utilization, and reducing production variability while maintaining consistency. To enhance productivity and adaptability in agriculture, a substantial transformation in the management of genetic resources, soil nutrients, water consumption, and land use is imperative. Diverse intelligent motivators, such as the implementation of organic farming and zero-budget natural farming, ought to be given due consideration. The utilization of renewable energy sources has the potential to serve as a more optimal approach for implementing climate-smart farming practices. The adoption of an integrated farming system model may prove to be a suitable option for the implementation of climate smart agriculture. The implementation of precision agriculture and its recent advancements have the potential to significantly impact the practice of Climate Smart Agriculture.

1.4 References:

1. Altieri, M. A., & Nicholls, C. I. (2017). The adaptation and mitigation potential of traditional agriculture in a changing climate. *Climatic Change*, **140**: 33-45.
2. Amin A., Mubeen M., Hammad H. M., Nasim W., (2015) Climate smart agriculture: an approach for sustainable food security. *Agricultural Communicaton*, **3**:13–21.
3. Barfoot, N. P., & Tchamba, N. M. (2019). Enhancing agricultural sustainability and productivity under changing climate conditions through improved agroforestry practices in smallholder farming systems in sub-Saharan Africa. *African Journal of Agricultural Research*, **14(7)**: 379-388.
4. Barfoot, P., & Brookes, G. (2014). Key global environmental impacts of genetically modified (GM) crop use 1996–2012. *GM crops & food*, **5(2)**: 149-160.
5. Batima, P., Bat, B., Tserendash, L., Bayarbaatar, S., Shiirev-Adya, S., Tuvaansuren, G., Natsagdorj, L., Chuluun, T. (2005). Adaptation to climate change, vol 90. ADMON Publishing, Ulaanbaatar.
6. Chartzoulakis, K., & Kasapakis, I. Tzobanoglou (2008). Improving water efficiency: the irrigation advisory service of Crete, Greece. In The 3rd international conference on water resources and arid environments and the 1st Arab Water Forum.
7. Das, S. (2017). Impact of climate change on livestock, various adaptive and mitigative measures for sustainable livestock production. *Approaches in Poultry, Dairy and Veterinary Science*, **(1)**: 33.
8. FAO (2006) Livestock’s long shadow: environmental issues and options. FAO, Rome.
9. Faurès, J. M., Bartley, D., Bazza, M., Burke, J., Hoogeveen, J., Soto, D., & Steduto, P. (2013). Climate smart agriculture sourcebook. FAO, Rome, 557.
10. Havlik, P., Valin, H., Mosnier, A., Obersteiner, M., Baker, J. S., Herrero, M., ... & Schmid, E. (2013). Crop productivity and the global livestock sector: Implications for land use change and greenhouse gas emissions. *American Journal of Agricultural Economics*, ***95*****(2)**: 442-448.
11. Herrero, M., Henderson, B., Havlík, P., Thornton, P. K., Conant, R. T., Smith, P., ... & Stehfest, E. (2016). Greenhouse gas mitigation potentials in the livestock sector. *Nature Climate Change*, **6(5)**: 452-461.

12. Hristov, A. N., Oh, J., Firkins, J. L., Dijksta, J., Kebreab, E., Waghorn, G., Makkar, H. P. S., Adesogan, A. T., Yang, W., Lee, C., Gerber, P. J., Henderson, B. & Tricarico, J. M. (2013). Mitigation of methane and nitrous oxide emissions from animal operations: a review of enteric methane mitigation options. *American Society of Animal Science,* **91**: 5045–5069.
13. John, W. H., Nicholas, J. C., Evan, W. C., Thomas, M. S., & Bill, W. (2009). IrriSatSMS irrigation water management by satellite and SMS-a utilization framework.
14. Khaledian, M. R., Mailhol, J. C., Ruelle, P., & Rosique, P. (2009). Adapting PILOTE model for water and yield management under direct seeding system: The case of corn and durum wheat in a Mediterranean context. *Agricultural water management*, **96(5)**, 757-770.
15. Lutz, D. (2013). Creating plants that make their own fertilizer. Washington University in St. Louis News Release. 22 August 2013.
16. Mittal, S. (2012). Modern ICT for agricultural development and risk management in smallholder agriculture in India. CIMMYT.
17. Nagargade, M., Tyagi, V., & Kumar, M. (2017). Climate smart agriculture: an option for changing climatic situation. Plant Engineering by Snježana Jurić. *IntechOpen*, 143-165.
18. Pankaj, P. K., Ramana, D. B. V., Pourouchottamane, R., & Naskar, S. (2013). Livestock management under changing climate scenario in India. *World Journal of Veterinary Science*, **1(1)**, 25-32.
19. Pathak, H. (2009). Agriculture and environment: Handbook of Agriculture, Directorate Information and Publication. ICAR, New Delhi, pp 62–92. F.
20. Purba, J., Sharma, R. K., Jat, M. L., Thind, H. S., Gupta, R. K., Chaudhary, O. P., ... & Gupta, R. (2015). Site-specific fertilizer nitrogen management in irrigated transplanted rice (Oryza sativa) using an optical sensor. *Precision Agriculture*, **16**; 455-475.
21. Shrawat, A. K., & Good, A. G. (2008). Genetic engineering approaches to improving nitrogen use efficiency. ISB news report, 1-5.
22. Steinfeld, H., Gerber, P., Wassenaar, T. D., Castel, V., Rosales, M., Rosales, M., & de Haan, C. (2006). Livestock's long shadow: environmental issues and options. Food and Agriculture Organization of the United Nations, Rome.
23. Subbarao, G. V., Tomohiro, B., Masahiro, K., Osamu, I., Samejima, H., Wang, H. Y., ... & Berry, W. L. (2007). Can biological nitrification inhibition (BNI) genes from perennial *Leymus racemosus* (Triticeae) combat nitrification in wheat farming? *Plant and Soil*, **299(1-2)**: 55-64.
24. Thornton, P. K., & Herrero, M. (2010). Climate Mitigation and Food Production in Tropical Landscapes Special Feature: Potential for reduced methane and carbon dioxide emissions from livestock and pasture management in the tropics. In *Proceedings of the National Academy of Science*, **107(46):** 19667-19672.
25. Wright, A. D. G., & Klieve, A. V. (2011). Does the complexity of the rumen microbial ecology preclude methane mitigation? *Animal feed science and technology*, **166**: 248-253.

ISBN: 978-81-19149-59-9

2. Soil Health as Key to Achieving Sustainability in Agriculture

Yashika Mandela

Department of Soil Science and Water Management
Dr. YS Parmar University of Horticulture and Forestry,
Nauni-Solan, H.P.

Monika Mandela

Department of Entomology (Ag.)
Veer Chandra Singh Garhwali
Uttarakand University of Horticulture and Forestry,
Bharsar-Pauri Garhwal, U.K.

Kiran Masta

Department of Soil Science and Water Management
Dr. YS Parmar University of Horticulture and Forestry,
Nauni-Solan, H.P.

Abstract:

Soil health ties agricultural and soil science to policy, stakeholder demands, and long-term supply-chain management. Soil health is the ability of soil to continue to operate as a vital living ecosystem that sustains plants, animals, and humans. While crop production has traditionally been the main emphasis of soil evaluations, soil health now also takes into account how the soil affects water quality, climate change, and human health. Despite rising acknowledgement of the significance of soil biodiversity, chemical markers continue to dominate efforts to measure soil health due to a lack of practical understanding and efficient techniques. This viewpoint discusses the definition and history of soil health as well as similarities to other soil ideas. We go over the ecosystem services that soils give, the tools used to evaluate the functionality of soils, and how they are incorporated into practical soil-health indices. Instead of only being a quantitative attribute, soil health should be viewed by scientists as an overarching principle that supports long-term sustainability goals. As a living system, the soil's health and quality preserve not just its biological products but also the environment and human health. A healthy environment based on plant inputs and soil interactions is known as "soil health." Negative impacts on soil health, soil pollutants, and soil loss strategies are becoming less common in developing nations.

2.1 Introduction:

A healthy soil performs as a living, dynamic system that offers a range of ecosystem services, including preserving water quality and plant production, managing the decomposition of recycled nutrients, and eliminating greenhouse gases from the environment. The diversity and activity of soil microorganisms are essential to the health of the soil and are therefore strongly related to sustainable agriculture. For soil and water, the scenario for improving soil quality evolves over time. Because of soil processes, the earth was regarded the domain's environment rather than a part of it. At the same time, globally accepted canons, indications, and requirements for pleasant air and water quality.

Soil quality, a notion related to soil health, is expanding, with soil quality rules in some countries having been successful to date (Filip, 2002; Nortcliff, 2002). Industrial agriculture, or so-called green revolution technology, increased agriculture's dependence on outside inputs, damaged the environment, depleted natural resources, harmed people's health, and presented sustainability problems for the industry as a whole. Numerous facts show that agrochemical-based, external input-heavy agriculture is not long-term viable due to a progressive decline in productivity factor and adverse effects on the health and quality of the soil, including soil organic carbon.

The foundation of organic farming is the management of soil organic matter, which protects the physical, chemical, and biological properties of the soil. In comparison to conventionally managed soil, organically managed soil has higher soil organic carbon and total nitrogen, decreased nitrate leaching, and higher biological soil quality. Research over a long period of time has shown that organic management generates more carbon from soil microbial biomass than conventional management. Organic agricultural practises have also been associated with increased soil ecosystem quality and long-term sustainability at the farm level. The nutrients in the soil, water, sunlight, and carbon dioxide (CO2) are all used by plants for photosynthesis and to generate food for people and other animals. In addition, soils hold onto rainwater and irrigation water before releasing it to support plant growth and reproduction. Through processes like precipitation and clay surface adsorption, which maintain the soil environment's chemical balance, soils also act as a filter for hazardous and nonhazardous metals. Most of the aforementioned soil functions are advantageous to both people and animals (Palm et al. 2007).

Excessive tillage activities result in the physical breakup of aggregates, which leads to surface crusting and compaction, which decreases infiltration and increases surface water runoff and soil erosion. The bulk of soil processes that are mediated by soil microbes are impacted by the loss of soil organic matter (SOM). Soil quality (SQ) deterioration harms ecosystem processes by bringing about unfavourable changes in soil properties.

Soil health refers to the soil's continuous capacity to perform as a crucial biological system. Within land-use limits, biological components are crucial for ecosystem function because they can preserve both the biological productivity of the soil and the quality of the surrounding environment. The soil is the main source of mineral nutrients for the bulk of living creatures. The right mineral elements reach the food chain thanks to soil management, which prevents mineral elements from being depleted or toxic to plants. Crop productivity, environmental sustainability, and human health are all directly and indirectly impacted by soil management. Soil management will be more and more important in the years to come due to the anticipated increase in world population and the associated demand for higher food production. The goal will be to manage soils sustainably through proper nutrient management and useful soil conservation practises in order to achieve future food security.

2.2 Soil Health:

Long-term agricultural production depends on the health of the soil, a valuable natural resource. According to Doran and Zeiss (2000, p. 20), "soil health" is "the capacity of soil to function within ecosystem boundaries to sustain biological activity, maintain environmental quality, and promote plant and animal health." The increased soil water retention and availability, soil aggregation, nutrient cycling and storage, and microbial diversity and function are only a few of the ecological services that soils provide. Assessing the soil's fitness to carry out planned functions and its capacity to withstand degradation are both parts of the process of assessing the soil's health. Land managers, producers, and researchers use a number of qualitative and quantitative markers to evaluate the relative worth of soil health. The following features should be found in a healthy soil:

- High organic content
- Good soil structure and tilth
- Enhanced water retention and penetration
- Compaction resistance
- High biological activity in the soil
- Availability and recycle of plant nutrient
- Resistance to erosion
- Absence of dangerous substances

2.2.1 Significance of Soil Health and Soil Quality:

Soil quality must be maintained in order to preserve animal and plant productivity, keep water or beautify the air, and ensure human habitation and fitness (Karlen et al., 1997; Arshad and Martin, 2002). Soil disease resistance has been understood for decades thanks to the application of soil health crops in recent years (Janvier et al., 2007). Soil health was defined by Van Bruggen and Semenov as the soil's tolerance to shocks and pressures (Van Bruggen and Semenov, 2000). It is sometimes difficult to distinguish between soil quality and soil health because the latter emphasises biotic soil inputs (Anderson et al., 2003). The health of the soil influences the health of the ecosystem, which affects the wellbeing of people, animals, and plants (Habberen, 1992; Doran, 2002).

2.3 Components of Soil Health for Sustainable Agriculture:

In the scientific literature, the phrases "soil health" and "soil quality" are frequently used interchangeably, and some people believe they are functionally equivalent. Farmers prefer the term "soil health," whereas scientists prefer the term "soil quality." 183 biotic indicators were created and tested by Ritz et al. (2009) for soil monitoring. Candidates for biological indicators that were most prevalent included: (1) Soil respiration and carbon cycling from multiple substrate-induced respiration; (2) Soil microbial taxa and community structure using terminal restriction fragment length polymorphism techniques; (3) Soil microbial community structure and biomass using extracted lipids, particularly phospholipid fatty acids; (4) Soil biochemical processes from multi-enzyme profiling; and (5) Nematodes, including (6) microarthropod; and (7) Visual recording of soil flora. (8) pitfall traps for invertebrates that live in the soil and on the ground, as well as (9) microbial biomass, the overall amount of life underground. However, they came to the conclusion that more research was required to understand how these biological indicators are affected by management changes, how they connect to soil functions, and how they may be used to highlight particular ecological processes. For the long-term growth of our agricultural systems and the appropriate use of national and international agricultural monitoring systems (ground truth data), it is essential to determine the components of soil health.

Healthy soil has been shown to prevent infections, maintain biological activity, break down organic matter, neutralise dangerous chemicals, and recycle nutrients, energy, and water. Karlen et al. (2003) defined soil quality as "the capacity of a specific type of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or improve water and air quality, and support human health and habitation." Additionally, soil quality was described by Bouma et al. (2017) as "the intrinsic capacity of a soil to contribute to ecosystem services, including biomass production." A deeper comprehension of soil quality can help targeted ecosystem services. The idea of soil quality is evolving to incorporate biological characteristics and processes that interact with chemical and physical components. The terms "soil quality" and "soil health" are frequently used interchangeably in the literature, as was already mentioned. In terms of timeline, they can be distinguished; "soil health" refers to the state of the soil over a brief period, whereas "soil quality" relates to the state of an individual over a long period (quality of life). Terms for soil state include "soil health" and "soil quality," and measuring these will help determine how past, present, and future land uses may affect the viability of agriculture.

2.3.1 The Distribution of Soil Microbes:

For microorganisms, soil aggregates offer a physical environment and play a significant role in regulating their overall population. In humic rendzina (heavy loam calcareous soil), aggregates 1-3 mm contained more bacteria, actinomycetes, and fungus than aggregates 5-7 mm. The population density of soil bacteria can also be influenced by the climate, vegetation, total organic carbon, and pH. When environmental and management parameters were considered in relation to the diversity and abundance of rhizosphere microorganisms, it became clear that soil type had a substantial impact on the microbial population. While modifications to soil pH, P, and K levels and root length indirectly increased bacterial population, fungal biomass was associated with an increase in above-ground plant output.

2.3.2 Element of Farming Methods to Enhance Soil Health:

Crop management practises that significantly affect soil quality include tillage, water and fertiliser management, cropping techniques, and land-use conversion.

A. Effect of Tillage: One of the most crucial land management techniques is tillage, which improves soil aeration and infiltration rates, prepares seedbeds, conserves soil and moisture, exposes soil-borne illnesses and insects to light, and controls weeds. To lessen the negative effects of tillage on soil quality, modern tillage concepts including no tillage, minimum tillage, stubble-mulch tillage, and conservation tillage practises have been created. In semiarid regions with rainfed conditions, zero tillage or conservation tillage techniques combined with crop residue integration increase the chance of crop production sustainability

(Sharma et al. 2005). Conservation tillage increased soil accessible P in the topsoil (0–20 cm) by 3.8%, K by 13.6%, and soil organic matter by 0.17% when compared to conventional tillage practises (Shao et al., 2016). Reduced soil erosion and improved soil moisture content are benefits of keeping crop residues on the top soil surface layer (full cover, no till; partial cover, strip tillage) (Celik et al., 2013; Mullins et al., 1998). Cereal rotations and legume cover crops increase soil SOC reserves (Fortuna et al. 2008).

B. Effect of Cropping Systems: In general, methods based on annual crop production such as agroforestry and tree plantations keep soil quality better. In comparison to cereal cropping systems without pulses, cereal farming systems with pulses improve soil quality better (Wienhold et al. 2006). In systems where rice is the primary crop, ploughing (puddling) causes the breakdown of capillary pores, a decreased void ratio, poor soil aggregates, dispersed fine clay particles, and low soil strength, as well as the formation of surface crusts and cracks after drying (Masto et al. 2008). According to Weerasekara et al. (2017), farming practises focused on pulse crops and cover crops prevent soil erosion and nitrogen loss. Utilising cover crops in crop rotation has numerous benefits, including a reduction in weeds, carbon sequestration, soil moisture conservation, and nonpoint source pollution. By fixing atmospheric nitrogen, legume cover crops increase soil nitrogen and decrease the demand for external N fertiliser.

C. Nutrient Management: According to Mandal et al. (2007), the INM ensures that crops receive appropriate nutrition while reducing the negative effects of hidden shortfalls and nutritional imbalance. Long-term INM practises considerably improved soil aggregation stability and physical quality as well as the yield of the maize-wheat system (Dutta et al. 2015). on contrast to irrigated production, the impact of INM is more notable on output from rainfed systems. Inceptisols in a tropical Indian soil under pearl millet farming have increased aggregation stability, labile carbon, and dehydrogenase activity due to long-term INM practises (Sharma et al. 2014). The SOC content, available nutrients, MBC, and the enzymes dehydrogenase and alkaline phosphatase in the topsoil of vertisols under soybean-wheat cropping systems were improved by using organic manures like cattle dung manure, vermicompost, and poultry manure in combination with mineral fertilisers based on N equivalents and crop nutrient requirements (Ramesh et al. 2009). In light-textured soil, farm compost application increases SOC content, earthworm population, and MBC while lowering BD, providing a favourable environment for crop growth and increasing yield in maize-based cropping systems (D' Hose et al. 2012).

D. Organic Farming: In order to increase physical, biological, and environmental resources such soil nutrient mineralization, microbial activity, abundance, and variety as well as yield and product quality, organic farming is gaining favour as the most sustainable agricultural method. When compared to mineral fertilisation, organic farming has been demonstrated to increase soil organic matter, N supply capability, and soil N sequestration by about 50% (Sesbania rostrata yielded 16.8 tonnes ha-1 dry matter in 13 weeks) (Gong et al., 2011 and Matoh et al., 2008). The organic systems with compost and peat sources had higher microbial populations and enzyme activity than conventional systems, according to a 12-year research of the rice (Oryza sativa) and maize (Zea mays) crops (Chang et al., 2014). The physical and chemical properties of the soil can be enhanced by organic farming. In comparison to conventional systems, organic systems in clay soil, for instance, increased soil water content by 15%, retention capacity by 10%, and bulk density by 8% in the top 20 cm of soil (Bassouny et al., 2016). Organic farming is less productive than conventional farming, however after 10–13 years of cropping, organic productivity can match conventional yield (Schrama et al., 2018). In general, the best way to enhance the quality of the land and the crops is through organic farming.

2.3.3 Impact of Organic Farming on Soil Health:

Impact on soil physical qualities: Soil physical attributes include structure, texture, bulk density, porosity, and water-holding capacity, among other things. It has been demonstrated that organic farming enhances the physical properties of the soil, including its structure, water-holding capacity, aeration, and temperature. Papadopoulos et al. (2014) claim that organic management can improve soil structure, organic matter content, and porosity. Crop rotation is a crucial part of organic farming since it alters the soil's physical composition both directly and indirectly. Changes in soil structure are directly influenced by the buildup of organic matter in the soil during the lean phase. In addition, crop rotation alters the architectural design of the diverse root systems of many different crops. Since organic farming absorbs more water and has less run-off, it is preferable in regions with significant rainfall, claim Lotter et al. (2003).

Impact on chemical properties of soil: Contrary to conventional agriculture, organic agriculture adds essential nutrients for quality improvement by following the natural cycle. While simultaneously boosting the amount of organic carbon in the soil, organic farming has the ability to maintain soil fertility. The sustainability of soil organic carbon and the availability of nutrients to plants are both guaranteed by the use of diverse organic inputs, such as FYM, vermicompost, green manuring, and so forth. High-quality FYM application enhances soil total nitrogen and organic matter, which is "a crucial substrate of cationic exchange and the warehouse of most available nitrogen, phosphorus, and sulphur; the primary energy source for microorganisms; and a key determinant of soil structure." Phosphorus is released more readily from decaying matter and its fixation in soil is reduced by organic acids and the humus they contain. Micronutrient availability for the plant is also guaranteed by organic nutrient input.

Organic inputs' effects on the biological characteristics of soil: While many academics restrict the idea of soil quality to physical and chemical characteristics, others believe that biological criteria are important and should be considered when evaluating soil quality. Since the flora and fauna in the soil have a significant impact on soil quality, these biological characteristics are essential for determining soil quality. The living components of soil organic matter are soil microbes. For soil to be produced, microbial biomass and activity in the soil are essential. It has been demonstrated that switching to organic farming increases microbial activity and biomass by 20–30% and 30–100%, respectively. In comparison to soil with a low organic matter concentration (which is treated inorganically), soil with a high organic matter content exhibits greater microbial activity and provides more soil N. Arbuscular mycorrizal fungi are a special type of fungus that collaborates with the plant's root system to increase water and nutrient intake. This mutualistic relationship helps plants absorb more phosphorus from the soil and shields them from many diseases. Increased microbial activity, which increases competition, parasitism, and predation in the rhizosphere, reduces the likelihood of plant disease infestation in organic farming.

Natural resources and biodiversity: The term "soil biodiversity" describes the diversity of taxonomic groupings found in soil, including nematodes, earthworms, fungi, bacteria, and worms. Numerous studies show that during the past 40 years, the quantity and diversity of a variety of plant and invertebrate species have decreased as a result of modern agriculture's intensification and expansion, posing a threat to biodiversity globally. Contrarily, organic farming supports the preservation of biodiversity.

The agro-economic and agro-ecological performance of biodynamic, bioorganic, and conventional farming systems in Central Europe were compared over a 21-year period, and the results showed that organic farming produced greater biodiversity and increased soil fertility. Recent studies, however, found no difference in any of the evaluated soil and microbial properties between conventional and organic farms, despite the fact that N mineralization was higher in organic farms. They also found no effect of landscape heterogeneity.

2.4 Soil Quality:

For optimum input allocation to increase the output of food and fibre, Warkentin and Fletcher (1977) established the idea of soil quality. Soil quality, according to Karlen et al. (1997), is "the capacity of a specific type of soil to function within a natural or managed ecosystem to sustain plant and animal productivity, maintain or improve water and air quality, and support human health."

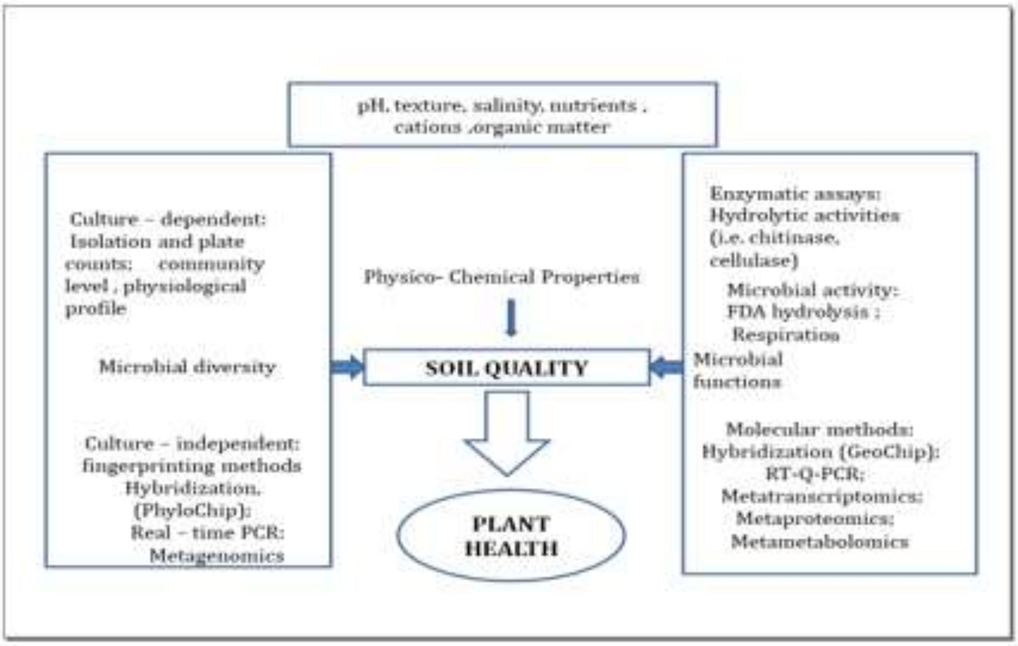


Figure 2.1: Elements that influence soil quality and some of the methods used. [Source: Antonio de Vicente, Diversity (2012), Institute for Horticultural Mediterranean and Subtropical Horticulture "La Mayora" (UMACSIC), Malaga, Spain].

2.4.1 Soil Quality Assessment:

The adverse impacts on soil functions caused by improper management and other natural variables are the main reason why soil quality assessment is necessary. By measuring changes in soil qualities brought on by management, shifting land uses, deforestation, and other causes, soil quality evaluation is a process.

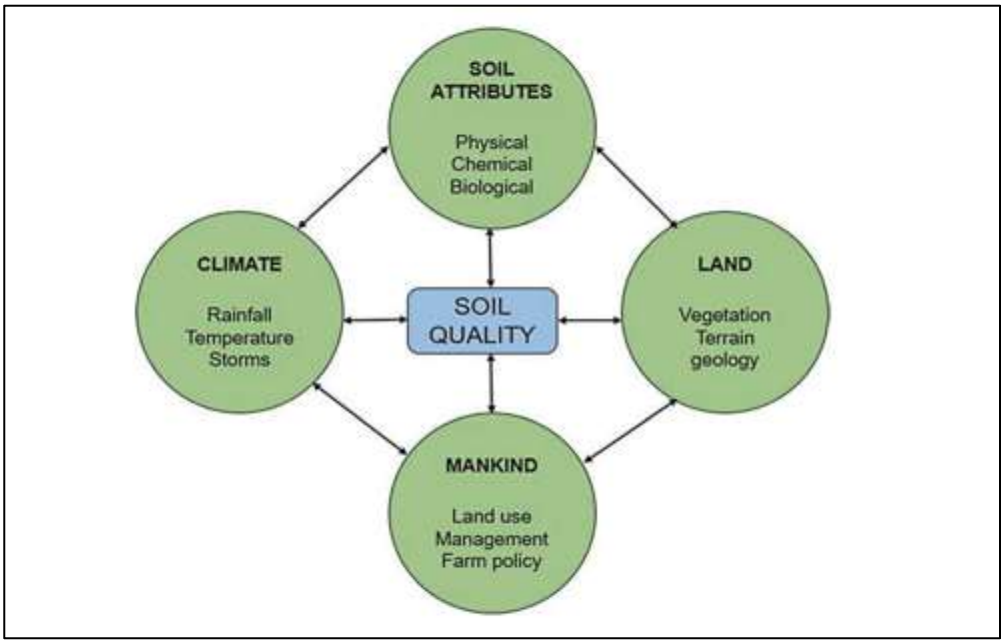


Figure 2.2: Factors influencing soil quality. (Modified from Arshad and Coen 1992)

2.4.2 Soil Quality Indicators:

More (2010) classifies soil quality indicators into four categories:

- Visual indicators
- Physical indicators
- Chemical indicators
- Biological indicatssors

A. Visual Indicators:

Visual indicators are obtained from field observations of qualitative soil characteristics such as soil depth, colour, erosion, gully formation, salt deposition, drainage, surface ponding, soil structure, consistency, mottles, rooting depth, root development, earthworm population, rat activity, and so on. Visual SQ indicators have the main benefit of being immediately examined without the requirement for time-consuming laboratory analysis (Bunemann et al. 2018). One of the numerous visible markers of soil quality that has lately attracted attention in the literature is soil structure (Emmet-Booth et al. 2016).

B. Physical Indicators:

Texture, structure, hydraulic conductivity, infiltration, porosity, bulk density, and aggregate stability are examples of physical SQ indicators. They are associated to seedling emergence, root growth, water movement, water holding capacity, penetration resistance, and other parameters, and they are used to evaluate physical SQ. Physical factors have a key role in controlling soil erodibility and the interactions between soil, plants, water, and the atmosphere (More 2010).

C. Chemical Indicators:

Important soil chemical processes include ionic diffusion, leaching, acidification, alkalinization, salinization, mineralization, and others. A desirable nutrient concentration must be maintained for the chemical quality of the soil. Chemical markers of SQ include pH, EC, salinity, sodicity, organic carbon, nitrogen fractions, phosphorus concentration, cation exchange capacity (CEC), and concentrations of heavy metals. Due to their ability to detect the bulk of nutrient-related changes in soil, soil pH and available P are the chemical indicators used in SQ evaluation most frequently. The pH of the soil is used to determine the activity of hydrogen ions in the soil solution. Indicators of plant nutrition are also present.

D. Biological Indicators:

Mineralizable nitrogen, soil organic matter, respiration, and microbial biomass (total bacteria and fungus) are biological markers of soil quality. Microorganisms play a significant role in organic matter decomposition and nutrient recycling. Key indicators of soil quality include earthworms, nematodes, termites, microorganisms, and their behaviour. Microbial biomass is a vital part of the soil's "active ingredient," which breaks down organic pollutants and circulates nutrients (Stenberg et al. 1998).

Enzymes including dehydrogenase, urease, phosphatases, and glucosidase are used to measure nutrient mineralization in soil and can give an early warning of potential risks to soil quality (Comino et al. 2018). The most reliable indicator of the soil's structural, microclimatic, nutritional, and hazardous status is the amount of earthworms present. By recycling soil nutrients, aiding in the gradual mixing of soil layers, and creating a better aeration and drainage system, earthworms play a crucial part in the conservation and improvement of soil. Earthworms are indicators of the water and nutrient cycles.

2.5 Critical Issues and Needs for Sustainable Management:

On the second day of the session, critical concerns for sustainable management were highlighted in a large group format. Small groups determined high priority research needs for identifying sustainable agricultural land management and management "strategies" to ensure long-term sustainability after identifying the primary concerns.

- An ecological strategy to managing diverse land uses in a sustainable manner.
- Consideration of farm size when developing sustainable agricultural method.

- Explain the crucial relevance of soil in terms of the environment, society, and economics.
- Prescriptive and descriptive assessment of agricultural system sustainability for land managers and scientists.

2.6 Conclusion:

W3The essential prerequisite for achieving sustainable agricultural and livestock production is the preservation of soil fertility and soil health. Organic farming methods, which are extremely complex and integrated biological processes, may be a viable technology alternative for maintaining good soil health. Because organic practises affect more than one component of the system at the same time, they have both direct and indirect effects on soil properties. Previous research on the impact of organic practises on several aspects of crop productivity, soil health, and the environment suggests that organic farming has the capacity to sustain soil health and fertility. Utilising an organic system enhances soil physical characteristics, microbial population and diversity, and nutrient mineralization. Surprisingly, the source of organic fertiliser (plant or animal-based) can influence microbe abundance and crop productivity. While plant fertiliser increases soil microbial abundance, animal fertiliser increases crop yield while decreasing the number of microorganisms. Organic cultural practises, on the other hand, are more expensive due to high labour costs and the lack of uniformity and stability of organic fertilisers. Accepting the appropriate crops and cropping practises that insulate more carbon will improve soil health. As a result, assessing soil health biological markers is critical. Despite the fact that numerous soil health and soil quality indices and measures have been introduced around the world, they are acceptable and appropriate specifications, descriptions, and methods for soil health and soil quality evaluation are no longer in situ.

2.7 References:

1. Anderson, T. (2003). Microbial eco-physiological indicators to assess soil quality. *Agriculture Ecosystems and Environment, 98*, 285-293.
2. Arshad MA, Coen GM (1992) Characterization of soil quality: Physical and chemical criteria. *Am. J. Altern. Agric.* 7(1–2):25–31
3. Arshad, M. A., & Martin, S. (2002). Identifying critical limits for soil quality indicators in agroecosystems. *Agriculture, Ecosystems and Environment, 88*, 153–160.
4. Bassouny M, Chen J. 2016. Effect of long-term organic and mineral fertilizer on physical properties in root zone of a clayey Ultisol. *Archives of Agronomy and Soil Science*. 62:819-828.
5. Biswas S, Ali M N, Goswami R. and Chakroborty S. 2014. Soil health sustainability and organic farming. *Journal of Food, Agriculture and Environment Vol.12 (3&4):* 237-243
6. Bouma J, Van Ittersum, M, Stoorvogel J, Batjes N, Droogers P, Pulleman M. 2017. Soil capability: Exploring the functional potentials o soil. In *Global Soil Security*; Springer: Cham, Switzerland. pp. 27–44.
7. Celik A, Altikat S, Way T. 2013 Strip tillage width effects on sunflower seed emergence and yield. *Soil and Tillage Research.*131:20-27.
8. Chang E, Wang C, Chen C, Chung R. 2014. Effects of long- term treatments of different

organic fertilizers complemented with chemical N fertilizer on the chemical and biological properties of soils. *Journal of Soil Science and Plant Nutrition.*60:499-511.

9. Comino F, Aranda V, García-Ruiz R, Ayora-Cañada MJ, Domínguez-Vidal A. 2018 Infrared spec- troscopy as a tool for the assessment of soil biological quality in agricultural soil under contrasting management practices. *Ecological Indicator*.87:117-126.
10. D'Hose T, Cougnon M, Vliegher AD, Bockstaele EV, Reheul D. 2012. Infuence of farm compost on soil quality and crop yields. *Archives of Agronomy and Soil Science*. 58(1):S71-S75.
11. Doran, John W, Stamatiadis, Stamatis and Haberern, John. (2002). "Soil health as an indicator of sustainable management" *Publications from USDA-ARS / UNL Faculty*. 180.
12. Doran, J.W., and M.R. Zeiss. 2000. Soil Health and Sustainability: Managing the Biotic Component of Soil Quality. *Applied Soil Ecology* 15: 3–11.
13. Dutta J, Sharma SP, Sanjay K, Sharma GD, Sharma N, Sankhyan K. 2015. Indexing soil quality under long-term maize-wheat cropping system in an acidic alfisol. *Communication in Soil Science and Plant Analysis*.46:1841-1862
14. Emmet-Booth JP, Forristal PD, Fenton O, Ball BC, Holden NM. 2016. A review of visual soil evaluation techniques for soil structure. *Soil Use and Management*. 32:623-634.
15. Filip, Z. (2002). International approach to assessing soil quality by ecologically-related biological parameters. *Agriculture, Ecosystems and Environment, 88*, 169-174.
16. Fortuna ARL, Blevins W, Frye W, Grove J, Cornelius P. 2008. Sustaining soil quality with legumes in no-tillage systems. *Communication in Soil Science and Plant Analysis*.39:1680-1699.
17. Gong W, Yan X, Wang J, Hu T, Gong Y. 2011. Long-term application of chemical and organic fertilizers on plant- available nitrogen pools and nitrogen management index. *Biology and Fertility of Soils*.47:767-775.
18. Haberern, J. (1992). Viewpoint: a soil health index. *Journal of Soil Water Conservation*, 47, 6.
19. Janvier, C., Villeneuve, F., Alabouvette, C., Edel- Hermann, V., Mateille, T., & Steinberg, C. (2007). Soil health through soil disease suppression: which strategy from descriptors to indicators. *Soil Biology and Biochemistry, 39*, 1-23.
20. Karlen, D L, Ditzler C, Andrews S S. 2003**.**Soil quality: Why and how? *Geoderma, 114*, 145–156
21. Karlen DL, Mausbach MJ, Doan JW, Cline RG, Harris RF, Schuman GE. 1997. Soil quality: a concept definition and framework for evaluation. *Soil Science Society of American Journal*.61:4-10.
22. Lotter D W, Seidel R. and Liebhardt W. 2003. The pPerformance of organic and conventional cropping systems in an extreme climate year. *Am. J. Alternative Agr.* **18**(3):146-154.
23. Mandal M, Patra AK, Singh D, Masto RE. 2007. Effect of long- term application of manure and fertilizer on biological and biochemical activities in soil during crop development stages. *Bio resource Technology*.98:3585-3592.
24. Matoh T, Saraswati R, Phupaibul P, Sekiya J. 2008. Growth characteristics of *Sesbania* Species under adverse edaphic conditions in relation to use as green manure in Japan. *Journal of Soil Science and Plant Nutrition*.992;38:741-747.

25. Masto RE, Chhonkar PK, Singh D, Patra AK. 2008. Alternative soil quality indices for evaluating the effect of intensive cropping fertilization and manuring for 31 years in the semi-arid soil of India. *Environmental Monitoring and Assessment*.136:419-435.
26. More SD. 2010. Soil quality indicators for sustainable crop productivity. *Journal of Indian Society of Soil Science*. 58:5-11.
27. Mullins GL, Alley SE, Reeves DW. 1998. Tropical maize response to nitrogen and starter fertilizer under strip and conventional tillage systems in southern Alabama. *Soil Tillage Research*.45:1-15.
28. Northcliff, S. (2002). Standardization of soil quality attributes. *Agriculture, Ecosystems and Environment, 88*, 161-168.
29. Palm C, Sanchez P, Ahamed S, Awiti A (2007) Soil: a contemporary perspective. Annu Rev Environ Resour 32:99–129
30. Papadopoulos, A., Bird, N., Whitmore, P. A. and Mooney, J. S. 2014. Does organic management lead to enhanced soil physical quality? *Geoderma* 213:435–443.
31. Ramesh P, Panwar NR, Singh AB, Ramana S, Rao AS. 2009. Impact of organic-manure combinations on the productivity and soil quality in different cropping systems in Central India. *Journal of Plant Nutrition and Soil Science*.172:577-585.
32. Ritz K, Black H I J, Campbell C D, Harris J A, Wood C. 2009 Selecting the biological indicators for monitoring soils: A framework for balancing scientific and technical opinion to assist policy development. *Ecol. Indic., 9*, 1212–1221.
33. Schrama M, de Haan J, Kroonen M, Verstegen H, Van der Putten, W. 2018. Crop yield gap and stability in organic and conventional farming systems. *Agriculture, Ecosystem and Environment*. 256:123-130.
34. Sharma KL, Grace JK, Chandrika MS.2014. Effect of soil management practices on key soil quality indicators and indicies in pearl millet (*Pennisetum americanum* (L) Leeke)–based system in hot semi-arid inceptisols. *Communication in Soil Science and Plant Analysis*.45:785-809.
35. Sharma KL, Mandal UK, Srinivas K. 2005. Long-term soil management effects on crop yields and soil quality in a dryland alfisol. *Soil Tillage Research*.83:246- 259.
36. Shao Y, Xie Y, Wang C, Yue J, Yao Y, Liu W. 2016. Effects of different soil conservation tillage approaches on soil nutrients, water use and wheat-maize yield in rainfed dry- land regions of North China. European Journal of Agronomy.81:37-45.
37. Stenberg B, Pell M, Torstensson L. 1998. Integrated evaluation of variation in biological chemical and physical soil properties. *Ambio*.27:9-15.
38. Tahat M M, Alananbeh K M, Othman YA. and Leskovar D I.2020. Soil Health and Sustainable Agriculture. *Sustainability.*12, 4859.
39. Van Burggen, A. H. C., & Semenov, A. M. (2000). In search of biological indicators for soil health and disease suppression. *Applied Soil Ecology, 15*, 13-24.
40. Warkentin BP, Fletcher HF. 1977. Soil quality for intensive agriculture. In: Proceedings of inter- national seminar on soil environ and fertilizer management in intensive agriculture, Society for Science of Soil and Manure – National Institute of Agricultural Science, Tokyo. p. 594-598.
41. Weerasekara CS, Udawatta RP, Gantzer CJ, Kremer RJ, Jose S, Veum KS. 2017. Effects of cover crops on soil quality:selected chemical and biological parameters. *Communication in Soil Science and Plant Analysis*.48:2074-2082.
42. Wienhold BJ, Pikul JL, Liebig MA, Mikha MM, Varvel GE, Doran JW. 2006. Cropping system effects on soil quality in the Great Plains: synthesis from a regional project. *Renewable Agriculture Food System*.21:49-59.

ISBN: 978-81-19149-59-9

3. Innovative Irrigation Techniques to Enhance the Water Use Efficiency and Sustainability in Agriculture

Srijeeta Majumder, D. K. Janghel

School of Agricultural Sciences,
GD Goenka University, Sohna Road, Gurugram,
Haryana, India.

Abstract:

Climate change poses significant challenges to agricultural systems, impacting food security, livelihoods, and environmental sustainability. Climate-smart agriculture (CSA) has emerged as a holistic approach to address these challenges by integrating climate change adaptation, mitigation, and sustainable agricultural practices. Innovative water irrigation techniques are revolutionizing water management in agriculture by incorporating advanced sensors, automation, precision delivery systems, and renewable energy sources, these techniques optimize water efficiency, minimize water waste, and contribute to sustainable agricultural practices. The advent of sensor-based irrigation systems, such as soil moisture sensors and weather-based controllers, enables precise and real-time monitoring of soil moisture levels and weather conditions. This data-driven approach facilitates targeted and optimized irrigation, minimizing water wastage and improving water use efficiency. Implementing these innovative irrigation technologies can help farmers adapt to water scarcity, increase productivity, and mitigate the environmental impact of irrigation in a changing world. Efficient and sustainable irrigation practices are crucial for optimizing water use in agriculture and mitigating the environmental impact of water-intensive farming. This abstract highlight some of the key innovative irrigation techniques that are being developed and implemented to enhance water efficiency and sustainability in agricultural systems.

Keywords:

Water, Irrigation, Water Use Efficiency, Climate Smart Agriculture, Sensor

3.1 Introduction:

In the face of climate change and increasing water scarcity, sustainable agriculture practices are crucial for ensuring food security and preserving the environment. Climate-smart agriculture focuses on adapting to and mitigating the effects of climate change while maintaining productivity and promoting resilience. One key aspect of climate-smart agriculture is the adoption of innovative irrigation techniques that optimize water use efficiency in agricultural systems. This article explores the importance of innovative irrigation techniques and their potential to advance water use efficiency and sustainability in agriculture.

Innovative irrigation techniques play a pivotal role in advancing water use efficiency and sustainability in agriculture under the principles of climate-smart agriculture. Drip irrigation, precision sprinklers, soil moisture sensors, rainwater harvesting, and smart irrigation management systems are just a few examples of technologies that can significantly improve water management practices on farms. By adopting these innovative techniques, farmers can optimize water use, conserve resources, and ensure the long-term viability of agricultural systems in the face of climate change and water scarcity challenges. Innovative irrigation technique under climate smart agriculture: One innovative irrigation technique in climate-smart agriculture is known as precision irrigation. Precision irrigation involves using advanced technologies to precisely deliver water to crops in the right amount, at the right time, and in the right location. This technique aims to optimize water use efficiency, reduce water wastage, and enhance crop productivity while minimizing environmental impact. Here are some key components and methods used in precision irrigation:

A. Drip Irrigation: Drip irrigation is a highly efficient irrigation method that delivers water directly to the plant's root zone, minimizing water loss through evaporation or runoff. By providing water directly to the plants in controlled amounts, drip irrigation reduces water wastage and allows for precise application tailored to the crop's needs. This technique not only conserves water but also improves crop yield and quality, making it a valuable tool for sustainable agriculture.
B. Precision Sprinklers: Precision sprinkler systems utilize advanced technologies to optimize water distribution. These systems are designed to deliver water uniformly, reducing overspray and runoff. By adjusting the application rate based on factors such as crop type, soil moisture levels, and weather conditions, precision sprinklers ensure that plants receive the right amount of water at the right time. This targeted approach minimizes water loss and enhances water use efficiency, supporting sustainable agricultural practices.
C. Soil Moisture Sensors: Soil moisture sensors are invaluable tools for efficient irrigation management. These sensors measure the moisture content in the soil and provide real-time data to farmers. By monitoring soil moisture levels, farmers can determine when and how much water to apply, avoiding under or over-irrigation. This data-driven approach enables precise irrigation scheduling, reducing water waste and optimizing plant health. Incorporating soil moisture sensors into irrigation systems promotes water conservation and sustainability in agriculture.
D. Rainwater Harvesting: Rainwater harvesting is a sustainable practice that involves collecting and storing rainwater for later use in irrigation. Capturing rainwater through techniques such as rooftop harvesting or surface runoff collection provides an additional water source for agriculture, reducing reliance on freshwater resources. By integrating rainwater harvesting systems with irrigation infrastructure, farmers can supplement their water supply during dry periods, enhancing water availability and sustainability.
E. Smart Irrigation Management: The emergence of digital technologies has enabled the development of smart irrigation management systems. These systems utilize weather data, soil moisture readings, and crop water requirements to optimize irrigation schedules and amounts automatically. By integrating data-driven decision-making into irrigation practices, smart management systems minimize water waste and enhance water use efficiency. Additionally, these systems often allow remote monitoring and control, empowering farmers to manage irrigation operations efficiently.

- **Soil Moisture Sensors:** These sensors are placed in the root zone of the plants to measure the moisture content of the soil. They provide real-time data that helps farmers determine the exact irrigation requirements of the crops, allowing them to irrigate only when necessary.
- **Weather-based Irrigation Controllers:** These controllers use weather data such as temperature, humidity, solar radiation, and wind speed to adjust irrigation schedules. By considering current and forecasted weather conditions, farmers can avoid unnecessary irrigation during periods of rainfall or high humidity, reducing water waste.
- **Drip Irrigation:** Drip irrigation involves delivering water directly to the roots of the plants through a system of tubes or pipes with emitters. This method ensures that water is applied precisely where it is needed, minimizing evaporation and runoff. Drip irrigation can significantly improve water use efficiency compared to traditional sprinkler systems.
- **Micro-Irrigation:** Micro-irrigation refers to the use of small amounts of water to irrigate individual plants or small groups of plants. Techniques such as micro-sprinklers or micro-jets can deliver water precisely to the plant's root zone, reducing water loss due to evaporation or wind drift.
- **Variable Rate Irrigation:** Variable rate irrigation involves adjusting the amount of water applied based on variations in soil type, crop type, topography, or other factors within a field. This technique allows farmers to apply more water to areas with higher water requirements and less water to areas with lower requirements, optimizing water distribution and crop yield.
- **Mobile Applications and Remote Monitoring:** Mobile applications and remote monitoring systems enable farmers to remotely monitor and control irrigation systems. These tools provide real-time information on soil moisture levels, weather conditions, and irrigation schedules, allowing farmers to make informed decisions and adjust irrigation practices as needed.

By adopting precision irrigation techniques, farmers can optimize water use, reduce water stress on crops, improve crop yields, and minimize the environmental impact associated with irrigation. This approach supports climate-smart agriculture by promoting sustainable water management practices in the face of changing climatic conditions.

3.2 What is Climate Smart Agriculture and How it is Important in Agriculture Production?

Climate-smart agriculture (CSA) refers to agricultural practices and systems that sustainably increase productivity, enhance resilience to climate change, and reduce greenhouse gas emissions. It is an approach that recognizes the challenges posed by climate change and seeks to address them through integrated and holistic strategies.

3.2.1 Importance of Climate-Smart Agriculture in Agriculture:

Adaptation to Climate Change: Climate change poses significant challenges to agricultural productivity and food security. CSA practices help farmers adapt to changing climatic conditions by improving soil and water management, promoting drought-tolerant crop varieties, implementing agroforestry, and adopting climate-resilient farming systems.

These measures enhance the ability of agriculture to withstand climate-related stresses such as extreme temperatures, droughts, and floods.

Mitigation of Greenhouse Gas Emissions: Agriculture is a significant contributor to greenhouse gas emissions, primarily through methane from livestock and nitrous oxide from fertilizers. CSA approaches aim to reduce these emissions by promoting sustainable land and water management practices, optimizing fertilizer use, adopting agroecological approaches, and implementing livestock management techniques that reduce methane production. By mitigating greenhouse gas emissions, CSA contributes to climate change mitigation efforts. Sustainable Resource Management: CSA practices prioritize the efficient and sustainable use of natural resources such as land, water, and biodiversity. They promote practices such as conservation agriculture, precision farming, and integrated pest management that minimize soil erosion, conserve water, protect biodiversity, and enhance ecosystem services. By ensuring the long-term viability of agricultural systems, CSA helps preserve natural resources for future generations.

Increased Productivity and Food Security: Climate-smart practices aim to enhance agricultural productivity while minimizing negative environmental impacts. By adopting CSA techniques, farmers can improve yields, optimize resource use, and increase the resilience of their farming systems. This leads to increased food production and improved food security, especially in the face of climate uncertainties and changing weather patterns.

Economic Resilience and Rural Development: Climate-smart agriculture practices can improve the economic resilience of farmers and rural communities. By diversifying agricultural production, adopting climate-resilient crops, and integrating livestock and crop systems, farmers can reduce risks and enhance their income-generating potential.

CSA also supports rural development by creating employment opportunities, improving market access, and fostering sustainable livelihoods in agricultural communities.

Knowledge and Innovation: Implementing CSA requires knowledge sharing, capacity building, and innovation. It encourages collaboration among researchers, extension services, farmers, and policymakers to develop and disseminate climate-smart practices and technologies. This collaborative approach fosters innovation and promotes the exchange of experiences and best practices, leading to continuous improvement in agricultural systems.

Sustainable Development Goals (SDGs): Climate-smart agriculture aligns with several of the United Nations' Sustainable Development Goals. It contributes to goals such as zero hunger, poverty eradication, climate action, sustainable cities and communities, and responsible consumption and production. By integrating climate and development objectives, CSA contributes to the broader sustainability agenda. In summary, climate-smart agriculture is important in agriculture because it helps farmers adapt to climate change, mitigate greenhouse gas emissions, promote sustainable resource management, enhance productivity and food security, foster economic resilience and rural development, stimulate knowledge sharing and innovation, and contribute to achieving sustainable development goals. By adopting climate-smart practices, agriculture can become more resilient, sustainable, and capable of addressing the challenges posed by climate change.

3.3 Innovative Irrigation Techniques:

In addition to precision irrigation mentioned earlier, there are several other innovative irrigation techniques that are being developed and implemented to improve water efficiency and sustainability in agriculture. Here are a few examples:

- **Aeroponics:** Aeroponics is a soilless irrigation technique that involves growing plants in an air or mist environment. The plants' roots are suspended in a chamber where a nutrient-rich mist is sprayed directly onto them. This method reduces water usage significantly compared to traditional irrigation systems, as water is delivered in a highly efficient manner, with minimal wastage.
- **Hydroponics:** Hydroponics is another soilless irrigation technique where plants are grown in a nutrient-rich water solution without soil. The roots are submerged in the nutrient solution, which is recirculated, reducing water usage compared to conventional farming. Hydroponics can be combined with techniques such as drip irrigation or nutrient film technique (NFT) to further optimize water use.
- **Subsurface Drip Irrigation (SDI):** SDI involves placing drip irrigation lines below the soil surface, delivering water directly to the plant roots. This method reduces evaporation losses and ensures precise water delivery to the root zone, improving water use efficiency and crop yield. It is particularly effective in areas with high evaporation rates or saline soils.
- **Fogging Systems:** Fogging systems create a fine mist or fog of water that envelops the crop area, providing a humid microclimate. This technique is particularly useful in arid regions or for high-value crops that require specific humidity levels. Fogging systems use less water compared to traditional sprinklers and can also help control pests and diseases.
- **Rainwater Harvesting:** Rainwater harvesting involves collecting and storing rainwater runoff for later use in irrigation. It can be done using various techniques such as rooftop collection systems, storage tanks, or underground reservoirs. Rainwater harvesting helps conserve freshwater resources and provides an alternative water source during dry periods.
- **Solar-Powered Irrigation:** Solar-powered irrigation systems utilize solar energy to power water pumps, eliminating the need for grid electricity or fossil fuels. These systems can be used with various irrigation techniques, such as drip irrigation or sprinklers, reducing both operational costs and environmental impact.
- **Wastewater Reuse:** Treating and reusing wastewater for irrigation purposes is an innovative approach that helps conserve freshwater resources. Treated wastewater can be used for non-edible crops or after additional treatment for food crops. This technique reduces the demand for freshwater sources and provides a sustainable irrigation option.

These innovative irrigation techniques offer opportunities to optimize water use, reduce water stress, and improve agricultural sustainability.

By implementing these techniques, farmers can enhance crop productivity, reduce water waste, and mitigate the environmental impact associated with irrigation practices.

3.4 New Technologies for Innovative Irrigation Purpose:

Several new technologies are emerging in the field of innovative irrigation that aim to improve water efficiency, reduce water waste, and enhance crop productivity. Here are some notable examples:

- **Sensor-Based Irrigation Systems:** Advanced sensor technologies are being used to monitor soil moisture levels, weather conditions, and plant water needs in real-time. These sensors provide accurate data that helps farmers determine the precise irrigation requirements of their crops. By integrating sensor data with automated irrigation systems, water can be applied only when and where it is needed, optimizing water use efficiency.
- **Internet of Things (IoT) and Smart Irrigation Controllers:** IoT devices and smart irrigation controllers allow for remote monitoring and control of irrigation systems. These systems use data from sensors, weather forecasts, and plant-based algorithms to automatically adjust irrigation schedules. Farmers can monitor and control their irrigation systems through mobile applications, ensuring efficient water use and reducing manual labour.
- **Cloud Computing and Data Analytics:** Cloud computing and data analytics technologies enable the collection, storage, and analysis of large-scale agricultural data. By analyzing historical and real-time data related to soil moisture, weather patterns, crop growth, and water usage, farmers can gain valuable insights to optimize irrigation strategies, improve crop yields, and conserve water resources.
- **Precision Sprinklers and Micro-Sprinklers**: Innovative sprinkler technologies such as precision sprinklers and micro-sprinklers deliver water more accurately and efficiently. These systems use specialized nozzles and control mechanisms to distribute water in a targeted manner, reducing water loss due to evaporation and wind drift. Precision sprinklers can be designed to match specific crop requirements and field conditions.
- **Mobile Applications and Decision Support Tools:** Mobile applications and decision support tools provide farmers with real-time information and recommendations for irrigation management. These tools integrate data from various sources, including weather forecasts, soil moisture sensors, and crop models, to help farmers make informed decisions on when and how much to irrigate. They often provide user-friendly interfaces and actionable insights for efficient irrigation management.
- **Automated Drip and Micro-Irrigation Systems:** Automated drip and micro-irrigation systems combine precision irrigation techniques with automation technology. These systems deliver water directly to the root zone of plants through a network of tubes or pipes with emitters. Automation features such as timers, sensors, and flow controllers ensure precise and efficient water delivery, minimizing water waste and optimizing resource use.
- **Solar-Powered Irrigation Systems:** Solar-powered irrigation systems utilize solar energy to power water pumps, eliminating the need for grid electricity or fossil fuels. Solar panels can be installed to generate electricity for irrigation purposes, reducing operational costs and carbon emissions. These systems are particularly useful in remote areas with limited access to electricity.

- **Fogging and Mist Systems:** Fogging and misting systems create a fine mist or fog that envelops the crop area. These systems are designed to provide localized humidity control and cooling, reducing water consumption compared to traditional sprinklers. Fogging and misting systems are beneficial in arid or high-temperature regions, promoting water-efficient irrigation.

These new technologies in innovative irrigation offer opportunities to enhance water management, increase crop productivity, and promote sustainable agricultural practices. By adopting these technologies, farmers can improve water use efficiency, reduce environmental impact, and ensure the long-term sustainability of agricultural systems.

3.5 Food Security by Innovative Irrigation Techniques:

Innovative irrigation techniques play a significant role in ensuring food security by improving water availability and efficiency in agriculture. Here's how these techniques contribute to food security:

Innovative irrigation techniques, such as precision irrigation, drip irrigation, and micro-irrigation, deliver water directly to the root zone of crops, minimizing water losses through evaporation and runoff. By optimizing water use efficiency, these techniques ensure that the available water resources are utilized effectively, increasing crop productivity and overall food production.

- **Water Conservation:** Innovative irrigation practices reduce water wastage and promote water conservation in agriculture. Technologies like soil moisture sensors, weather-based controllers, and automated irrigation systems enable farmers to apply the right amount of water at the right time, based on crop needs and environmental conditions. Conserving water resources through innovative irrigation techniques helps sustain agricultural production in water-scarce regions and during drought conditions.
- **Expansion of Cultivable Land**: In some cases, innovative irrigation techniques like aeroponics, hydroponics, or vertical farming enable cultivation in areas with limited arable land or adverse environmental conditions. By utilizing soilless cultivation methods and efficient water delivery systems, these techniques allow for food production in urban areas or regions where traditional farming practices may be challenging.
- **Climate Change Adaptation**: Innovative irrigation techniques help farmers adapt to the impacts of climate change, such as increased temperatures, changing rainfall patterns, and water scarcity. By utilizing technologies that optimize water use and reduce reliance on rainfall, farmers can mitigate the negative effects of climate change on crop production. This adaptation contributes to stable food production and availability, reducing the vulnerability of communities to food insecurity.
- **Enhanced Crop Productivity**: Efficient and targeted water delivery through innovative irrigation techniques ensures that crops receive adequate water throughout their growth stages. This promotes healthy plant development, minimizes water stress, and maximizes crop yields. Higher crop productivity contributes to increased food availability, addressing food security challenges at the local and global levels.

- **Extension of Growing Seasons:** Some innovative irrigation techniques, such as greenhouse irrigation systems or protected cultivation methods, enable year-round food production by creating controlled growing environments. This extension of growing seasons allows for continuous crop cultivation, reducing seasonal variations in food availability and enhancing food security. By incorporating innovative irrigation techniques, farmers can optimize water use, improve crop productivity, and adapt to climate change impacts, ultimately contributing to enhanced food security. These techniques provide opportunities for sustainable and efficient agricultural practices, ensuring a stable and sufficient food supply for communities.

3.6 How Innovative Irrigation Revolutionizes Water Management in Agriculture:

Innovative irrigation techniques have revolutionized water management in agriculture by improving water use efficiency, reducing water wastage, and optimizing irrigation practices. These advancements have significant benefits for agricultural productivity, water conservation, and sustainability. Here are some ways in which innovative irrigation has transformed water management in agriculture:

Precision Irrigation: Precision irrigation technologies, such as drip irrigation, micro-sprinklers, and precision sprinklers, enable precise and targeted application of water to crops. These systems deliver water directly to the root zone of plants, minimizing water loss through evaporation or runoff. By providing water in the right amount, at the right time, and in the right place, precision irrigation significantly improves water use efficiency and reduces overall water consumption.

Sensor-Based Irrigation Management: Sensor technologies, including soil moisture sensors, weather stations, and evapotranspiration (ET) sensors, provide real-time data on soil moisture levels, weather conditions, and crop water requirements. Farmers can use this information to make informed decisions about irrigation scheduling, ensuring that water is applied only when needed. Sensor-based irrigation management helps prevent over-irrigation and under-irrigation, leading to optimized water use and improved crop performance. Irrigation Scheduling Tools: Innovative irrigation scheduling tools, often based on advanced algorithms and models, assist farmers in determining the optimal timing and amount of water required for their crops. These tools consider various factors such as crop type, growth stage, weather conditions, soil characteristics, and water availability. By integrating multiple variables, irrigation scheduling tools help farmers make data-driven decisions, reducing water waste and enhancing water productivity.

Remote Monitoring and Control Systems: Remote monitoring and control systems enable farmers to monitor and manage irrigation systems from a distance. These systems use wireless sensors, telemetry, and internet connectivity to provide real-time information on water flow, system performance, and irrigation events. Farmers can remotely adjust irrigation settings, detect leaks or malfunctions, and optimize water use efficiency without physically being present in the field. Remote monitoring and control systems enhance convenience, save time, and prevent water losses due to system failures or human error.

Smart Irrigation Management Platforms: Smart irrigation management platforms leverage the power of data analytics, machine learning, and artificial intelligence to optimize irrigation practices. These platforms collect and analyze data from various sources, including weather forecasts, soil moisture sensors, crop models, and historical data. They provide farmers with actionable insights, recommendations, and automated irrigation control algorithms to optimize water application and improve crop water productivity.

Water-Efficient Irrigation Techniques: Innovative irrigation techniques, such as alternate wetting and drying (AWD), subsurface irrigation, and vertical farming, promote water conservation and efficiency. AWD, for example, involves periodically drying the field between irrigation events, which reduces water use without compromising crop yields. Subsurface irrigation delivers water directly to the root zone through buried pipes or drip lines, minimizing evaporation losses. Vertical farming systems utilize hydroponics or aeroponics, where crops are grown in vertically stacked layers with a recirculating water system, reducing water requirements compared to traditional field-based agriculture.

By adopting these innovative irrigation approaches, farmers can optimize water use, minimize water waste, improve crop water productivity, and reduce the strain on water resources. These advancements in water management contribute to sustainable agriculture, support food security, and mitigate the environmental impacts associated with excessive water consumption in agriculture.

3.7 Conclusion:

The innovative irrigation techniques play a crucial role in advancing climate-smart agriculture by improving water efficiency, reducing water waste, and promoting sustainability. These techniques leverage cutting-edge technologies and approaches to optimize irrigation practices and mitigate the environmental impact of water-intensive farming. By adopting precision irrigation methods, such as sensor-based systems and smart controllers, farmers can monitor and adjust water delivery in real-time based on crop needs, soil moisture levels, and weather conditions. This targeted approach minimizes water wastage, enhances water use efficiency, and ensures that crops receive the right amount of water at the right time.

Innovative sprinkler systems, such as precision sprinklers and micro-sprinklers, enable accurate water distribution, reducing evaporation and wind drift. This not only conserves water but also improves the effectiveness of irrigation, leading to better crop yields and resource optimization. Soilless cultivation techniques like aeroponics and hydroponics offer water-saving alternatives that deliver water directly to plant roots, minimizing water consumption while maintaining crop productivity. These techniques are particularly relevant in regions facing water scarcity or where traditional soil-based cultivation is challenging. Integration of renewable energy sources, such as solar-powered irrigation systems, reduces dependence on fossil fuels and contributes to climate change mitigation. By harnessing solar energy, farmers can power irrigation pumps and reduce greenhouse gas emissions associated with conventional energy sources. Overall, innovative irrigation techniques in climate-smart agriculture provide sustainable solutions to the challenges posed by water scarcity, climate change, and the need for resource-efficient farming.

By implementing these techniques, farmers can enhance water management, increase productivity, conserve natural resources, and contribute to a more resilient and sustainable agricultural sector. Continued research, development, and adoption of these innovative practices are crucial for building climate resilience and ensuring food security in the face of a changing climate.

3.8 References:

1. Arif, C., & Heng, L. K. (2020). Sustainable Irrigation Management for Climate-Smart Agriculture: A Review. Water, 12(3), 843.
2. FAO. (2013). Climate-Smart Agriculture Sourcebook. Food and Agriculture Organization of the United Nations.
3. Grafton, R. Q., Williams, J., Jiang, Q., & Morrison, M. (2021). Climate-Smart Irrigation. Annual Review of Environment and Resources, 46, 69-98.
4. Regev, Y., & Pereira, L. S. (2019). Precision Irrigation—Challenges and Opportunities for Enhancing Water-Use Efficiency. Water Resources Research, 55(6), 4802-4822.
5. Vellidis, G., Tucker, M., & Perry, C. (2019). Climate-Smart Agriculture and Precision Irrigation. In Precision Conservation (pp. 209-225). Elsevier.
6. Yazar, A., & Zengin, M. (2020). Innovative Irrigation Techniques for Sustainable Agriculture: Past, Present, and Future. Water, 12(6), 1627.
7. Zhang, X., & Li, Y. (2020). Intelligent irrigation systems and applications in smart agriculture. Sensors, 20(10), 2932.

ISBN: 978-81-19149-59-9

4. Climate Change Impacts on Forest and Its Management Options

Dr. Barnali Saikia

Assistant Professor, Dept. of Agrometeorology
SCS College of Agriculture, AAU,
Rangamati, Dhubri, Assam.

Abstract:

The productivity, biodiversity as well as ecosystem of forests are vulnerable to climate change. If it continues like this some of the valuable goods and services provided by forests may be compromised. Amongst the different weather parameters the temperature and rainfall are the main contributing factors of climate change that harms the whole ecosystem of forest. Forest fire, deforestation, increasing pollution level in air are other devastating affects to forests. The outbreak of disease, pests etc can also devastate the forests by defoliating, weakening, and killing the trees. As the insects can complete 4-5 life cycles within a short period of time with increase in temperature there may be severe infestation due to climate change. Forest fires can also release CO2 to the atmosphere that contributes towards climate change. Therefore, to protect the forests from these losses its management is essential to increase forest ecosystem services and reduce vulnerability to climate change.

Keywords:

Weather, Productivity, Ecosystem, Deforestations

4.1 Introduction:

Climate change is the long term conspicuous deviation from normal weather patterns in terms of temperature and rainfall. Now a day's the general people without any scientific knowledge can understand the reality of climate change by feeling the implications and changes in day to day life. Although natural causes like volcanic eruption, variation on solar cycle etc. are there manmade causes like burning of fossil fuel and coal, deforestation etc are the main drivers of climate change. Burning of fossil fuels causes combustion and increases the temperature of earth that leads to green house effect. Amongst the green house gases carbon di oxide is the highest contributor towards global warming. So the mitigation of CO2 seems to be to good approach to reduce carbon concentration in the atmosphere. The trees absorb carbon dioxide when they are grown and release greenhouse gases if they are cut down and are burned or left to rot. From this point of view, projects involving reforestation and intensive planting of new forests have been emerging all over the world as they are presented as simple measures to implement [1,2,3]. Lots of mega projects in Africa or India are being carried out to eradicate the increasing level of CO2 [4-8]. For example, the green wall that is erected in Africa, that is made of trees, to prevent the advance greenhouse gases another process or tool that contributes to CO2 removal from the atmosphere and to store for a certain period of time.

This storage occurs mainly in oceans, seas, soils, forest where organisms capture carbon and release oxygen into the atmosphere. The balance between CO2 captured by forest through photosynthesis is 14.1 PgCyr-1 and CO2 released through respiration and forest fire is 11.6 PgCyr-1 that represents a positive balance of capture and storage.[9]. Forests sequester large quantities of carbon; of the 450–650 Pg of carbon stored in vegetation (IPCC, 2013), over 360 Pg is in forest vegetation [10]. Globally, forest loss not only releases a large amount of carbon to the atmosphere, but it also significantly diminishes a major pathway for carbon removal long into the future [11]. Tropical forests, which hold the greatest amount of above ground biomass and have one of the fastest carbon sequestration rates per unit land area [12], face the greatest deforestation pressure (FAO, 2020).

4.2 Climate Change Impacts on Forest:

Climate change has profound implications for people and the natural world. In case of forests, the extreme weather events has a direct consequence to forest environments by increasing the occurrence of rural fires and changing environmental conditions that lead to the proliferation of exotic forest species that could present in an invasive behavior due to a faster adaptation to the new climatic parameters [13–16]. Plant growth is inhibited because of changes in weather patterns in terms of temperature, rainfall etc. Development of land, suppression of natural periodic forest fire and air pollution together has also impact on forests. If these are likely to continue in the decades ahead, some of the valuable goods and services provided by forests may be compromised. Climate change can also alter the frequency and intensity of forest disturbances such as insect outbreaks, invasive species, wildfires, and storms. Although in some cases, forests can recover from a disturbance but these acts can reduce forest productivity and change the distribution of tree species.

Along with the different weather parameters like temperature, precipitation, the carbon-di-oxide have effect on overall growth and development of forest species. Because of warming temperature some forest species have a tendency to shift their habitat but some species are at risk as they cannot adapt to a changed habitat as temperature passes the threshold level. On the other hand in Antarctica and Greenland, because of higher air temperatures huge ‘ice sheets’ on land are melting which run off into the oceans. The warming planet is also causing an expansion of sea water, increasing its volume. Both of these factors are driving an increase in global sea-levels and the global sea-level has risen by around 20 cm since the start of the 20th century. This has made storm surges – the rise in sea level that occurs during intense storms – more likely to exceed existing sea defences and cause flooding. As many densely-packed cities are in low-lying coastal regions around the world, this hazard can affect large numbers of people. This is particularly true in developing countries such as Bangladesh, but cities like Venice and Miami are also low lying and will be affected too. In the UK, rising sea levels have contributed to recent decisions to abandon areas of coastline, such as the village of Fairbourne on the Welsh coast.

Again, because of increase in temperature, the warmer air holds more water, making heavier downpours. This increased heavy rainfall may lead to increased flooding, damaging property and threatening lives. Again, because of change in precipitation pattern some areas will face drought and some areas will be flooded. Plants have a maximum limit of tolerating scarcity of water. It crosses that threshold level some plants in forest may die.

There is also a risk of forest fire because of drought situation. In UK, there is evidence that some specific weather events, such as the heavy rainfall in the winter of 2014/15, have been made more likely by climate change.[17] Similar impacts are occurring elsewhere in the world. The record amount of rain that fell on Houston during Hurricane Harvey in 2017 helped make it the second most costly hurricane to hit the USA since 1900. Climate change has made a damaging downpour like this around three times more likely.

If we study effect of CO2 on forest, increase in CO2 concentration have a positive effect if water and nutrient are not limiting factors, with good productivity in plants. Overall growth of the plants in forest ecosystem will be good with good fertility in non limiting condition of water and plants will have wider spreadibility. Along with these weather events, forests ecosystem can be disturbed by diseases and pests outbreak and forest fire etc. Although in some cases forest trees recovers but in most of the time productivity of forest decreases. The outbreak of insects often defoliate, weaken, and kill trees. In Colorado in 2007, pine beetles had damaged more than 650,000 acres of forest area and spruce beetles had damaged more than 3.7 million acres in southern Alaska and western Canada.[18] Some insects like hemlock woolly adelgid change its habitat to northern climate with the warming of climate as it is very sensitive to cold weather.[19] Moreover, due to lack of natural controls, such as predators or pathogens, as well as inadequate defenses in trees, can allow insects to spread. As the insects can complete 4-5 life cycles within a short period of time with increase in temperature there may be severe infestation due to climate change. The native vegetation may be replaced by invasive plant species as they are more tolerant to change in climatic condition.[18][20]

4.3 Deforestation and Climate Change:

Approximately 30% of the Earth’s land mass is covered by forests [21]. Existance of these forests provide social, economic, ecological and aesthetic benefits to natural systems and people. Moreover, presence of forest acts a hub for biodiversity, it supplies food, have medicinal and economic value, help in hydrological cycle regulation, protect soil cover, and serve as aesthetic and recreational sites. In addition exchanges of water, carbon dioxide, energy and other chemical species with the atmosphere are because of influence of forest [22], [23].

But sometimes these forest trees are removed or cleared off for farm use or some other purposes. There has been a significant decrease in primary forest area by 300 million ha since 1990. Between 2000 and 2010, around 13 million hectares of forest were converted to other uses or naturally lost, compared to 16 million hectares per year during the earlier decade [22]. As a result atmosphere as well as soil is disturbed. In soil, flux of carbon is disturbed. It also results in soil degradation, carbon emission as a result of plant decomposition left on forest floor, albedo effect, and intensification of hydro-meteorological hazards. Another consequence of deforestation is increasing risk of landslides, slope destabilization, floods, increased surface runoff and soil erosion. After the Kashmir earthquake (2005) an increased risk of landslides and debris flow was encountered due to exploitation of forests. In 2010 Pakistan experienced the worst flood of its history. Scientists termed the unprecedented rate of monsoon rains as impacts of climate change in the region.

Moreover, wildfire causes huge loss to forests. In U.S wildfires consumed more than 8 million acres of forest in the year 2011 (an area roughly the size of Maryland), that causes 15 deaths and more than $1.9 billion damages. Rise in temperature and drought conditions during the early summer contributed towards this loss [24]. Climate change is projected to increase the extent, intensity, and frequency of wildfires in certain areas of the country. Warmer spring and summer temperatures, coupled with decreases in water availability, dry out woody materials in forests and increase the risk of wildfire. As fires releases CO2 to the atmosphere it contributes towards climate change.

4.4 Management of Forest in Changing Climate:

By realizing the impact of climate change the priority should be given on management options. In management aspects productivity as well as sustainability of resources should be given importance. Management of ecosystem is another concern where capturing of carbon and carbon sequestration is done. According to Seidl et al. [25]) sustainable forest management is prerequisite for management of sustainable forest. It is seen that forest species are damaged by invasive species that increases the load of forest ultimately leading to forest fire. Based on the scenario in which climate changes lead to an expected increase in temperature, maintaining the structure and functions of Mediterranean forests has become a challenge for forest managers. Vila-Cabrera et al. [26] showed that research is focused mainly on strategies to decrease risk and promote resistance in the short term, rather than on enhancing long-term resistance. On the other hand, as expected in economic activities, management strategies seek to obtain benefits in the short term and frequently have unintended consequences on other adaptation objectives and untargeted ecosystem components that are so important in Mediterranean-type climate regions.

There is an another attempt to reflect the environmental and social as well as economic benefits provided by forests which is called Sustainable forest management (SFM). As adopted by FAO, SFM is the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems [27]. It becomes widely accepted after the UN Conference on Environment and Development in 1992 (the ‘Earth Summit’ in Rio de Janeiro), which first saw international commitment to the concept of sustainable development more broadly.

More precise definitions of SFM inevitably vary from region to region, since the types of forests, the needs of the populations who live in and around them, and the social, economic, environmental and political contexts in which their protection and management are set also vary regionally. Although it is undoubtedly true that the concept of SFM may be appealed to more frequently than it is implemented in reality, it has had a major impact on policy-making and practices relevant to the world’s forests. Active forest management enhances carbon uptake, both because the rate of carbon uptake slows as forests mature, net primary productivity declines and natural mortality increases, and also because unmanaged forests increase the chance of massive carbon losses from disturbances such as fire, insects or disease infestations[28]. Harvesting mature trees and replanting should therefore increase the rate of carbon uptake, as well as generating timber for wood products.

4.5 Conclusion:

Climate change is a global issue with many implications. It has many consequences on forest and on other hand forests helps in mitigating the impact of climate change. It protects the biodiversity, act as a protective layer to the soil, and maintains atmospheric temperature too. But due to deforestation the natural atmosphere is disrupted leading to change in climate and we face devastations. Globally, forest loss releases a large amount of carbon to the atmosphere. So management of forest is a effective tool to cope up with the impact of climate change. Through management options productivity of forests as well as sustainability of resources can be maintained as well as ecosystem can also be restored.

4.6 References:

1. Metz, B.; Davidson, O.; DeConinck, H. Carbon Dioxide Capture and Storage: Special Report of the Intergovernmental
2. Kirschbaum, M.U.F. Can Trees Buy Time? An Assessment of the Role of Vegetation Sinks as Part of the Global Carbon Cycle. Clim. Chang. 2003, 58, 47–71. [CrossRef]
3. Grace, J. Understanding and managing the global carbon cycle. J. Ecol. 2004, 92, 189–202. [CrossRef]
4. Le, H.D.; Smith, C.; Herbohn, J. What drives the success of reforestation projects in tropical developing countries? The case of the Philippines. Glob. Environ. Chang. 2014, 24, 334–348. [CrossRef]
5. Ravindranath, N.; Chaturvedi, R. K.; Murthy, I. K. Forest conservation, afforestation and reforestation in India: Implications for forest carbon stocks. Curr. Sci. 2008, 216–222.
6. De Jesus, R.M. The need for reforestation. In Proceedings of the International Workshop on Large-Scale Reforestation, Corvallis, Oregon, 9–10 May 1990; p. 81.
7. Jindal, R.; Swallow, B.; Kerr, J. Forestry-based carbon sequestration projects in Africa: Potential benefits and challenges. Nat. Resour. Forum 2008, 32, 116–130. [CrossRef]
8. Reynolds, T.W. Institutional Determinants of Success among Forestry-Based Carbon Sequestration Projects in Sub-Saharan Africa. World Dev. 2012, 40, 542–554. [CrossRef]
9. Finkl, C.W. (Ed.) Carbon cycle. In Encyclopedia of Earth Sciences Series; Springer: Berlin, Germany, 2018.
10. Pan, Y., Birdsey, R. A., Phillips, O. L., and Jackson, R. B. (2013). The structure, distribution, and biomass of the world's forests. Annu. Rev. Ecol. Evol. Syst. 44, 593–622.
11. Houghton, R. A., and Nassikas, A. A. (2018). Negative emissions from stopping deforestation and forest degradation, globally. Glob. Change Biol. 24, 350–359. doi:10.1111/gcb.13876
12. Harris, N. L., Gibbs, D. A., Baccini, A., Birdsey, R. A., De Bruin, S., Farina, M., etal.(2021).Globalmapsoftwenty-firstcenturyforestcarbonfluxes.Nat.Clim. Change11,234–240.doi:10.1038/s41558-020-00976-6
13. Rosenzweig, C.; Iglesias, A.; Yang, X.; Epstein, P.R.; Chivian, E. Climate Change and Extreme Weather Events; Implications for Food Production, Plant Diseases, and Pests. Glob. Chang. Hum. Heal.2001,2,90–104. [CrossRef]

14. Flannigan, M.D.; Krawchuk, M.A.; De Groot, W.J.; Wotton, B.M.; Gowman, L.M. Implications of changing climate for global wildland fire. Int. J. Wildland Fire 2009, 18, 483–507. [CrossRef]
15. Hansen, A. J.; Neilson, R. P.; Dale, V. H.; Flather, C. H.; Iverson, L. R.; Currie, D. J.; Shafer, S.; Cook, R.; Bartlein, P.J. Global change in forests: Responses of species, communities, and biomes: Interactions between climate Change and land use are projected to cause large shifts in biodiversity. BioScience2001,51,765–779. [CrossRef]
16. Pautasso, M.; Döring, T.F.; Garbelotto, M.; Pellis, L.; Jeger, M.J. Impacts of climate change on plant diseases—opinions and trends. Eur. J. Plant Pathol. 2012, 133, 295–313.
17. Schaller, N. et al. (2016) Human influence on climate in the 2014 southern England winter floods and their impacts. Nature Climate Change, 6, 627–634.
18. CCSP (2008). The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States. Chapter 3: Land Resources: Forest and Arid Lands. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Backlund, P. , A. Janetos, D. Schimel, J. Hatfield, K. Boote, P. Fay, L. Hahn, C. Izaurralde, B.A. Kimball, T. Mader, J. Morgan, D. Ort, W. Polley, A. Thomson, D. Wolfe, M. Ryan, S. Archer, R. Birdsey, C. Dahm, L. Heath, J. Hicke, D. Hollinger, T. Huxman, G. Okin, R. Oren, J. Randerson, W. Schlesinger, D. Lettenmaier, D. Major, L. Poff, S. Running, L. Hansen, D. Inouye, B.P. Kelly, L Meyerson, B. Peterson, and R. Shaw. U.S. Environmental Protection Agency, Washington, DC, USA.
19. USGCRP (2014). Horton, R., G. Yohe, W. Easterling, R. Kates, M. Ruth, E. Sussman, A. Whelchel, D. Wolfe, and F. Lipschultz, 2014: Ch. 16: Northeast. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 16-1-nn.
20. USGCRP (2009). Global Climate Change Impacts in the United States. “Climate Change Impacts by Sectors: Ecosystems.” Karl, T.R., J.M. Melillo, and T.C. Peterson (eds.). United States Global Change Research Program. Cambridge University Press, New York, NY, USA.
21. Percy K.E., Jandl R., hall J.P. and Lavigne M., 2003, The Role of Forests in Carbon Cycles, Sequestration, and Storage, International Union of Forest Research Organizations, 1.
22. Joseph S., Rita P., Wright M., Rafique, M. and Afzal K., 2004, Landscapes, soils, and mound histories of the Upper Indus Valley, Pakistan: new insights on the Holocene environments near ancient Harappa, Journal of Archaeological Science, 31, 6, 777–797.
23. Song F., Qi h., Wei h., Chang h.h., Ruopu L. and Zhenghong T., 2014, Tang. Projected climate regime shift under future global warming from multi-model, multi-scenario CMIP5 simulations, Global and Planetary Change, 112, 41–52.
24. USGCRP (2014). Groffman, P. M., P. Kareiva, S. Carter, N. B. Grimm, J. Lawler, M. Mack, V. Matzek, and H. Tallis, 2014: Ch. 8: Ecosystems, Biodiversity, and Ecosystem Services. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 195-219. doi:10.7930/J0TD9V7H.
25. Seidl, R.; Schelhaas, M.J.; Lexer, M.J. Unraveling the drivers of intensifying forest disturbance regimes in Europe. Glob. Chang. Biol. 2011, 17, 2842–2852.

26. Vilà-Cabrera, A.; Coll, L.; Martínez Vilalta, J.; Retana, J. Forest management for adaptation to climate change in the Mediterranean basin: A synthesis of evidence. For. Ecol. Manag. 2018, 407, 16–22.
27. General Guidelines for the Sustainable Management of Forests in Europe (Resolution H1 of the Second Ministerial Conference on the Protection of Forests in Europe, 16–17 June 1993, Helsinki), para D; available at http://www.mcpfe.org/files/u1/helsinki_resolution_h1.pdf.
28. Hektor, B., Backéus, S. and Andersson, K., 'Carbon balance for wood production from sustainably managed forests', Biomass and Bioenergy, 93 (2016), or the studies reviewed and summarised in 'Maximising carbon storage through sustainable forest management' (American Hardwood Export Council, nd).

ISBN: 978-81-19149-59-9

5. Impact of Climate Change in Fruit Crops

Somendra Meena, Mohit Janbandhu
Department of Fruit Science,
College of Horticulture, Dr. Panjabrao Deshmukh Krishi Vidyapeeth,
Akola, Maharastra, India.

Akshay Kumar Singh Pratihar
Department of Entomology,
Maharana Pratap University of Agriculture and Technology,
Udaipur, Rajasthan, India.

Suman Poonia
Department of Vegetable Science,
Acharya Narendra Deva University of Agriculture & Technology, Kumarganj,
Ayodhya, Uttar Pradesh.

Abstract:

Climate change is a major worldwide issue that poses serious dangers to agricultural systems, particularly fruit crops. The influence of climate change on fruit crops is examined in this abstract, with an emphasis on phenology, quality, and disease and pest dynamics. Fruit crop phenological variations have been reported in response to changing climatic circumstances. Warmer temperatures and shifting precipitation patterns can all have an impact on when flowers bloom, buds break, and fruits mature. These alterations can upset the delicate balance between the plant and its environment, resulting in decreased fruit set, changed growth patterns, and lower yields. Such phenological variations can have a domino impact on the ecological interactions within fruit crop ecosystems. Climate variation also has an impact on the quality of fruit harvests. Fruit size, colour, flavour, and nutritional content can all be affected by rising temperatures. Furthermore, changes in temperature can impact the sugar-to-acid ratio, affecting the flavour and general appeal of fruits. These quality variations can have serious consequences for both producers and consumers, resulting in economic losses as well as possible effects on human health and nutrition. Climate change also has an impact on the dynamics of pests and illnesses in fruit crops. Pest populations can grow as temperatures rise, causing greater agricultural damage. Similarly, changed precipitation patterns can foster the spread of fungal and bacterial infections. These variables not only cause direct output losses, but they also increase reliance on chemical pesticides, posing environmental and health problems. Assessment of adaptation and mitigation techniques is required. This chapter addresses the effects of climate change has an impact on a various fruit crops, as well as strategies for dealing with these potential issues.

5.1 Introduction:

Long-term changes in global weather patterns and temperatures caused by human activities, particularly the use of fossil fuels and deforestation, are referred to as climate change. The

Earth's temperature has always varied naturally throughout time, but the current fast warming is primarily due to greenhouse gas emissions caused by humans. According to the Intergovernmental Panel on Climate Change (IPCC), the Earth's temperature might rise by up to 4°C by the end of the century, causing sea-level rise, extreme weather events, and other consequences that would have far-reaching consequences for human civilizations and ecosystems. According to NASA statistics from October 2020, the CO2 concentration in the atmosphere grew quickly to 400 ppm in 2014, with a recent record of 415 ppm (Source-https://climate.nasa.gov/vital-signs/). Between 1906 and 2005, air temperature rose by 0.74°C (IPCC 2007a). In 2019, the most recent annual average anomaly was 0.99°C. By 2100, global temperatures are forecast to rise by up to 6°C, while CO2 concentrations are likely to rise by 550 to 850 ppm [21]. Depending on future development, the average temperature in the Indian subcontinent will rise by 0.5 to 1.2°C by 2020, 0.88 to 3.16°C by 2050, and 1.56 to 5.44°C by 2080, according to the IPCC [59]. The principal drivers of climate change are unpredictable rainfall patterns and unexpectedly high or low temperature regimes, both of which have far-reaching consequences for agriculture in general and horticulture in particular.

5.2 Climate Change and Fruit Crop Production:

Climate, an essential environmental element, has a substantial influence on fruit crop production. Plant physical characteristics such as vigour, canopy development, and reproductive traits such as fruiting ability and fruit size reduction, as well as quality characteristics such as less colour development, low juice content, decreased shelf-life, and increased pest attack, all contributed to poor fruit quality and low fruit production [25]. Temperate crops' ability to adapt to unexpected weather changes over a specific time of the growing season in any historically inhabited temperate crop region is jeopardised, potentially resulting in serious production issues in the near future [4]. The spread of existing pests, diseases, and weeds, as well as the increased likelihood of incursions into new crops, as well as the appearance of minor pests, illnesses, and physiological problems such as sunburn, fruit cracking, and tip burn. Appropriate cooling hours are critical for optimal vegetative development and fruiting in temperate fruit species. In temperate fruit orchards, a lack of chilling hours leads to inconsistency in bud break and fruiting [66]. In the Shimla district's central hills, the trend is to abandon potato and apple production entirely. In this regard, the snowfall pattern and apple output in Himachal Pradesh have been confirmed. Apple production per acre decreased from 10.8 to 5.8 tonnes. This is only one instance of climate change. As a result of climate change, various abiotic factors are arising, which has an influence on several horticultural fruit crops and their physiological, anatomical, morphological, and biochemical features. Temperature, drought, salinity, floods, CO2 concentration rise, and insect-pest outbreak have the greatest influence on fruit output [17].

5.2.1 Climate Change's Impact on Fruit Crop Phenology:

One of the well-known effects of climate change is a shift in the period of plant growth activity, known as phenology. Climate change has affected the vegetative and reproductive phases of fruit plants. Flowering is an important stage in fruit development that influences yield and productivity. Pome fruit flower buds may wholly or partially abscise in mild winters, resulting in smaller flower bud clusters that resemble leafy spurs. Climate change has influenced flowering, fruiting, and, eventually, yield [60]. In the case of apples, a shortage of chilling time resulted in incomplete flowers and poor fruit set [24]. Chilling hours had an impact on both the quality and quantity of flowering and fruit set. An rise in early spring temperature of 0.45°C/decade (1973-2009) resulted in a 1.6-day/decade advance in apple and pear blossoming [18]. The following crops saw comparable results in various areas throughout the world. In France, a rise in average growing temperature of 2-3°C (1964-2009) increased blooming, veraison, and harvest by 13-19 days in grapes [64]. Veraison for the cultivars "Riesling" and "Gewurtztraminer" will be advanced by up to 23 days by 2100 [13]. Due to temperature changes in February and March, the peak blooming period of the cherry tree has migrated earlier by 5.5 days in the last 25 years. Temperature has risen by 1.8°C in the last 25 years [39]. In apple, insufficient cooling needs during warm seasons produce various phenological disruptions such as late blooming, extended flowering durations, and a longer interval between flowering and harvest [14]. A significant relationship was discovered between blooming development and changes in maximum and lowest temperature throughout time in numerous locations around Iran (Kerman, Shiraz) [16]. In citrus fruits, flowering progresses at rates of 3.15-3.39 days/°C for Kerman and 4.3-4.47 days/°C for Shiraz. Hermaphrodite flowers were more closely associated with greater temperatures following bloom initiation [52]. The warm (15.9°C) temperature, which is 3-5°C above than normal, resulted in undeveloped pistils [53].

5.2.2 The Influences of Climate Change on Fruit Crop Physiology:

A. Temperature Effect:

The physiological activities of plants are regulated by temperature. Imbalanced temperatures have the following consequences. For example, 1. Heat stress, 2. Inadequate chilling for temperate crops 3. Pollination activity disruption. Heat stress promotes evaporation, which causes stomatal closure and a decrease in CO2 inflow, eventually driving respiration and reducing photosynthesis. Chilling hours will be reduced by 30 to 60% by 2050 and up to 80% by 2100, according to the National Climate Assessment 2014. The Warmer climatic circumstances were found to have a substantial impact on flowering, fruit set, yield, and quality in peach cultivars. In mild winter years, flower abortion occurs, resulting in a decreased fruit output [3]. Temperature stress has a significant impact on pollination activity, which contributes for 35 percent of global food supply [31]. Plant-pollinator interactions are hampered by temporal (phenological) and geographic (distributional) misalignments. Temporal changes are already visible, as Apis mellifera increased their activity time before the flowering maxima of their preferred feed species. Areas in developing countries are altering geographically [18]. Crop plants that are incompatible with themselves, pollinator restricted, or pollinator specialised are more sensitive to this hazard. A flower bud can become vegetative in warm night time temperature [12]. Because of their prolonged flowering time, fruit crops are more vulnerable to climate change. The hormones required for tree growth and development are altered by temperature. Mango and litchi have already shown early flowering and crop harvesting. In January, low temperatures (11.5 °C), high humidity (>80%), and gloomy weather all delay panicle emergence, although low temperatures during panicle development diminish hermaphrodite flowers [10]. Mango malformation is common in locations with harsh winters and may benefit from a warmer temperature. Mango, banana, papaya and sapota output and productivity stayed found to be negatively connected to temperature and rainfall during a ten-year period (2007-2017) in Navasari district in Gujarat (India). [63].

- **Drought:** Drought is a common occurrence in dry and semi-arid areas with irregular precipitation, and it is defined as a absence of precipitation [32]. Water stress may be particularly vital to yield response throughout phenological stages and is critical in planning irrigation within large limited water zones [27]. Stress affects perennial fruit tree yields by diminishing the amount of fruits and the cell size of surviving fruit before to or during the flowering and post-blooming seasons [48;49]. Drought reduces banana growth, yield, and productivity by reducing the plants' capacity to photosynthesize. Lack of adequate water at the finger growth stage leads bunches to shorten [62]. African banana production losses are mostly caused by an inadequate supply of water, which has a detrimental influence on nutritional intake [65]. Drought stress lowers finger numbers during floral initiation in bananas, whereas it correlates to poor filling following emergence [37]. Moisture stress has been shown to reduce the size and quantity of tomatoes. The occurrence of blossom end rot and sunscald was greater in the very stressed plants. Irrigation treatments had a substantial impact on TSS content, which increased with stress level as fruit water content dropped [7]. Long-term water stress causes fruit and flower drop in avocado during blooming and fruit development. Plants cultivated on sandy soils with low irrigation capacity are more vulnerable to drought stress than plants planted in clay soils. Freshly planted orchards are particularly sensitive to drought stress due to poor root system development and fast growth of foliage in the early stages [32].

B. Rainfall:

Rainfall is another significant aspect that has arisen as a result of climate change. Crop output is reduced by uneven or no rainfall, particularly in rainfed areas. Heavy rainfall in locations with inadequate drainage reduces soil oxygen availability, which kills the growth of helpful microorganisms, and water-logged conditions promote the spread of insect-pests and illnesses, reducing crop output. Rainfall during the flowering period reduces fruit set, growth, and production. Inadequate rainfall influences pests, resulting in low fruit output [38]. Fruits in heavy rainfall areas are susceptible to illnesses such as anthracnose in mango fruit during the maturity stage [47]. Rain during flowering washed off the pollen from the flower's stigma, As a result, fruit setting is poor or non-existent. In Gujarat, unseasonal rain followed by a heavy dew assault reduced fruit setting, increased fruit drop, and increased the frequency of sooty mould and powdery mildew by 80-90 percent. [52]. Extended water stress cycles result in yield losses ranging from 10% to 40%. Water-logging cycles lasting more than two days are beginning to limit Cape gooseberry leaf area. After four days of exposure, the stem diameter decreases, as do bud initiation, fruits, and flowers [2].

C. CO2 Effect:

The physiological status of a plant is affected by increased CO2 concentration. It is essential for photosynthesis, which creates the plant's biomass. In response to increased CO2, raising net photosynthetic proportion in grapes while reducing stomatal conductance enhances innate water usage efficiency in Portugal. In general, they observed that increasing ambient

CO2 levels increases yield irrespective of any positive or negative effects on grape maturity. Even though they were well into reproductive maturity (17 years), sour orange trees were more susceptible to increasing CO2 levels. At the time of harvest the trees cultivated with CO2 enrichment (350-650 ppm CO2) exhibited significantly higher root biomass, leaf biomass, branch biomass, fruit biomass, and total biomass than the trees grown in natural circumstances [29]. The heat generated by CO2-related global warming in open habitats, as well as soil water evaporation, are anticipated to offset the benefits of enriched CO2 for plant biomass production, resulting in shorter growth periods, reduced yield, and more yield variance [57].

5.2.3 Climate Change Impact on Quality of Fruits:

Quality requirements are critical in order to obtain a profitable price in the export market. Changing climatic circumstances have an influence on the optimal conditions for appropriate pigmentation and secondary metabolite formation, both of which are required to yield excellent fruits. Temperature fluctuation may also contribute to perfect growth conditions. 'Kent' strawberries have higher antioxidant activity during warm days (25°C) and mild nights (18-22°C) [67]. Climate change has also been demonstrated to have negative consequences, such as earlier ripening in California near the end of the century, which may result in lower quality grapes in the region [20]. Due to browning and berry burn, incidental heat shocks (over 35°C) resulted in the loss of 50% of the berries [30]. In terms of quality, simulated climate change scenarios had a greater influence on technical (primary metabolism) maturity than phenolic (secondary metabolism) [28], Rising temperatures reduce the quality of grape wine production by hastening the maturation period of the grapes and decreasing acidity and colour. Fruit availability may be shortened as a result of quicker maturation and ripening [34] Mandarin oranges grown in direct sunlight (35°C) were 2.5 times firmer than those grown in shadow (20°C) because direct sunlight reduces the activity of cell wall enzymes (cellulase and polygalacturonase) during growth, which slows ripening [69].

Grapes are a well-known example, with bunches exposed to direct sunlight ripening before those matured in shaded positions inside the canopy [68]. High temperatures have also been reported to hinder the development of the fruit's colour. When the temperature rises and unseasonal rains fall, downy mildew damage ensues. When fruits produced at higher temperatures were stored at 3°C, there was a breakdown incidence, which is attributable to the lower calcium content in the fruits grown at higher temperatures [5]. Sunburn may occur when fruits, such as litchi, are exposed to excessively high temperatures for a lengthy period of time or even for a short period of time during their growth and development [40].

Greater watering requirements owing to increased evaporation, as well as speedier tree development due to faster heat unit accumulation, are the causes of the reduced fruit sizes and anthocyanin content in litchi [42]. Apple fruit marketing relies heavily on the red hue of the fruit. One of the most important factors affecting the development of apple fruits' red hue is temperature. In discs treated at 20 and 25 degrees Celsius compared to 30 degrees Celsius, the red colour density was higher [45]. Due to extreme temperature and moisture stress, sunburn and fruit breaking are becoming increasingly prevalent in apples, which has drastically decreased fruit quality [50]. High temperatures has tens water core incidence in pear [55].

Table 5.1: Impact of Climate Change on the Nutritiousness of Fruit

Fruit crop	Climate variable	Nutritional quality variables	observations
Apple	Humidity, Temperature and solar radiation	Sugar-acid ratio, Anthocyanin and Vitamin-C content	Apples now have higher anthocyanin concentrations, vitamin C contents, and sugar-acid ratios thanks to rising temperatures and decreased sunshine.
banana	Rainfall, Temperature and solar radiation	Carbohydrate content and concentrations of micro-nutrient	The average fruit weight and content decreased whereas P, Mg, and Ca levels increased as the average daily temperature increased. The impacts of temperature, rainfall, and soil type on quality variables were all different.
Grape	UV and Sunlight exposure	Anthocyanin, total phenolic and tannin content	As grapes are exposed to more UV rays and sunshine, the anthocyanin, total phenolic, and tannin content of wine likewise rises.
Grape	Rainfall and Temperature	Phenolic and Anthocyanin content	Temperature increases were adversely linked with grape anthocyanin and phenol levels. Temperature affects phenolic content more when rainfall is below normal.
Citrus (orange)	Soil salinity	Content of micro-nutrients in leaves	As soil salinity increased, the micronutrient composition of sour orange leaves on different rootstocks changed. Ca2+, K+, and Mg2+ concentrations decreased, P concentrations stayed constant, while Na+ and N concentrations increased.
Citrus (orange)	Frost	Proteomic and metabolic profiles	The cold has impacted protein levels as well as primary and secondary metabolites. Some fruit constituents were expressed more fully as a result of the frost, whereas others were expressed less fully.

5.2.4 Fruit crop Climate variable Nutritional quality variables observations:

Apple Humidity, Temperature and solar radiation Sugar-acid ratio, Anthocyanin and Vitamin-C content Apples now have higher anthocyanin concentrations, vitamin C contents, and sugar-acid ratios thanks to rising temperatures and decreased sunshine. Banana Rainfall, Temperature and solar radiation Carbohydrate content and concentrations of micro-nutrient The average fruit weight and content decreased whereas P, Mg, and Ca levels increased as the average daily temperature increased. The impacts of temperature, rainfall, and soil type on quality variables were all different.

Grape UV and Sunlight exposure Anthocyanin, total phenolic and tannin content As grapes are exposed to more UV rays and sunshine, the anthocyanin, total phenolic, and tannin content of wine likewise rises.

Grape Rainfall and Temperature Phenolic and Anthocyanin content Temperature increases were adversely linked with grape anthocyanin and phenol levels. Temperature affects phenolic content more when rainfall is below normal.

Citrus (orange) Soil salinity Content of micro-nutrients in leaves As soil salinity increased, the micronutrient composition of sour orange leaves on different rootstocks changed. Ca2+, K+, and Mg2+ concentrations decreased, P concentrations stayed constant, while Na+ and N concentrations increased.

Citrus (orange) Frost Proteomic and metabolic profiles The cold has impacted protein levels as well as primary and secondary metabolites. Some fruit constituents were expressed more fully as a result of the frost, whereas others were expressed less fully.

5.2.5 Climate Change's Impact on Fruit Crop Area Suitability:

The yield, flowering, and quality of tropical fruits vary from year to year due to changes in the rainfall distribution pattern [52]. Warming has enlarged the tropical zone during the last several decades, [36], emphasising the need of additional areas for tropical foods. A 1°C rise in temperature can drastically affect the region suitable for tropical fruits. Several fruit crop favourable areas may become somewhat suitable, and new suitable ones may emerge. Temperature rises are likely to have a greater impact on the reproductive systems of these crops. A 0.7-1.0°C temperature increase may modify the current zone suitable for quality production of Dushehari and Alphonso mango cultivars [51]. The best environment for a mango variety Dushehari suffers greatly with a 1°C increase in temperature, but Alphonso (a mango cultivar) is most likely restricted to the Ratnagiri area because to its resilience to shifting environmental conditions [9]. Certain findings were drawn from a research of worldwide banana production and its appropriateness under climate change scenarios, such as an increase in suitable regions owing to temperature rise, mostly in areas with an average temperature of 24°C [1]. According to studies of 24 places throughout the world, all of the sites indicate a linear rise in temperature, making climate change a problem for civilization It is expected that the region with tropical growth climate would rise, whilst present tropical zones will experience serious climatic challenges [11].

5.2.6 Climate Change's Influence on Pest and Disease Incidence in Fruit Crops:

Pest and disease incidence in fruit crops has increased as a result of climate change. Changes in flowering time and temperature can result in the introduction of novel pests, minor pests becoming severe pest status, and the breakdown of resistance. According to the National Research Centre for Banana annual report 2012, Sigatoka disease has reached dangerous levels in Maharashtra, where it was never considered a problem before, as a result of climate change. Stormy weather increases the likelihood of bacterial gummosis in pome and stone fruits. Climate change has the ability to alter pathogen development stages and rates, as well as host resistance and pathogen-host interaction physiology. Tropical insects (physiological optima) are more sensitive to warming than higher latitude insects [17]. A decrease in the number of specific vector insects in tropical climates might reduce the occurrence of specific viruses such as citrus leprosy (mealy bug), papaya ring spot (aphid), pineapple wilt (mealy bug), and others [15].

Temperature and rainfall patterns, for example, have a direct impact on the lifecycle of many insect pests. Climate change might have an impact on regional distribution, population growth rates, generation numbers, overwintering, developmental seasons, crop-pest phenology synchrony, pest invasion by migratory pests, and interspecific interactions [46]. When the temperature was raised from 20 to 35°C, fruit fly development increased in mango cv. Chausa. With the possibility of a third generation of codling moth, preventive measures (e.g., pesticides) would need to be strengthened and extended in order to manage this additional generation, meaning an increased risk of chemical residual effects on fruits [21]. Climate change has increased disease incidence, water consumption, and insect infestation, resulting in a rise in input costs in Pakistan's Punjab plains citrus orchards [44].

5.3 Adaptation Strategy to Mitigate Ill Effects of Climate Change Fruit crops:

Adaptation is vital, but mitigation is also required since even if all emissions were halted, temperatures would continue to rise for decades before stabilising. If the rate of rise is not slowed, it will reach several disastrous tipping points, hastening climate change to the point where adaptation may become scarce [61]. Integrating adaptation and mitigation is the most effective method for increasing both adaptation and mitigation [23]. There is enough room in agriculture, land use, and forestry to address adaptation and mitigation at the same time, since each give’s chance for the other. Soil organic carbon amplification is the most important adaptation and mitigation strategy in tropical production systems because it not only has the biggest agriculture-based mitigation potential but also provides resistance to climate change

A. Change of Crop and Varieties:

One of the most important adaptation measures is crop and variety change in response to climate change. Crop cultivars that can survive both biotic and abiotic stressors provide increased climate resilience. Identifying more adaptable cultivars as well as a variety of cultural practises may assist producers in maintaining current output. Drought-tolerant cultivars and types that may avoid stressful periods by having a shorter fruiting season must be developed/identified. Drought-tolerant Pomegranate hybrid Ruby, Annona hybrid Arka Sahan, and Grape root stock Dogridge (Vitis champine) have all been discovered to be promising. Different races and genetic bases must be investigated and tested [43]. The origin of fruits should be investigated for climatic adaptability. For example, mono-embryonic type mango might be studied for a land-logged environment in northern India with a well-defined winter, whereas poly embryonic type mango could be evaluated for a coastal climate for adaptation to changing climate [36].

B. Canopy Management:

Canopy management improves yields and fruit quality by increasing leaf and fruit exposure [33]. When done correctly, it reduces resource competition and enhances crop physiological processes. It is critical in several situations, like Litchi. The primary goal of training in younger plants is to form the canopy and establish a sturdy structure that provides increased resistance against heavy winds. Training and trimming mature plants seeks to maintain desired form and maximise tolerable surface area.

Pruning helps retain the vitality of aged plants/orchards that might otherwise acquire senility. Pruning has been shown to stimulate shoot start. Rising CO2 levels in the atmosphere are anticipated to promote canopy development, which may provide a more favourable micro-climate, more sensitive tissue, more inoculum interception, more potential for infection, more polycyclic infection, and a radiation shield for inoculums. If all leaves removed during training or pruning are integrated into the soil, and 50% of hard biomass is utilised as lumber with a life of more than 30 years, pruning and training are predicted to have a net mitigating impact. [56], By removing 25% of the canopy, researchers discovered an improvement in light utilisation in mango.

C. Efficient Water Management:

Coconut has had the highest rate of drip system adoption among crops, followed by banana, grape, papaya, pomegranate, mango, and sapota [10]. Even though rain fall has increased slightly, water availability is expected to be limited as more intense rain produces more runoff. An effective irrigation method, such as drip irrigation, will save substantial water that may be utilised to extend the watered area. More favourable soil moisture combined with increasing CO2 levels may induce increased biomass production and soil-carbon enrichment [16].

D. High Density Planting (HDP):

Tropical fruits have high adaptability and mitigation potential since they not only produce more but also collect biomass and soil carbon per unit area. Terrestrial carbon uptake in a well-managed high-density perennial planting can be up to 1.5 times that of regular planting in one life cycle. HDP is already being used selectively in mango, guava, banana, citrus, pineapple, pomegranate, papaya, cashew, and coconut. These successes should be replicated for other tropical fruits such as litchi, longan, and so on. Mango, guava, and citrus trees can be planted at 2.5 m x 2.5 m, 3 m x 3 m, and 1.8 m x 1.8 m instead of 10 m x 10 m, 6 m x 6m, and 6 m x 6 m. Canopy control is critical to success, but future high-density plantings must use dwarfing rootstock, inter-stock, and scion varieties. HDP success necessitates a combination of canopy management and growth regulators [32].

E. Protected Cultivation:

Protected cultivation with net houses or poly houses offers the benefit of modifying the microclimate and exposing the crop to fewer weather extremes. Increased CO2 levels in the growth environment can also help to improve photosynthesis [29]. Protected farming has the extra benefit of reducing insect and disease damage as well as wild animal harm [30]. In India, over 40,000 hectares of protected agriculture are employed, largely for annuals or as a nursery for perennial crops.

5.4 Conclusion:

Climate change has had an important role on fruit crop phenology, quality, and susceptibility to diseases and pests. Temperature changes, rainfall patterns, and extreme weather events have thrown off the timing of blooming, fruit ripening, and overall crop growth, resulting in decreased yields and poor fruit quality. Furthermore, rising temperatures and changed precipitation patterns foster the development of diseases and pests, creating further difficulties to fruit production. Implementing adaptive strategies such as breeding resilient crop varieties, improving irrigation and water management, implementing integrated pest management practises, and adopting sustainable farming techniques can help mitigate the adverse effects of climate change and ensure the long-term sustainability of fruit crop production.

5.5 References:

1. Ahamed, N., Srivastava, K.K., Lal, S. (2011) Global warming carved niche for apple production. Indian Journal of Horticulture, 56(1):9-11.
2. Aldana, F., García, P. N., & Fischer, G. (2014). Effect of waterlogging stress on the growth, development and symptomatology of cape gooseberry (Physalis peruviana L.) plants. Revista de la Academia Colombiana de Ciencias Exactas, Físicas y Naturales, 38(149), 393-400.
3. Alonso, J. M., Ansón, J. M., & Espiau, M. T. (2005). Determination of endodormancy break in almond flower buds by a correlation model using the average temperature of different day intervals and its application to the estimation of chill and heat requirements and blooming date. Journal of the American Society for Horticultural Science, 130(3), 308-318.
4. Ameglio, T., Alves, G., Bonhomme, M., Cochard, H., Ewers, F., Guilliot, A., ... & Valentin, V. (2000, August). Winter functioning of walnut: involvement in branching processes. In 4. Colloque international sur l'arbre (p. np). IQ Collectif.
5. Atkinson, C. J., Taylor, L., Taylor, J. M., & Lucas, A. S. (1998). Temperature and irrigation effects on the cropping, development and quality ofCox's Orange Pippin'andQueen Cox'apples. Scientia Horticulturae, 75(1-2), 59-81.
6. Birhanu, K., & Tilahun, K. (2010). Fruit yield and quality of drip-irrigated tomato under deficit irrigation. African Journal of Food, Agriculture, Nutrition and Development, 10(2).
7. Brown, D. S. (1952, January). Climate In Relation to Deciduous Fruit Production in California. IV. Effect of The Mild Winter Of 1950-51 On Deciduous Fruits in Northern California. In Proceedings of the American Society for Horticultural Science (Vol. 59, No. JUN, pp. 111-118). 701 North Saint Asaph Street, Alexandria, Va 22314-1998: Amer Soc Horticultural Science.
8. Calberto, G., Staver, C., & Siles, P. (2015). An assessment of global banana production and suitability under climate change scenarios. Climate change and food systems: global assessments and implications for food security and trade. Rome: Food Agriculture Organization of the United Nations (FAO).
9. Chadha, K.L. (2015). Global climate change and Indian horticulture. In: Chaudhary ML, Patel VB, Siddiqui MW, Verma RB (eds) Climate Dynamics in Horticultural Science:Impact, Adaptation and Mitigation, Volume 2. Apple Academic Press, 1-26.
10. Coakley, S. M., Scherm, H., & Chakraborty, S. (1999). Climate change and plant disease management. Annual review of phytopathology, 37(1), 399-426.
11. Dinesh, M. R., & Reddy, B. M. C. (2012). Physiological basis of growth and fruit yield characteristics of tropical and sub-tropical fruits to temperature. Tropical fruit tree species and climate change, 45.

12. Duchêne, E., Huard, F., Dumas, V., Schneider, C., & Merdinoglu, D. (2010). The challenge of adapting grapevine varieties to climate change. Climate research, 41(3), 193-204.
13. El Yaacoubi, A., El Jaouhari, N., Bourioug, M., El Youssfi, L., Cherroud, S., Bouabid, R., ... & Abouabdillah, A. (2020). Potential vulnerability of Moroccan apple orchard to climate change–induced phenological perturbations: effects on yields and fruit quality. International Journal of Biometeorology, 64, 377-387.
14. Feichtenberger, E., Bassanezi, R. B., Spósito, M. B., & Belasque Jr, J. (2005). Doenças dos citros. Manual de fitopatologia, 2, 239-269.
15. Fitchett, J. M., Grab, S. W., Thompson, D. I., & Roshan, G. (2014). Spatio-temporal variation in phenological response of citrus to climate change in Iran: 1960–2010. Agricultural and forest meteorology, 198, 285-293.
16. Ghini, R., Bettiol, W., & Hamada, E. (2011). Diseases in tropical and plantation crops as affected by climate changes: current knowledge and perspectives. Plant pathology, 60(1), 122-132.
17. Gordo, O., & Sanz, J. J. (2005). Phenology and climate change: a long-term study in a Mediterranean locality. Oecologia, 146, 484-495.
18. Grab, S., & Craparo, A. (2011). Advance of apple and pear tree full bloom dates in response to climate change in the southwestern Cape, South Africa: 1973–2009. Agricultural and Forest Meteorology, 151(3), 406-413.
19. Hayhoe, K., Cayan, D., Field, C. B., Frumhoff, P. C., Maurer, E. P., Miller, N. L., ... & Verville, J. H. (2004). Emissions pathways, climate change, and impacts on California. Proceedings of the national academy of sciences, 101(34), 12422-12427.
20. Hirschi, M., Stoeckli, S., Dubrovsky, M., Spirig, C., Calanca, P., Rotach, M. W., ... & Samietz, J. (2012). Downscaling climate change scenarios for apple pest and disease modeling in Switzerland. Earth System Dynamics, 3(1), 33-47.
21. IPCC (Intergovernmental Panel on Climate Change) (2014) Climate Change 2014: The Physical Science Basis. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press; 2014:996.
22. IPCC, (2007b). A report of working group one of the intergovernmental panel on climate change summary for policy makers. Intergovernmental Panel on Climate Change.
23. IPCC. Climate change (2007a), impacts, adaptation and vulnerability. Cambridge/New York: Cambridge University Press.
24. Jackson, J. E., & Hamer, P. J. C. (1980). The causes of year-to-year variation in the average yield of Cox's Orange Pippin apple in England. Journal of Horticultural Science, 55(2), 149-156.
25. Jangra, M. S., & Sharma, J. P. (2013). Climate resilient and apple production in Kullu valley of Himachal Pradesh. International Journal of Farm Sciences, 3(1), 90-97.
26. Jones, H. G. (2004). Irrigation scheduling: advantages and pitfalls of plant-based methods. Journal of experimental botany, 55(407), 2427-2436.
27. Jones, G. V., & Davis, R. E. (2000). Climate influences on grapevine phenology, grape composition, and wine production and quality for Bordeaux, France. American journal of enology and viticulture, 51(3), 249-261.

28. Kimball, B. A., Idso, S. B., Johnson, S., & Rillig, M. C. (2007). Seventeen years of carbon dioxide enrichment of sour orange trees: final results. Global Change Biology, 13(10), 2171-2183.
29. Kizildeniz, T., Pascual, I., Irigoyen, J. J., & Morales, F. (2018). Using fruit-bearing cuttings of grapevine and temperature gradient greenhouses to evaluate effects of climate change (elevated CO2 and temperature, and water deficit) on the cv. red and white Tempranillo. Yield and must quality in three consecutive growing seasons (2013–2015). Agricultural water management, 202, 299-310.
30. Klein, A. M., Vaissière, B. E., Cane, J. H., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C., & Tscharntke, T. (2007). Importance of pollinators in changing landscapes for world crops. Proceedings of the royal society B: biological sciences, 274(1608), 303-313.
31. Kumar R, B. M., & Saroj, P. L. (2019). Morphological, physiological, biochemical and molecular facet of drought stress in horticultural Crops.
32. Kumar, R.A.J.E.S.H. (2015). Climatic Issues Affecting Sustainable Litchi (Litchi chinensis SONN.) Production In Eastern India. Author Copy, 95.
33. Nath, V., Kumar, G., Pandey, S. D., & Pandey, S. (2019). Impact of climate change on tropical fruit production systems and its mitigation strategies. Climate change and agriculture in India: Impact and adaptation, 129-146.
34. Kumar, R., & Kumar, K. K. (2007). Managing physiological disorders in litchi. Indian Horticulture, 52(1), 22.
35. Lobell, D. B., Bonfils, C., & Duffy, P. B. (2007). Climate change uncertainty for daily minimum and maximum temperatures: a model inter-comparison. Geophysical research letters, 34(5).
36. Lovett, R. A. (2007). Climate change pushing tropics farther, faster. National Geographic News, 3
37. Mahouachi, J. (2007). Growth and mineral nutrient content of developing fruit on banana plants (Musa acuminata AAA,'Grand Nain') subjected to water stress and recovery. The Journal of Horticultural Science and Biotechnology, 82(6), 839-844.
38. Makhmale, S., Bhutada, P., Yadav, L., & Yadav, B. K. (2016). Impact of climate change on phenology of mango-the case study. Ecology, Environment and Conservation, 22(9), S127-S132.
39. Miller-Rushing, A. J., Katsuki, T., Primack, R. B., Ishii, Y., Lee, S. D., & Higuchi, H. (2007). Impact of global warming on a group of related species and their hybrids: cherry tree (Rosaceae) flowering at Mt. Takao, Japan. American Journal of Botany, 94(9), 1470-1478.
40. Mitra, S. K., Pathak, P. K., Debnath, S., Sarkar, A., & Mondal, D. (2008, August). Elucidation of the factors responsible for cracking and sunburn in litchi and integrated management to minimize the disorders. In III International Symposium on Longan, Lychee, and other Fruit Trees in Sapindaceae Family 863 (pp. 225-234).
41. Nath, V., Kumar, G., Pandey, S. D., & Pandey, S. (2019). Impact of climate change on tropical fruit production systems and its mitigation strategies. Climate change and agriculture in India: Impact and adaptation, 129-146.
42. Nawaz, R., Abbasi, N.A., Hafiz, I.A., Khalid, A., Ahmad, T., & Aftab, M. (2019). Impact of climate change on kinnow fruit industry of Pakistan. Agrotechnology, 8(186), 2.
43. Pan, H. H., & Shü, Z. H. (2007). Temperature affects color and quality characteristics of 'Pink'wax apple fruit discs. Scientia Horticulturae, 112(3), 290-296.

44. Parmesan, C. (2007). Influences of species, latitudes and methodologies on estimates of phenological response to global warming. Global change biology, 13(9), 1860-1872.
45. Moutinho-Pereira, J., Gonçalves, B., Bacelar, E., Cunha, J. B., Countinho, J., & Correira, C. M. (2015). Effects of elevated CO2 on grapevine (Vitis vinifera L.): physiological and yield attributes. Vitis-Journal of Grapevine Research, 48(4), 159.
46. Ploetz RC (Ed.). Diseases of tropical fruit crops. CABI 2003.
47. Powell, D. B. B. (1974). Some effects of water stress in late spring on apple trees. Journal of Horticultural Science, 49(3), 257-272.
48. Powell, D. B. B. (1976). Some effects of water stress on the growth and development of apple trees. Journal of Horticultural Science, 51(1), 75-90.
49. Rai, R., Joshi, S., Roy, S., Singh, O., Samir, M., & Chandra, A. (2015). Implications of changing climate on productivity of temperate fruit crops with special reference to apple. Journal of Horticulture, 2(2), 135-141.
50. Rajan, S. (2008). Implications of climate change in mango. Impact assessment of climate change for research priority planning in horticultural crops. Central Potato Research Institute, Shimla, 36-42.
51. Rajatiya, J., Varu, D. K., Gohil, P., Solanki, M., Halepotara, F., Gohil, M., ... & Solanki, R. (2018). Climate change: Impact, mitigation and adaptation in fruit crops. Int J Pure Appl Biosci, 6, 1161-1169.
52. Bhattacharjee, P., Warang, O., Das, S., & Das, S. (2022). Current World Environment.
53. Rodrigo, J., & Herrero, M. (2002). Effects of pre-blossom temperatures on flower development and fruit set in apricot. Scientia Horticulturae, 92(2), 125-135.
54. Rosenheim, J. A., & Tabashnik, B. E. (1991). Influence of generation time on the rate of response to selection. The American Naturalist, 137(4), 527-541.
55. Sakuma, F., Umeya, T., Tahira, K., Katagiri, S., & Hiyama, H. (1995). Effects of high temperature and/or gibberellin treatments during early fruit development on the occurrence of watercore in Japanese pear (Pyrus pyrifolia Nakai cv. Hosui). Journal of the Japanese Society for Horticultural Science, 64(2), 243-249.
56. Schaffer, B., & Gaye, G. O. (1989). Effects of pruning on light interception, specific leaf density and leaf chlorophyll content of mango. Scientia Horticulturae, 41(1-2), 55-61.
57. Schultz, H. (2000). Climate change and viticulture: a European perspective on climatology, carbon dioxide and UV-B effects. Australian Journal of grape and wine research, 6(1), 2-12.
58. Sdoodee, S., Lerslerwong, L., and Rugkong, A. (2010). Effects of climatic condition on off-season mangosteen production in Phatthalung Province. Department of Plant Science, Faculty of Natural Resources, Prince of Songkla University.
59. Sen, V., Rana, R. S., & Chauhan, R. C. (2015). Impact of climate variability on apple production and diversity in Kullu valley, Himachal Pradesh. Indian Journal of Horticulture, 72(1), 14-20.
60. Sharma, I. M. (2012). Changing disease scenario in apple orchards: Perspective, challenges and management strategies. In Proceedings of the National Symposium on Blending Conventional and Modern Plant Pathology for Sustainable Agriculture, Indian Institute of Horticultural Research, Bengaluru (p. 123).
61. Sthapit, B. R., Ramanatha Rao, V., & Sthapit, S. R. (2012). Tropical fruit tree species and climate change.

62. Surendar, K. K., Devi, D. D., Ravi, I., Krishnakumar, S., Kumar, S. R., & Velayudham, K. (2013). Water stress in banana-A review. Bulletin of Environment, Pharmacology and Life Sciences, 2(6), 1-18.
63. Swati, S., Shrivastava, P. K., & Singh, N. (2019). Influence of Regional Weather Changes on Major Fruit Production and Productivity of Navsari District of Gujarat State, India. Current Journal of Applied Science and Technology, 35(3), 1-8.
64. Tomasi, D., Jones, G. V., Giust, M., Lovat, L., & Gaiotti, F. (2011). Grapevine phenology and climate change: relationships and trends in the Veneto region of Italy for 1964–2009. American Journal of Enology and Viticulture, 62(3), 329-339.
65. Van Asten, P. J., Fermont, A. M., & Taulya, G. (2011). Drought is a major yield loss factor for rainfed East African highland banana. Agricultural water management, 98(4), 541-552.
66. Viti, R., Andreini, L., Ruiz, D., Egea, J., Bartolini, S., Iacona, C., & Campoy, J. A. (2010). Effect of climatic conditions on the overcoming of dormancy in apricot flower buds in two Mediterranean areas: Murcia (Spain) and Tuscany (Italy). Scientia Horticulturae, 124(2), 217-224.
67. Wang, S. Y., & Zheng, W. (2001). Effect of plant growth temperature on antioxidant capacity in strawberry. Journal of agricultural and food chemistry, 49(10), 4977-4982.
68. Woolf, A. B., Bowen, J. H., & Ferguson, I. B. (1999). Preharvest exposure to the sun influences postharvest responses of ‘Hass’ avocado fruit. Postharvest Biology and Technology, 15(2), 143-153.
69. Woolf, A. B., Ferguson, I. B., Requejo-Tapia, L. C., Boyd, L., Laing, W. A., & White, A. (1999). Impact of sun exposure on harvest quality of ‘Hass’ avocado fruit. Rev. Chapingo Ser. Hortic, 5, 353-358.
70. Omasa, K., Kai, K., Taoda, H., Uchijima, Z., Yoshino, M., Yoshino, M., & Ono, H. S. P. (1996). Variations in the plant phenology affected by global warming. Climate change and plants in East Asia, 93-107.

ISBN: 978-81-19149-59-9

6. Soil as A Net Carbon Sink

Immanuel Chongboi Haokip, M. Homeshwari Devi,

Sanjay Srivastava

ICAR-Indian Institute of Soil Science,
Bhopal.

Ampee Tasung

ICAR-RC for NEH Region,
Arunachal Pradesh Center, Basar.

Abstract:

Carbon (C) is a vital element and found in all life forms, and is regulated by the exchange between oceanic, geologic, pedologic, biotic and atmospheric pools largely in the form of CO2. Among this, the C stored in the upper part of the terrestrial are susceptible to anthropogenic activities and can act as a source as well as sink of C. As a C sink, soils have the potential to sequester 0.45 to 0.90 Pg C per year. This storage may be through soil inorganic carbon (SIC) and soil organic carbon (SOC), although the mechanism and extend of sequestration though SIC is largely unknown. Both the SIC and SOC storage can be affected by a wide number of factors, including climate, soil characteristics, and other management factors. Soil C stabilization is necessary for soils to act as a C sink, and occurs mainly through three mechanisms of soil C stabilization: physical, chemical, and biological. Theoretically, there exists a soil C saturation level, beyond which additional C input will only accumulate in labile soil C pools that have a relatively faster turnover. Saturation deficit is the difference between a soil's theoretical saturation level and the current C content. The proportion of C stabilized would be greater in soils with larger C saturation deficits, and the relative stabilization efficiency would decrease as C input level increased.

Keywords:

Carbon stock, storage, organic carbon, inorganic carbon, sequestration, saturation

6.1 Introduction:

Long-term changes in global weather patterns and temperatures caused by human activities, Carbon (C) is a vital element present in all living cells and is the major building block for life on Earth. It also occurs in numerous minerals found in soils and geological strata, rocks, ocean, fossil fuels, sedimentary deposits, terrestrial biosphere, and atmosphere [1]. The global C cycle is regulated by five main reservoirs, and there is an exchange of C mainly in the form of CO_2 from one reservoir to another: oceanic (~39000 Pg of C, 1 Pg = 10^{15} g), geologic (~5000 Pg C), pedologic (soil) (~2500 Pg C), biotic (~560 Pg C) and the atmospheric reservoir (~750 Pg C) [2]. The stored C in terrestrial biosphere (soil, vegetation), atmosphere, and upper layers of ocean are active in nature and are susceptible to anthropogenic activities whereas those in the sedimentary rocks are relatively inert, and change over a scale of millions of years [1].

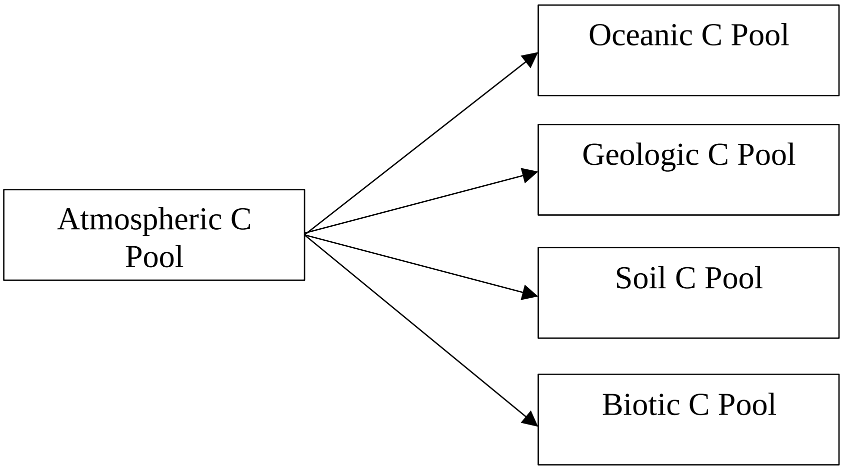


Figure 6.1: Principal carbon reservoirs on the earth [1].

6.2 Soil Carbon Pools:

Soil C pools can be broadly divided into soil inorganic carbon (SIC) and soil organic carbon (SOC). Upto 100 cm soil depth, the SOC is predicted to be 1200-1600 Pg, whereas SIC is estimated to be about 695-940 Pg [3]. In most regions, SOC is the major contributor to total soil C except in dryer regions such as arid, semiarid and/or semi-humid areas where SIC, mainly in the form of Ca and Mg carbonates forms the dominant pool [4]. In arid and semiarid areas, the SIC might be 2 to 10 times higher than that of SOC [5].

The SIC is further divided into primary carbonate, also known as lithogenic inorganic carbon (LIC), and secondary deposited carbonate known as pedogenic inorganic carbon (PIC). The LIC are inherited from parent materials whereas PIC is formed through dissolution and precipitation of carbonates in parent materials and derived from the weathering of $CaSiO_3$ [6].

Compared to SIC, the SOC gained more attention because the SOC pool is more reactive, highly dynamic, played vital role in soil quality, fertility, productivity, climate change mitigation, and reflect the soil and ecosystem processes [1]. The SOC is divided into different pools depending on their mean residence time (MRT) in the soil. The labile C have the quickest turnover among the different SOC pools and its MRT ranged a few days only. It may consist of simple sugars, simple organic acids and microbial metabolites that can be easily mineralized. The slow or intermediate consists of structural plant residues and physically stabilized C that turnovers in decades whereas the resistant fraction are the inert fraction largely resistant to decomposition by soil microbes with MRT of thousand years [7]. The labile SOC is subjected to rapid mineralization by soil microbes while the stable and recalcitrant remains chemically inert and microbial transformation [8].

6.3 SIC As A Net C Sink:

Soil serve as an important C sink with the ability to sequester 0.45 to 0.90 Pg C per year [2]. Soil can sequester C either by direct or indirect sequestration. Direct soil C sequestration occurs by inorganic chemical reactions that convert CO_2 into SIC compounds such as Ca and Mg carbonates, while indirect C sequestration takes place when CO_2 in the atmosphere is removed through photosynthesis and stored in the soil after decomposition. During the formation of LIC and PIC, one mole of carbonate requires two moles of carbonic acid and liberate one mole of CO_2 to the atmosphere (Eq (1)) [9]:

$$Ca^{2+} + 2HCO_3^{-} \leftrightarrow CaCO_3 + H_2O + CO_2\uparrow \quad (1)$$

This reaction will act as a net C sink if the source of CO_2 in the HCO_3^- is respiration of soil microbes or decomposition of organic matters in soil. However, this reaction will become a source of atmospheric CO_2 if the HCO_3^- is from irrigation water [10]. During the formation of secondary carbonate from $CaSiO_3$ weathering, two moles of atmospheric CO_2 are converted to bicarbonate (HCO_3^-) (Eq (2)). This can lead to the sequestration of atmospheric CO_2 in soils [11].

$$CaSiO_3 + 2CO_2\downarrow + 3H_2O \rightarrow HCO_3^{-} + Ca^{2+} + H_4SiO_4 \quad (2)$$

However, the rate of this reaction in soil is extremely slow and are typically on the order of 50–500 mol Ca^{2+} ha^{-1} yr^{-1} [12]. Even if soil management practices could hasten the speed of the reaction to twice or thrice, only 0.001–0.01 t C-CO_2 ha^{-1} yr^{-1} will be consumed which suggest that this reaction is of minor importance as the global C sink [9]. As a result, many studies do not consider SIC as a C sink, probably due to the longer time needed for changes in carbonates compared to SOC. However, recent studies have demonstrated soil organisms to be an important component in the formation of secondary carbonate and may quicken the turnover of the SIC too [13].

6.3.1 Factors Affecting SIC As a Net C Sink:

The ability of the soil to store C as carbonates depends on factors such as climate, soil characteristics and other management factors.

A. ***Climatic Factors:*** Climatic factors such as precipitation and temperature significantly affect the processes of evaporation and leaching, which in turn influence the dissolution and re-precipitation of carbonates [14]. At high temperature and low precipitation, such as arid and semi-arid areas, there is accumulation of PIC due to slow carbonate dissolution and leaching [10]. Increasing aridity also encourages formation of petrocalcic and calcic strata as there is little water to leached down the accumulated carbonates [15]. The quantity and depth of carbonate accumulation is also affected by the amount and frequency of precipitation received in the region. Thus, the time taken to store the same quantity of SIC will be longer in arid areas and shorter in humid area [16].

B. ***Topography and Landscape:*** The topography and position of the soil affects the amount, rate and depth of carbonate accumulation in soil. In general, carbonates may or may not be present in the upper parts of a hillslope, while thick calcretes may be formed at toeslope [17]. Stability of a landscape also influences the amount and depth of carbonate accumulation in the profile. Unstable soil surfaces prone to erosion and water movement leads to less carbonate accumulation and their deeper localization [10].

C. ***Vegetation and Soil Organisms:*** The presence of roots and microbes in soil modulates the concentration of CO_2 and pH in soil. At the vicinity of the roots, the CO_2 increases a hundred-fold accompanied by lower pH [18]. This increase protons and carboxyl groups released by the roots carbonate dissolution five to ten-fold [10]. Carbonate solubility increases near the roots because the CO_2 concentration is almost 100 times higher in the rhizosphere. Soil microorganisms can also produce a visible accumulation of carbonates within a few days if Ca^{2+} ions are available in solution, bacteria. Extracellular polymers such as polysaccharides and amino acids may also control the formation and morphology of $CaCO_3$ [20].

D. ***Land Cover and Land Use Change:*** The characteristics of vegetation and changes in land use also affects the SIC deposition in soil. Among the different natural vegetation, desert has the highest SIC, followed by grassland, farmland, marsh, shrubland, meadow, and forest [21]. Conversion of natural vegetation to agricultural use was found to increase not only the loss of even the most recalcitrant SIC, but also redistributes it in the profile [22]. In China, losses of SIC from 51% of total cultivated soil was estimated at about 0.5–4.0 kg C m^{-2} [11].

E. ***Soil acidification through fertilizers:*** Acidification of soil due to long-term application of acidic fertilizers or other soil acidifying agents also could affect the SIC sequestration in soil. The decrease in soil pH aid the dissolution in the carbonates thereby resulting in lower SIC accumulation in the surface soil [23].

F. ***Soil Characteristics:*** Soil physicochemical properties such as by soil texture, structure, pH, ion strength and soluble Ca^{2+} and Mg^{2+} affects the accumulation of carbonates. The texture and structure of a particular soil affects the infiltration, percolation, translocation and the quantity of water it can absorbed which thereby influenced the amount and depth of carbonate accumulation in soil [24]. The soil pH influences the size of the carbonate crystal, morphology and bicarbonate/carbonate ratio in soil [25]. As the soil pH increases above 7, there is lower bicarbonate/carbonate which favours carbonate crystal formation and precipitation of smaller crystals into bigger ones [25]. The ionic strength of different salts also affect the rate of carbonate dissolution and precipitation, and as a result, carbonate dissolution in saline soils takes longer and occurs earlier compared to salt-free soils. The pattern of carbonate distribution in soil is similar to the pattern of the Ca^{2+} and Mg^{2+} present in soil, but the relation is stronger with soluble Ca^{2+} Also, higher concentration of soluble Ca^{2+} and Mg^{2+} in soil favours carbonate precipitation [26].

6.4 SOC As a Net C Sink:

For the SOC to act as a net C sink, atmospheric CO_2 must be transferred into plant biomass and its conversion into long-lived stable and recalcitrant SOC through humification that is resistant to changes [27]. This process primarily relies on removal of atmospheric CO_2 and storage in the plant biomass through photosynthesis, decomposition of the pant biomass in the soil and storage as stable and protected fraction SOM [28].

Thus, SOC sequestration could be achieved by increasing above and below-ground vegetation in a unit land area, retaining the biomass to be converted into SOC, protection and stabilization of the SOC against decomposition and erosion [27].

6.4.1 Factors Affecting SOC Sequestration:

SOC sequestration depends on many factors including climate, soil depth, soil texture and mineral present, nutrient content, topography and aspects, and the initial content of SOC [27].

A. ***Climate:*** Climatic factors such as temperature and precipitation enormously affect soil C sink capacity through its effects on C inputs through biomass production and C losses through decomposition. Temperature directly affects SOC sequestration by increasing the rate of organic matter decomposition whereas presence of moisture slows down the decomposition thereby facilitating in the accumulation and stabilization of SOC [29]. As a result, decomposition of SOC is more rapid in tropical regions than in temperature regions. Also, soils of humid regions generally have higher SOC content that those from dry regions which could be attributed to higher biomass production in humid regions [27]. It is estimated that the decrease in SOC with per degree increase in mean annual temperature is 1896 kg ha^{-1} [30]. Soils of humid regions are often richer in SOC than soils of dry regions and this can be due to a greater production of biomass and lesser decomposition in humid regions [31].

B. ***Soil Properties:*** Soil texture, mineralogical compositions, depth and types, pH, bulk density and porosity determine the amount of C sequestered. Soil texture (amount and type) is key soil property that govern the potential of the soil to sequester SOC in soils. Soils with more clays could sequester more C, and among the different types of clay; smectitic clays are more potent in C accumulation and sequestration [32]. Irrespective of soil types, higher SOC are found at the surface soil and decreases with increasing depth of profile except in some vertisols due to natural mixing of soil [33]. Among the different soil orders, soils with low organic matter content such as aridisols have lowest SOC whereas highest SOC is found in histosols [34]. Soil mineral composition determine the quantity of SOC stored in soil, its turnover time, and atmosphere-ecosystem C fluxes. The presence of multivalent cations such as Ca^{2+}, Al^{3+} or Fe^{3+} leads to accumulations of SOC in comparison to other cation types [35]. Soil pH affects microbial enzymatic efficiency, and mineralization of SOM is most rapid at neutral pH, suggesting that both extremely alkaline and acidic condition are detrimental for the growth of microbes in soil [36]. Soil porosity affects the movement and availability of water and air in soil thereby affecting the decomposition and accumulation of SOC [37].

C. ***Management Factors:*** The change of forestland to cultivated land destroys the soil aggregate structure, which enhances SOM mineralization and CO_2 emissions that subsequently reduce the soil C sink capacity. It has been estimated that 303 t C ha^{-1} is retained in tropical forests [38], 66 t C ha^{-1} and 44 t C ha^{-1} in temperate and boreal forests, respectively [39]. Clearance of forests for cultivation or other uses as result of urbanization in the past one and half century was estimated to result in losses of about 136 (±55) Gt C in to the atmosphere [40]. Cropping and their management practices that increase C input and reduce the release of CO_2 to the atmosphere will aid in building up the SOC content of soils. Thus, suitable management practices under different land-use and agro-climatic conditions is important to sequester C in the soil [41].

6.5 Crop Management Practices for Improving Soil C Sink Capacity:

Adoption of improved practices can increase the C sequestration in soil. Some of these practices discussed in brief.

A. ***Adoption of Conservation Agriculture CA):*** According to the FAO, conservation agriculture (CA) system combines minimum soil disturbance, maintaining a permanent soil cover with crop residues and/or cover crops, and diversification of plant species through varied crop sequences and associations involving at least one legume crop. Excessive tillage is responsible for disrupting soil aggregate, and exposes particulate organic matters (POM) protected within soil macroaggregates to microbial decay [42]. When the number of tillage is reduced through the adoption of reduced tillage or no-till, SOC exposure to decomposition by microbes is reduced thereby reducing the loss of SOC from the soil [43].

   Adoption of reduce tillage or no-till have been considered an important C sequestration tool. In the US, SOC sequestration under no-till widely varies from 0.45 Mg C ha^{-1} y^{-1} [44] to 0.27 Mg C ha^{-1} y^{-1} in the South-East, from 0.27 to 0.40 Mg C $ha^{-1}y^{-1}$in the North West and between 0.30 and −0.07 Mg C $ha^{-1}year^{-1}$ in the North [45]. The worldwide C sequestration potential under no-till system is projected to be around 0.57 Mg C $ha^{-1}y^{-1}$ [46]. Data from 69 paired conventional tillage and no-till showed that adoption of no-till increased soil C by 3.15 (± 2.42) t ha^{-1} in the surface soil, but declined by 3.30 (± 1.61) t ha^{-1} in the 20–40 cm soil layer [47].

   Overall, adopting NT did not enhance soil total C stock down to 40 cm. in vertisol of Central India, no-till (4.22 ± 0.133 Mg C ha^{-1}) resulted in significant increase of SOC content in soil as compared to reduced tillage (3.84 ± 0.123 Mg C ha^{-1}) and conventional tillage (3.65 ± 0.04 Mg C ha^{-1}) in the surface 5 cm layer [48]. It is estimated that, CA could increase SOC stock by 1.8 t C ha^{-1} yr^{-1} in the first 10-years of adoption [31]. Returning crop residue back to the soil is done either through incorporation or retention which provide large inputs of C to soils and enhance SOC. Maintaining a permanent soil cover through addition of crop residue accompanied by no-tillage improve the soil physical, chemical and biological properties with reduced greenhouse gas emission especially CO_2 [25]. Meta-analysis results indicated that residue return in China increased SOC storage by 11.3% compared to residue removal [49]. It can sequester about 14 to 30 t CO_2e ha^{-1} in European Union [50]. One of the main disadvantages of improving C sequestration through crop residue return is the potential of elevated N_2O emission that offset the benefits from C sequestration [51]. In soils with very low fertility, the soil may not be able to produce sufficient crop biomass to significantly increase the C sequestration in the soil [52].

   Transitioning from conventional agriculture to no-till or minimum tillage could also possibly result in yield penalty thereby affecting the quantity of crop residue available for retention or incorporation with very less or no C sequestration [53]. Diversifying the cropping system with legumes is important to improve SOC content in soil. Inclusion of suitable crop species such as legumes which have more root systems in the rotation rather than a monoculture system can add more biomass into the system and is often accompanied by enhancing the soil C sequestration [54, 55]. Biomass addition into the soil through roots of a cover crop in no-till system was found to have a close relationship with the increase in SOC stocks over the years [55]. Meta analyses of 139 plots at 37 different sites showed higher SOC sequestration under cover crop than in the reference croplands [56].

B. ***Organic Manures:*** Composts and farmyard manures are a good source of organic matter and their application to soil could be an effective way of enhancing the SOC contents of soil, both by virtue of the added C in the amendment itself and through improvement of soil properties such as nutrient transformation and supply, soil–water balance control or buffering of pollutants. Both single addition of large dose and multiple addition of smaller dose of stable compost showed similar rates in SOC sequestration but the response was highest in the first thirty years in case of single addition but build up continued for over a century in the stable and recalcitrant pools [57]. Meta analyses of 101 research findings encompassing over 592 treatments disclosed that application of organic manures could improve the SOC stock by 10.7 Mg C ha^{-1}, which is 35.4% from the control [58].

C. ***Mulching:*** Mulching is one of the most sustainable approaches in sequestering C. Not only this, organic mulching using crop residues also keep the soil thermal regime at moderate level, reduce evaporation and erosion, improve soil health and nutrient availability. Saroa and Lal [59] reported that the rate of mulch application had a significant positive effect on the SOC concentration in 0–5 cm depth and was highest when soil received 16 Mg C ha^{-1}.

D. ***Organic Agriculture:*** Farming practices affect both input and turnover rates of SOM. Organic farming systems is a farming system devoid of the use of any chemical inputs such as chemical fertilizers and pesticides to improve ecosystem functions, animal and human health. It relies on the use of organic products instead of harmful chemical to protect crops and increase productivity. Many studies have reported the positive effects of organic agriculture [60], while inconsistent or unreliable conclusions have also been reported [61]. Analysis of 68 datasets revealed that after conversion of conventional system to organic system, the mean increase in SOC content was 2.2% per year [62]. Another analysis of datasets from 74 studies found that SOC stocks were 3.50±1.08 Mg C ha^{-1} higher in organically managed soils than in inorganically managed soils [63].

E. ***Agroforestry:*** Association of trees with crops on the same land-unit could improve soil C sequestration compared with pastures or field crops and is affected by the number of site-specific biological, climatic, soil, and other management factors. Many authors believed that agroforestry systems have a higher potential to sequester C in soil. This inference can be drawn from the huge amount of atmospheric CO$_2$ captured by trees during photosynthesis and storage of C in their biomass and acts a potent C sequestration tool. It is estimated that the C sequestration potential in agroforestry system can range from 1.25 to as high as 173 Mg C ha^{-1} y^{-1} [64].

F. ***Integrated Nutrient Management (INM):*** Integrated nutrient management (INM) is the judicious use of both organic and chemical inputs to enhance farm productivity and production. These chemical and biological inputs acts in synergy to improve crop protection, nutrient availability, soil properties and health, and thus the crop productivity. INM has been established as an efficient management practice that can enhance SOC [65]. In an inceptisol, long term application of recommended dose of primary nutrients with farm yard manure for over four decades resulted in maximum increase SOC and organic matter compared with the unfertilized one [66]. An increase of 17% SOC in the top 15 cm layer was observed when 20 t ha^{-1} of farm yard manure was along with mineral fertilizers after 32 years in the upper Indo-Gangetic Plains [67].

Compared with the use of chemical fertilizers alone, INM was found to improves the soil C sequestration by 2.3 Mg C ha^{-1} [68].

G. ***Restoration Of Degraded Lands:*** Restoring degraded and abandoned lands could be an important tool for sequestering C in soil through ecological succession [2]. Restoration of degraded land can promote soil and vegetation health thereby increasing C stocks both in soil and in biomass. Lal and Bruce [69] estimated that 100 M ha of degraded land worldwide are unfit for cultivation. If the C sequestration rate of these land to be around 0.25 t C ha^{-1}, it may be estimated that this degraded land can be used to sequester about 0.025 Gt C $year^{-1}$. In India, it has been projected that restoration of degraded soils could effectively sequester 9.8–13.9 Tg C ha^{-1} [52]. Meena et al. [70] reported that creation of agricultural ecosystem models on degraded land increase the C sequestration potential; and highest CO_2 sequestration (Mg C ha^{-1}) was found in the forest land system (115.1) followed by karonda (*Carissa carandas*) cultivation land (41.1), guava + green gram cultivation land (38.9), mono-cropping wheat cultivated land (22.0), mono-cropping rice cultivation land (17.6), pasture land (9.40) and lowest in seasonal pond area (0.87).

H. ***Biochar Application:*** Biochar is a stable C compound produced as a byproduct of pyrolysis of biowaste. Due to its inertness, biochar application is another way of increasing soil refractory organic C pool. Meta analysis showed that biochar derived from crop residue increased SOC stock and contributes largely to the stable pool [71]. Result from 64 studies with 736 individual treatments showed a mean increase in SOC stocks by 13.0 Mg C ha^{-1} [72]. However, there are also some reports that biochar application may accelerate degradation of both native SOC and biochar C, and may not an effective tool for C sequestration. The effect of biochar in increasing the SOC contents of soils were higher in soils with higher clay contents than those with lower clay contents [72]. Recently, the potential of biochar in the restoration of degraded lands (e.g., saline soils and mine tailings) has been confirmed [73].

6.6 Assessment of Soil C Sequestration:

Assessment on soil C stock requires data on soil bulk density (Mg m^{-3}), concentration of soil SIC or SOC expressed as % (w/w) basis and soil depth (in m). The C sequestration is usually calculated in terms of increase in C stock in soil.

$$\text{SOC (Mg ha}^{-1}) = \text{SOC (\%)} \times \text{Bulk density (Mg m}^{-3}) \times \text{Depth (cm)} \tag{3}$$

Total soil C is determined by high temperature combustion in CN analyser [74] while SOC is determined by [75], and SIC is the difference between total and organic C.

6.7 Soil C Stabilization:

For soils to sequester and act as a C sink, soil C needs to be stored in stable C pools. Soil C stabilization is critical for the determination of the soil C sink capacity under different climatic and management regimes. Soil C stabilization that retards the decomposition of SOM by reducing the C mineralization rate through three main mechanisms: (a) physical, (b) chemical, and (c) biological (biochemical) [76].

~~*A.*~~ ***Physical Protection:*** In physical stabilization, stabilization of soil C is due to physical protection of the soil C within the macro (>250 μm) and micro-aggregates (<250 μm) through their intimate association with clay and amorphous minerals in soil. This type of protection limits the accessibility of soil microbes and their enzyme from mineralizing it. It also obstructs movement of oxygen, water and other substrates necessary for microbes.

B. ***Chemical Stabilization:*** Chemical stabilization refers to C associated with the formation of primary organomineral complexes that are chemically inert from mineralization or inherently recalcitrant such as that of lignin. This is the dominant mechanism controlling the soil C stabilization and is central to soil C sequestration [77]. Chemical stabilization in soil is greatly influenced by amorphous and poorly crystalline Fe/Al mineral components in soil, and is the main mechanism leading to soil aggregate formation [78].

C. ***Biological Stabilization:*** Biological stabilization of SOC refers to the complex inherence chemical structure of the biomolecule, which is a function of intra- and inter-structural bond strength, their degree of regularity in occurrence and aromaticity [42].

6.8 Soil C Saturation:

Soil C Saturation is a concept that suggests that soils C capacity is not unlimited and this is determined by the reactive mineral surface area available for retaining SOC. Beyond the maximum limit, the soil will not further sequester any C [79]. Many SOC models assume that their soil C sequestration increase linearly with increase in C added to the soil irrespective the antecedent SOC content [42]. Practically, this was observed to be true in many cultivated soils that have low and moderate SOC status. In contrast, soil inherently high in SOC status did not show any rise in the SOC content following continued exogenous C input that suggest that the SOC have eventually reach equilibrium known as soil C saturation level. This phenomenon is also visible from some long-term studies that shows signs of C saturation as evident from the non-responsive nature of SOC status to continuous input of C sources. This suggests that with increasing C supply, the SOC stock will reach the upper limit beyond which the SOC accumulation rate will start decreasing. Beyond this level, additional C input will only accumulate in labile soil C pools that have a relatively faster turnover and will not add to the stable C pools in soil. The difference in SOC levels between the SOC saturation level and present SOC level is known as SOC saturation deficit [79]. The larger the deficit, the higher will be the proportion of SOC stabilized in soil.

6.9 Conclusion:

Soil plays a crucial role as a net C sink, actively sequestering and storing C from the atmosphere after its stabilization into inert and recalcitrant forms. Through the accumulation of SOC and SIC, soils have the potential to mitigate climate change by reducing atmospheric CO_2 levels. The quantity of C sequestered in soil is affected by climate, soil site characteristics and management factors. Among the various agricultural practices, practices that improve soil C sink capacity includes conservation agriculture, retention of crop residues, organic farming, crop rotation, mulching, restoration of degraded land, agroforestry, etc. The ability of the soil to sequester C is not unlimited. It is mainly affected by initial soil C status and proportion of C stabilized will be greater when the deficit is higher.

ISBN: 978-81-19149-59-9

7. Agroforestry as Answer to Rising Carbon Emission in Agriculture

Amarjeet Singh Bhogal, Shibani Ritusmita Borah

Ph.D. Scholar,
Department of Plant Breeding and Genetics,
Assam Agricultural University.

Hrishikesh Nath, Indrani Debasmita Borah

Ph.D. Scholar,
Department of Agronomy,
Assam Agricultural University.

Abstract:

Carbon emission is a major threat to the ecosystem as it triggers the global warming resulting in rise of the atmospheric temperature, contributing towards climate change. IPCC explains five key sectors as industry, buildings, energy, transportation, and AFOLU responsible for maximum release of carbon emission. Agroforestry is a critical component in mitigating the negative effects of changes in the climate. Agroforestry offers a unique chance to meet the mitigation as well as adaptation goals for climate change. Agroforestry systems lower greenhouse gas emissions from soils by storing carbon in soils and woody biomass. Recent research in various agroforestry systems in various ecological conditions has highlighted the need of agroforestry in restoring carbon stocks in biomass above ground and soil, as well as enhancing economic stability and diminishing vulnerability to climate change.

Keywords:

Agro-forestry, Climate Change, Carbon emission, Diminishing, Vulnerability

7.1 Introduction:

Agroforestry is an integrated approach to growing trees with agricultural practices. It is the cultivation and utilization of forest trees with crops, including livestock rearing, in an agricultural system. American economic geographer J. Russell Smith first formally described agroforestry in his book entitled “Tree Crops: A Permanent Agriculture”(1929)[1]which he saw as a solution to the destructive erosion that frequently followed the cultivation of sloping lands[2] It is a dynamic, ecologically oriented bio-resource management strategy that diversifies and maintains productivity while also building social institutions via the inclusion of woody perennials within farms and agricultural landscapes [3]. Carbon Emissions for a specific duration represent the total carbon equivalent greenhouse gas emissions associated with the consumption of energy during that period, represented in metric tonnes of equivalent carbon dioxide.

Carbon emissions are the most significant contributors to greenhouse gas (GHG) emissions, which trigger environmental degradation [4]. They are frequently assigned to the five primary sectors defined by the IPCC as industry, buildings, energy, transportation, and AFOLU [5].

7.2 Current Scenario Under Agroforestry:

Agroforestry has been utilized in India as a means of existence and a source of income from time immemorial. Boosted agricultural forestry in the entire nation can help to solve certain of the most serious difficulties brought on by climate change (Dhyani*etal* 2016, CAFRI Vision 2015) [6][7]. Aside from its environmental benefits, crop forest cultivation meets around fifty percent of the necessities for fuel wood, 65 percent for small timbers, 70-80 percent for plywood, 60 percent raw material for paper pulping and 9-11 percent for green fodder for cattle (NRCAF 2013) [8].

The ultimate objective of agroforestry for climate change is to enhance and sustain the standard of living of impoverished rural economy of farmers. Tree-crop integration can benefit the farming community by providing consistent revenues, diversifying land use and local skills, increasing nutritional and livestock security, and improving ecological health [9]. In the Haridwar and Yamuna Nagar areas of North India, agri-silviculture exhibited a B: C ratio of 3.85 with a net return of 1.97 lakhs ha-^{1}[10]. In the coastal states of the country, *Casuarina equisitifolia* has become a significant fast-growing tree species that is highly suitable for agroforestry. Groundnut + *Casuarina*-based system generated around 89,000 net annual returns per hectare, (Saravanan and Vijayaraghavan 2014)[11].

The versatile *Melia azedarach* tree species is well-known for its insecticidal and curative properties and is frequently grown along bunds and canals in irrigated areas, and the leaves are fed to goats. *Melia azedarach* grown with a soybean crop generated a net return that was 19% greater than that of a soybean crop alone [12][13]. Likely, sorts of agroforestry systems are improving farmer livelihoods, particularly in rainfed areas. Agroforestry systems can improve farmers' socioeconomic scenario while also contributing to the region's overall expansion. This is evident in terms of higher revenue and the creation of new job possibilities (Dhyani et al 2003) [14]. Agroforestry provides a unique opportunity to fulfil both climate change and mitigation as well as adaptation aims. Agroforestry systems minimize greenhouse gas emissions from soils by storing carbon in soils and woody biomass [15]. Recent investigation regarding different agroforestry activity systems in multiple ecological conditions has drawn attention to the significance of agroforestry systems for generating and storing carbon stocks in aboveground biomass and soil, as well as in boosting income and reducing risk to climate change. Agroforestry has the largest potential of any land use assessed for reducing carbon from the earth's atmosphere.

India recently declared voluntary commitments to the United Nations Framework Convention on Climate Change (UNFCCC) for climate change mitigation measures in the form of Intended Nationally Determined Contributions (INDCs). India plans to reduce GDP emissions by 33-35% by 2030 compared to 2005 levels. The aim will be met by expanding forest cover through afforestation and agroforestry, along with increasing the share of sources of renewable energy such as biodiesel, bioenergy, and solar energy [16].

7.3 Impact of Carbon Emission on Agriculture and Forestry:

A direct significant adverse impact of carbon emission has been observed on agriculture and forestry worldwide. Global CO2 emissions from fossil fuel burning are higher than ever, having grown 1000 times over the previous two centuries. Approximately 270 (30) Pg C was emitted towards the earth's atmosphere as carbon dioxide in an outcome of combustion of fossil fuels and cement manufacturing from 1858 to 1998.

Land-use change, including as forest loss, biomass burning, and soil cultivation, on the other hand, has emitted around 136 (55) PgC [17]. The CO_2 emissions generated by land-use change include soil and biotic pool depletion. With roughly 1550 Pg of SOC as well as 750 Pg of soil inorganic carbon (SIC) to a depth of one meter , global soils are the third largest of the 5 global C pools (after oceanic and geologic pools)[18].Thus, at a one-meter depth, the total soil C pool is 2300 Pg, representing 41 times the amount of the biotic pool (560 Pg) and threefold the atmospheric pool (760 Pg). The SOC pool is highly reactive, acts as the primary site of action for the bulk of pedological and edaphological operations, and is susceptible to both natural and human perturbations. As a result, the transformation of ecosystems to agricultural habitats reduces the SOC pool. The drop is driven by disruptions in C and other element cycles (for example, N, P, S), as well as components of hydrologic and energy budgets. A drop in energy restored to the soil, an increase in mineralization rate due to modifications to moisture in the soil and temperature regimes, as well as an elevation in losses due to leaching and erosion all contribute to a rapid decline in the SOC pool within agricultural ecosystems. The majority of farming soils have reduced by 50% to two-thirds of their original SOC pool. Soils with high antecedent pools lose more than soils with low antecedent pools, and soils in warm and dry climates lose more than soils in cool and moist climates, and practices of low-input subsistence agriculture lead to soil fertility mining rather than science-based or commercial agricultural systems that maintain a positive nutrient balance in soil. Soil erosion is responsible for 19-32 Pg (26 9 Pg) of the anthropogenic depletion from the soil C pool[19]. SOC pools in the majority of agricultural soils are now lower than their maximum capacity due to historic loss induced by historical agricultural practices and soil management practices. The process of taking CO_2 from the atmosphere and preserving it in long-lasting carbon reservoirs is known as carbon sequestration. Chemical reactions underpin abiotic C sequestration methods such as chemical scrubbing, capture and injection into geological formations and deep oceans, and natural creation of secondary carbonates (Halmannand Steinberg, 1999; DOE, 1999) [20][21]. The biotic C sequestration methods are biological reactions that collect atmospheric C and store it in long-lived pools (e.g., biotic, soil, and oceanic). The primary biotic mechanism that finally transports C into the biotic, soil, and marine pools is photosynthesis. Photosynthate and biosolids are transferred into the soil C pool by humification, aggregation, and eluviation into the subsoil, where they are shielded from human disruption. The exchange of organic C into humus through metabolic and physical mechanisms in the pedosphere is known as soil C sequestration.

The aim is to restore greater biomass to the soil that can be mineralized, to transfer C to the subsoil away from the region of disturbance, and to encourage the formation of organometal aggregates or solid micro and macro aggregates. Enhancing the SOC pool in farm and damaged soils can boost soil health and crop yield while also being environmentally friendly.

When the SOC pool in a soil has been depleted by prior land uses, the SOC pool typically responds linearly to carbon restoration [22][23][24][25]. Carbon storage in soil is a win-win method that boosts productivity, improves environmental management, and reduces global warming[26].

7.4 Sustainable Measures to Mitigate Carbon Emission:

Optimum utilization of available resources with a minimal disturbance to the ecosystem should be carried out to mitigate the carbon emission including the following-

A. **Afforestation and reforestation:** A component of a forest restoration and afforestation programme is the planting of forest trees in agricultural areas. As a result, by accumulating carbon in trees as they develop (carbon stock), the effort serves to lower the concentration of green house gases in the environment.

B. **Reducing the use of Nitrogenous fertilizers:** To increase crop yields, food industry depends on N fertilizer, yet this practice is unsustainable. The synthetic N fertilizer supply chain was predicted to emit 1.13 $GtCO_2e$ in 2018, making up 10.6% of crop-related emissions and 2.1% of overall emissions. N fertilizer manufacturing generated 38.8% of the overall synthetic N fertilizer-related emissions, with field emissions accounting for 58.6% and transportation accounting for 2.6%. 62% of worldwide emissions were attributed to India, China, the US, & the European Union. In regional food production, historical trends demonstrate a large disparity in general and individual N consumption. Reducing total N fertilizer output and usage, as well as changing to organic crop production, provides enormous reduction potential as well as in many cases, achievable emission reduction potential [27].

C. **Shifting to Battery Electric Vehicles (BEV):** Modern automobiles are significant contributors to carbon emissions. The pollution emitted by motor vehicles hurts the global ecology. According to researchers, BEVs are a vital technology for lowering GHG emissions and fulfilling the goal of reducing the carbon content of the energy sector [28].

D. **Maximum utilization of renewable energy:** In both the immediate and long-term, renewable energy cuts CO_2 emissions. However, the combustion of petroleum and natural gas increases CO_2 emissions. The usage of renewable energy improves environmental quality significantly by lowering CO_2. The optimal use of renewable energies such as wind power, solar power, water energy, and so on over petroleum and coal has become crucial for lowering carbon emissions since they generate less pollution and so contribute to enhancing climatic quality by lowering pollution. In both the immediate and long-term, renewable energy cuts CO_2 emissions. However, the combustion of petroleum and natural gas increases CO_2 emissions. The usage of renewable energy improves environmental quality significantly by lowering CO_2. The optimal use of renewable energies such as wind power, solar power, water energy, and so on over petroleum and coal has become crucial for lowering carbon emissions since they generate less pollution and so contribute to enhancing climatic quality by lowering pollution [29][30].

E. **Recycle and reuse:** Natural aggregates produce the most CO2 due to the petroleum that's used in their distribution. By substituting 68% of all natural aggregate with recycled aggregates, CO2 emissions can be reduced by 53%. Construction is one of the commercial sectors that has the greatest environmental impact and contributes to warming temperatures because it consumes a large number of substances, supplies, and energy, almost all of which come from non-renewable sources. In this sense, the production of building materials accounts for about 10% of global energy consumption. Establishment and destruction phases contribute approximately 40% of solid waste generated in industrialized nations, while the construction goods operation phase emits roughly 40% of global glasshouse gases (GHG), establishing building manufacturing as one of the commercial sectors with the highest global energy consumption[31].Thus, recycling and reusing resources can help to reduce carbon emissions to a large extent.

7.5 Capturing Carbon in Tree Biomass:

The rate of biomass carbon stored in the silvi-pastoral system was 6.72 t C/ha/yr in 8 years, which is two times more than the rate of 3.14 tC/ha/yr from natural grassland, according to comparative studies conducted by NRCAF [32] on the generation of biomass from natural grassland and silvi-pastoral system composed of *Albizia amara, Dichrostachys cinerea,* and *Leucaena leucocephala* as woody perennial. Approximately 16,400 t/yr of carbon is stored annually in agricultural forestry, which includes species like *Eucalyptus sp*., *Populus deltoides, Tectona grandis,* and *Anthocephalus chinensis* trees [33].

In a natural grassland in semi-arid Uttar Pradesh, introduced species of *Albizia procera, Eucalyptus tereticornis*, *Albizia lebbeck*, *Embilica officinalis*, and *Dalbergia sissoo* accumulated 8.6, 6.92, 6.52, 6.25, and 5.41 t/ha/yr of biomass [34]. Here, silvipasture held 1.89–3.45 tC/ha of the system's carbon while pure pasture held 3.94 t C/ha of it.

7.6 Potential of Carbon Sequestration at The Agro-Forestrial Scenario in India:

Only through switching from lower biomass land uses (such as grasslands, crop fallows, etc.) to tree-based systems like agroforestry, forests, and plantation forests will the atmosphere's CO_2 levels be reduced [35].

There is sufficient evidence that an agroforestry system has a greater overall potential for (biomass) productivity, soil fertility to be enhanced, soil conservation, nutrient cycling, microclimate regulation, and carbon sequestration than an annual system[36].In Indian agro-forests, carbon sequestration ranges from 19.56 Mg C/ha/yr in Uttar Pradesh in the north to a carbon pool of 23.46–47.36 Mg C/ha/yr in Rajasthan's tree-bearing desert agro-ecosystems[37].

The biomass of above-ground plants, such as wood and fuel-wood, as well as the biomass of below-ground plants, such as roots and soil microbes, as well as all the forms of inorganic as well as organic C in soils, including the deep root zone, all contribute to the sequestration of carbon in terrestrial pools. Trees and crops are the two key elements in agro-forestry systems that primarily sequester CO_2. The overall amount sequestered in each component varies widely and is largely influenced by a number of variables, such as the system type (and its components' nature and plant age), site quality, and historical land-use [38].

7.7 Carbon Sequestration Through Crops:

Although trees sequester more carbon in agro-forestry systems, crops also fix and store a sizeable quantity of carbon. Crops enhance the soil's organic matter, a key contributor to the terrestrial C pool [39]. Adoption of suitable crop rotations, integrated soil fertility management [40], careful use of fertilizers and organic amendments [41], and the implementation of conservation agriculture can all result in an increase in the soil's carbon pool. One of the key characteristics of Indian agriculture is the diversity of agricultural systems. The variety of soil and climatic factors that affect the total agro-ecological conditions for the growing of a crop or group of crops identified the cropping system.

There is numerous researches on CSP of crops and cropping systems accessible in published literature. However, there is a significant impact on soil organic carbon stocks due to the selection of crop species, cropping system, the timing of fallowing, and both the quantity and quality of residue returned to the soil [42]. There are reportedly more than 250 double cropping systems in use across the nation. However, 30 significant cropping systems were recognized in each district of the nation based on the rational distribution of crops. In an experiment at the ICAR-Indian Institute of Soil Science in Bhopal, evaluated the ability of various crops to store carbon [43]. They found that maize, sorghum, and pearl millet were more capable of doing so than rice, finger millet, and soybean.

The potential for carbon sequestration of various cropping systems in Indian agriculture was examined through various long-term experiments (LTEs) in various agroclimatic zones of India. The C-sequestration rate ranged from 0.02 Mg C/ha/yr (in NPK treatment for soybean-wheat cropping systems over the 28-year period at Jabalpur in Madhya Pradesh) to 1.2 Mg C/ha/yr [44].

This review unequivocally shows that long rotation agro-forestry systems, including windbreaks, shelterbelts, woodlots, boundary plantations, agri-horticulture, silvi-pasture, home landscapes, and multi-storied systems, have a significant capacity to store carbon in biomass. (ii) The potential for soil carbon sequestration is great in short rotation systems (agri-silviculture). (iii) Tropical bamboos and fast-growing hardwoods like *Eucalyptus, Poplar, Melia, Casuarina,* and *Leucaena* have a greater potential for biomass than slow-growing species. (iv) the potential for soil carbon sequestration is comparable for both types (long as well as short rotation AFS).

As a result, there is strong evidence that agro-forestry is advantageous for maintaining farm revenue as well as for its positive effects on climate change adaptation and mitigation. Along with providing food, fuel, fodder, and lumber, crops combined with trees help keep atmospheric CO_2 levels within tolerable ranges. Except for forests, agro-forestry systems have the highest potential for sequestering carbon. However, the CSP of an agro-forestry system varies depending on factors like tree species, system age, crop/variety, type of agro-climate, etc. Different agro-forestry systems are represented by the various agro-climatic zones in India, and their aboveground and belowground (soil) CSP range from 0.25 to 19.14 Mg C/ha/yr and 0.003 to 3.98 Mg C/ha/yr, respectively. Agro-forestry systems have the capacity to store and sequester carbon, but they also provide the one-of-a-kind chance to boost India's tree cover to a level of 33%.

7.8 Future Prospects:

Nature-based solutions are the only long-term answers to ecological concerns. Only sustainable practices, such as agroforestry has the potential to reverse man-made ecological problems. Agroforestry implies more revenue and less danger from unpredictable weather conditions for farmers since trees have very high climatic resilience. It also frees up the farmer's time off the farm to pursue related or alternative work for additional revenue.

The farmer might start small rural processing businesses using wood and other tree raw materials. By storing emissions in soil and biomass, lowering fossil fuel use via fewer field equipment runs, enhancing the conservation of energy surrounding farm buildings, and boosting nitrogen fertilizer efficiency, agroforestry practices can decrease net greenhouse gas budgets. As a result, agro-forestry will plays vital role in supporting the environment in the future.

7.9 Conclusion:

In terms of emissions of carbon, agroforestry is vital to strengthening farmers' rural economy and ensuring global security. It can aid in preparing for and mitigating climate change by decreasing risks and enhancing agricultural landscape adaptability, as well as promoting species migration to more favorable circumstances, carbon sequestration, and glasshouse gas emissions reduction. Due to it being a greenwood-plant-based method that increases useful variety at many scales, agroforestry as stands out as an agricultural management substitute under climate change. By establishing microclimates, perennial components can benefit crops and livestock. It may be used to make forest corridors or paths in agricultural areas, which would improve habitat connectivity. It offers comprehensive and synergistic mitigation and adaptation benefits. By conserving emissions in soil and biomass, lowering fossil fuel use via reducing field equipment runs, enhancing energy savings near farm buildings, and boosting nitrogen fertilizer efficiency, agroforestry practices can decrease net greenhouse gas budgets. Agroforestry may give significant advantages from mitigation in exchange for the quantity of land utilized in the processes.

It provides an amazing chance to achieve the mitigation as well as adaptation goals for climate change. The release of carbon is among the more significant factor contributing to greenhouse gas (GHG) emissions, which promote environmental degradation, and agroforestry is one of the most important global warming remedies.

7.10 References:

1. Smith, J. R. (1929). Tree crops: a permanent agriculture. Quinn and Boden Company. *Inc., Rahway*.
2. Gold, M. A. (2017, December 15). *agroforestry. Encyclopedia Britannica*. https://www.britannica.com/science/agroforestry
3. National Agro-forestry Policy (2014) Government of India Department of Agriculture & Cooperation Ministry of Agriculture New Delhi
4. Stern, D. I. (2004). The rise and fall of the environmental Kuznets curve. *World development, 32*(8), 1419-1439.

5. Lamb, W. F., Wiedmann, T., Pongratz, J., Andrew, R., Crippa, M., Olivier, J. G. J., & Khennas, S. (1990). de la Rue du Can, S., Minx, J.(2021). *A review of trends and drivers of greenhouse gas emissions by sector from*.
6. Dhyani SK, Asha Ram, and Dev I 2016 Potential of agroforestry systems in carbon sequestration in India, Indian Journal of Agricultural Sciences 86 (9) 1103–12
7. CAFRI Vision 2050 Jhansi: CAFRI, 2015.
8. NRCAF 2013 Vision 2050, National Research Centre for Agroforestry, Jhansi
9. Smith J 2010 Agroforestry: reconciling production with protection of the environment. Organic Research Centre, Elm Farm, Hamstead Marshall, Newbury, p 24
10. Singh R, Singh C, Gulati A, and Kujur S 2016 Current status of poplar based agroforestry for economic development: A case study of Haridwar and Yamuna Nagar Districts, *Indian Forester* 142(50) 487-492
11. Saravanan S and Vijayaraghavan A 2014 *Casuarinaequisitifolia* based agroforestry system for higher economic returns for the farming communities in Tamilnadu, India, Fifth International Casuarina workshop, Mamallapuram, India, 03-07 February, 2014 p.61
12. Al-Rubae AY 2009 The potential uses of *MeliaAzedarach* L. as pesticidal and medicinal plant,review, *American-Eurasian Journal of Sustainable Agriculture.* **3**(2) 185-194
13. Patil SJ, Mutanal SM, and Patil HY 2009 *Meliaazedarach* based agroforestry system in transitional tract of Karnataka, *Karnataka Journal of Agriculture Sciences* **25**(4) 460-462
14. Dhyani SK, Sharda VN, and Sharma AR 2003 Agroforestry for water resources conservation: issues, challenges and strategies, in *Agroforestry: Potentials and Opportunities* (eds) Pathak PS and Newaj, Ram Jodhpur, India: Agribios
15. Dev, I., Ram, A., Bhaskar, S., & Chaturvedi, O. P. (2019). Role of Agroforestry in current scenario. *Agroforestry in Climate Resilience and Rural Livelihood; Dev, I., Ram, A., Kumar, N., Singh, R., Uthappa, AR, Handa, AK, Eds*, 1-10.
16. IPCC. 2000. Land Use, Land Use Change and Forestry. IPCC, Special Report. Cambridge University Press: Cambridge
17. Batjes NH. 1996. The total C and N in soils of the world. *European Journal of Soil Science* **47**: 151–163.
18. Lal R. 1999. Soil management and restoration for C sequestration to mitigate the accelerated greenhouse effect. *Progressive Environmental Science***1**: 307–326
19. Halmann MM, Steinberg M. 1999. Greenhouse gas carbon dioxide mitigation. *Science & Technology*. Lewis: Boca Raton, FL.
20. DOE. 1999. *Carbon Sequestration: Research and Development*. National Technical Information Service: Springfield, VA.
21. Rasmussen PE, Collins HP. 1991. Long-term impacts of tillage, fertilizer, and crop residue on soil organic matter in temperate semi-arid regions.*Advances in Agronomy* **45**: 93–134.
22. Paustian K, Collins HP, Paul EA. 1997. Management controls on soil carbon. In *Soil Organic Matter in Temperate Agroecosystem, Long-Term Experiments in North America*, Paul EA, Paustian K, Elliott ET, Cole CV (eds). CRC Press: Boca Raton, FL; 15–49.
23. Powlson SD, Smith P, Coleman K, Smith K, Glending MJ, Korschens M, Franko U. 1998. A European network of long-term sites for studies on soil organic matter. *Soil & Tillage Research***47**: 309–321.

24. Lal R. 2001. World cropland soils as a source or sink for atmospheric C. *Advances in Agronomy***71**: 145–174
25. Lal, R. (2003). Offsetting global CO2 emissions by restoration of degraded soils and intensification of world agriculture and forestry. *Land Degradation & Development*, *14*(3), 309-322.
26. Menegat, S., Ledo, A., &Tirado, R. (2022). Greenhouse gas emissions from global production and use of nitrogen synthetic fertilisers in agriculture. *Scientific Reports*, *12*(1), 14490.
27. Fuinhas, J. A., Koengkan, M., Leitão, N. C., Nwani, C., Uzuner, G., Dehdar, F., and Peyerl, D. (2021). Effect of battery electric vehicles on greenhouse gas emissions in 29 European Union countries. *Sustainability*, *13*(24), 13611.
28. Jahanger, A., Chishti, M. Z., Onwe, J. C., &Awan, A. (2022). How far renewable energy and globalization are useful to mitigate the environment in Mexico? Application of QARDL and spectral causality analysis. *Renewable Energy*, **201**.514-525.
29. Szetela, B., Majewska, A., Jamroz, P., Djalilov, B., & Salahodjaev, R. (2022). Renewable energy and CO2 emissions in top natural resource rents depending countries: the role of governance. *Frontiers in Energy Research*, 242.
30. Burciaga, U. M., Sáez, P. V., & Ayón, F. J. H. (2019). Strategies to reduce CO2 emissions in housing building by means of CDW. *Emerging Science Journal*, **3**(5), 274-284.
31. Bentrup, G.; MacFarland, K. (2020). Agroforestry. U. S. Department of Agriculture, Forest Service, Climate Change Resource Center. www.fs.usda.gov/ccrc/topics/agroforestry.
32. NRCAF. 2007. Vision 2025. National Research Centre for Agroforestry, Jhansi.
33. Shepherd, D. and Montagnini, F. 2001. Carbon Sequestration Potential in mixed and pure tree plantations in the humid tropics. *J Trop for Sci* **13**: 450–459.
34. Nair, P. K. R., Nair, V. D., Kumar, B. M. and Showalter, J. M. 2010. Carbon sequestration in agroforestry systems. *Advances in Agronomy,* **108**: 237–307.
35. Kursten, E. 2000. Fuelwood production in agroforestry systems for sustainable land use and CO_2 mitigation. *Ecol Eng,* **16**: S69–S72.
36. Newaj, R. and Dhyani, S. K. 2008. Agroforestry for carbon sequestration: Scope and present status. *Indian Journal of Agroforestry*, **10**:1–9.
37. Pandey, D. N. 2002. Carbon sequestration in agroforestry systems. Climate Policy **2**: 367–77.
38. Dhyani, S. K., Newaj, R. and Sharma, A. R. 2009. Agroforestry: its relation with agronomy, challenges and opportunities. *Indian Journal of Agroforestry,* 54(**3**): 249–66.
39. Ciampitti, I. A., García, F. O., Picone, L. I. and Rubio, G. 2011. Soil carbon and phosphorus pools in field crop rotations in Pampean soils of Argentina. *Soil Science Society of America Journal*, 75(**2**): 1–10.
40. Wright, A. L. and Hons, F. M. 2005. Tillage impacts on soil aggregation and carbon and nitrogen sequestration under wheat cropping sequences. *Soil and Tillage Research*, **84**: 67–75.
41. Schuman, G. E., Janzen, H. H. and Herrick, J. E. 2002. Soil carbon dynamics and potential carbon sequestration by rangelands. *Environmental Pollution*, **116**: 391–6.
42. Halvorson, A. D., Wienhold, B. J. and Black, A. L. 2002. Tillage, nitrogen and cropping system effects on soil carbon sequestration. *Soil Science Society of America Journal* **66**: 906–12.

43. Kushwah, S. K., Dotaniya, M. L., Upadhyay, A. K., Rajendiran, S., Coumar, M. V., Kundu, S. and Subba Rao, A. 2014. Assessing carbon and nitrogen partition in kharif crops for their carbon sequestration potential. *National Academy Science Letter*, 37**(3)**: 213–7.
44. Pandey, D., Agrawal, M., Bohra, J. S., Adhya, T. K. and Bhattacharyya, P. 2014. Recalcitrant and labile carbon pools in a sub-humid tropical soil under different tillage combinations: A case study of rice–wheat system. *Soil and Tillage Research*, **143**: 116–22.

ISBN: 978-81-19149-59-9

8. Biochar and its Role in Sustainable Agriculture

Manish Tomar, Kannoj

Department of Agronomy,
CCS Haryana Agricultural University,
Hisar.

Ruchika Choudhary, Narendra Kumar Bhinda

Department of Agronomy,
Rajasthan College of Agriculture,
MPUAT, Udaipur.

Abstract:

Biochar is a carbon-rich material produced through the process of pyrolysis, which involves heating biomass in the absence of oxygen. In recent years, biochar has gained significant attention due to its potential benefits in improving soil fertility, mitigating greenhouse gas emissions and promoting sustainable agricultural practices. It improves soil structure and porosity, enhancing water-holding capacity and reducing erosion. Biochar's permeable structure creates a favourable environment helpful for microorganisms in the soil, enhancing the cycling of nutrients and boosting soil fertility. Furthermore, biochar contributes to climate change mitigation by sequestering carbon in the soil for extended periods. This carbon sequestration potential helps to reduce greenhouse gas emissions and mitigate climate change impacts. So, biochar holds significant promise as a sustainable agricultural tool. Its ability to improve soil fertility, reduce greenhouse gas emissions and enhance crop productivity makes it a valuable resource for achieving sustainable farming practices. Implementing biochar-based strategies requires careful consideration of production methods, application rates and long-term effects, paving the way for a more sustainable and resilient agricultural future.

Keywords:

Sustainable, Greenhouse, Farming, Biochar, Stability.

8.1 Introduction:

As the global population continues to grow, it has become increasingly important to implement sustainable agriculture practices. 'Sustainable agriculture' involves the integration of various sciences, including biology, ecology, chemistry, physics, economics and social sciences (Lichtfouse *et al.*, 2009) to develop agricultural practices that are environmentally friendly, socially just and economically viable. These practices aim to produce crops sustainably while minimizing the negative impacts of intensive land use (Hester and Harrison, 2005). In essence, sustainable agriculture is about farming profitably while reducing harm to the environment.

Regardless of being largely seen as unsustainable, environmentally harmful, and unlikely to keep up with rising demand, the green revolution has been successful in feeding the world's population over the past five decades (Barrow, 2012). Conventional farming methods, including conventional tillage and the indiscriminate use of agrochemicals, have degraded natural resources. This has led to an increase in soil degradation and a reduction in their capacity for growing crops. The burning of crop residues further contributes to greenhouse gas emissions, which warm the atmosphere, jeopardise global food security and ultimately lead to climate change.

The adverse effects of the green revolution paved the way for sustainable farming. The utilisation of naturally derived ecologically friendly materials has been a hot subject of investigation in recent years. A recent breakthrough is the creation of biochar from crop residue, which may prove to be a vital and useful element of sustainable agriculture. Biomass is heated with little to no oxygen to form biochar. It has a high percentage of carbon, a chemical structure that is stable and resistant to decay, high porosity and a large specific surface area. Due to its characteristics, it has the potential to effectively store large amounts of carbon in the soil over the long term, improving soil fertility and crop productivity under various biotic and abiotic stresses (Akhtar *et al.*, 2014; Barrow, 2012), reducing global warming, and moving towards achieving global food security.

8.2 Biochar:

Biochar is a carbon-rich, porous solid that is produced when organic materials such as agricultural waste, wood, and manure are heated at high temperatures (between 200 and 800°C) in an oxygen-deprived environment through a process called pyrolysis (Lehmann *et al.*, 2006). Various organic materials, including animal manure, municipal sewage sludge, crop and forestry waste products, urban yard waste, industrial biomass byproducts, and crop residues can be used to create biochar. Biochar is composed of ash, labile carbon and recalcitrant carbon. Any nutrients present in biochar are found in the ash, which is the inorganic component. Labile carbon is the fraction of biochar that can be decomposed by soil microorganisms and is lost through respiration as CO_2. Recalcitrant carbon, on the other hand, resists degradation by soil organisms and is incredibly stable and long-lasting.

8.3 Properties of Biochar:

The physicochemical characteristics are essential for governing biochar's biogeochemical interactions in soil environments as well as for determining their agronomic and environmental effects. The two key variables affecting the qualities of biochar are the pyrolysis process's temperature and the initial feedstock's characteristics (Cantrell *et al.*, 2012).

A. Specific Surface Area:

The specific surface area of biochar typically ranges from 1.5 to 500 $m^2\ g^{-1}$ (Li *et al.*, 2018). The pyrolysis temperature can affect the specific surface area and the formation of micropores in biochar. At lower temperatures, the interior pore structure of biochar is filled with tars, volatiles and other products formed as a result of thermal degradation of biomass, reducing the specific surface area. With the increase in temperature, these compounds break down into volatile gases and escape, leading to the formation of more microporous structures and a larger specific surface area (Bansal *et al*., 1988). However, when the temperature reaches a critical value, the specific surface area decreases due to the degradation of the microporous structure and the widening of the micropores (Brown *et al*., 2006). The specific surface area of biochar is important because it affects its adsorption capacity.

B. pH:

Biochar is generally alkaline due to the presence of carbonates, phosphates and ash formed during the process of pyrolysis (Yuan *et al.*, 2011). The pH of biochar can also be affected by the feedstock materials and pyrolysis temperature used. For example, biochar made from legumes has a higher pH than biochar made from non-leguminous materials under the same pyrolysis conditions. As the temperature increases, the pH of biochar increases due to the breakdown of acidic functional groups such as carboxyl and phenolic hydroxyl and the volatilization of organic acids (Chintala *et al.*, 2014).

C. Surface functional groups:

The specific surface area of biochar is an important characteristic because it affects its ability to adsorb metal ions and organic molecules. Increasing the pyrolysis temperature can increase the development of micropores and the specific surface area of biochar. Biochar contains several functional groups, including carboxyl, carbonyl and hydroxyl groups. According to Anton-Herrero *et al*. (2018), most of these functional groups are oxygen or alkaline containing and give biochar good hydrophobicity or hydrophilicity, ion exchange and buffering capabilities.

The number of functional groups on the surface of biochar is closely related to the carbonization temperature. As the carbonization temperature increases, the concentration of C-O, C-H, and O-H bonds in biochar decreases, along with the number of hydroxyl and carboxyl groups and acid groups, while the number of alkaline groups increases. Overall, the number and density of functional groups decrease as the carbonization temperature increases (Gul *et al*., 2015; Wang, 2015).

D. Cation exchange capacity (CEC):

During the process of carbonization, certain oxygen containing functional groups such as carboxyl, hydroxyl and carbonyl are preserved due to the partial degradation of cellulose, increasing the CEC of biochar. The preservation of these functional groups depends on the type of biomass, pyrolysis temperature and carbonization technique used (Lee *et al.*, 2010).

Within a specific temperature range, increasing the temperature reduces the negative charge on the surface of biochar due to the destruction of oxygen-containing functional groups (Lee *et al*., 2010; Suliman *et al*., 2017). However, the content of alkali metals such as Ca, K and Mg in biochar increases with temperature, which can increase CEC (Kalinke *et al*., 2017).

E. Stability:

Biochar is characterized by its high carbon content, low solubility, high boiling point, and structure that includes a high degree of carboxylate esterification and aromatization. A fraction of aromatic C in the biochar rises as the pyrolysis temperature increases as a result of the H/C and O/C ratios decline, and it is thought that the lower the ratio, the more aromaticity and stability there will be (Baldock and Smernik, 2002).

8.4 Effect of Biochar on Soil:

Biochar has unique physical and chemical properties that can improve soil quality and fertility by enhancing nutrient cycling, reducing nutrient loss and increasing soil microbial activity.

8.4.1 Physical Properties:

Biochar's larger surface area and micropores can affect the soil's surface area, pore size distribution, bulk density, water and nutrient holding capacity, and penetration resistance (Chintala *et al*., 2014). Since biochar often has a higher surface area than sand and is comparable to or higher than clay, adding it to the soil as an amendment can increase the soil's total specific surface area. The high porosity of biochar due to its numerous micropores can improve the physical quality of the soil where it is incorporated. Over time, the interaction of biochar with clay and soil organic matter can lead to the formation of micro aggregates, increasing the soil's porosity (Cheng *et al*., 2006). This increased porosity and surface area can allow the soil to retain more moisture and nutrients, reduce its bulk density and decrease penetration resistance.

8.4.2 Chemical Properties:

Due to the combination of its high surface area and porosity, biochar can retain and absorb plant nutrients, hence enhancing soil fertility. Increased cation exchange capacity (CEC), lowered nitrogen leaching, liming and other beneficial effects of biochar amendment to the chemical properties of soil. Biochar can boost soils' CEC, especially for sandy, highly weathered soils that are deficient in nutrients due to the presence of oxidised functional groups (such as carboxyl groups) on the surface of biochar, as well as the exposed organic acids adsorbed by the biochar, contributes to the biochar's negative surface charge, are likely to be responsible for the increase in CEC in biochar amended soil (Liang *et al*., 2006).

However, this depends on the qualities of biochar and how long it has been in the soil after being applied. Ageing increases the amount of acidic functional groups in biochar, particularly carboxylic groups (Cheng *et al*., 2006). It has been found that biochar can hinder both nitrification and ammonification (DeLuca *et al*., 2009). It further decreases nitrate leaching caused by NO_3^- adsorption on the anion exchange surface of the material which might be the result of slower rates of nitrification (Dempster *et al*., 2012). Due to the biochar's pH and improved cation retention in the soil (such as Ca^{2+}, Mg^{2+} and K^+), the application of biochar can improve soil pH (Novak *et al*., 2009; Sohi *et al*., 2010). This way, by giving plants nutrients, biochar can contribute directly to soil fertility.

8.4.3 Biological Properties:

The composition of flora and fauna in the soil is constantly changing in response to soil conditions and management practices, including the addition of biochar. Biochar can alter the physio-chemical properties of soil, favourably influencing microbial activity and affecting soil microbiological properties.

Soil is home to a complex community of organisms, and biochar has been shown to change the composition of microbial communities while also improving the soil's bulk density, pH, water and nutrient availability (Gul *et al*., 2015; Khodadad *et al*., 2011).

Biochar's high surface area and ability to adsorb nutrients make it an ideal environment for microorganisms such as bacteria, actinomycetes and arbuscular mycorrhizal fungi to colonize, thrive and reproduce (Pietikainen *et al.*, 2000).

Its unique pore size properties may also protect these microorganisms from predators such as protozoa and nematodes. Biochar can also significantly influence diazotrophs (N_2-fixing bacteria), leading to increased biological N-fixation (Thies and Rilling, 2009).

Table 1. Effect of Biochar on different soil properties

Parameter	**Findings**	**Reference**
Cation exchange capacity	50% increase	Glaser *et al*., 2002
Fertilizer use efficiency	10-30% increase	Gaunt and Cowie, 2009
Liming agent	1 unit pH increase	Lehman and Rondon, 2006
Biological nitrogen fixation	50-72% increase	Lehman and Rondon, 2006
Soil moisture retention	Up to 18% increase	Srinivasarao *et al.*, 2012
Bulk density	Soil dependent	Laird, 2008
Methane emission	100% decrease	Rondon *et al.*, 2005
Nitrous oxide emissions	50% decrease	Yanai *et al*., 2007
Mycorrhizal fungi	40% increase	Warnock *et al*., 2007

(Bhinda *et al*., 2022)

8.5 Effect of Biochar on Climate Change Mitigation:

Agriculture contributes significantly to anthropogenic global warming. So, lowering agricultural emissions, primarily methane (CH_4) and nitrous oxide (N_2O), could be a vital component of the effort to slow down climate change.

8.5.1 Carbon Sequestration:

Crop residue and soil organic matter microbiological decomposition or burning are the primary sources of carbon dioxide emissions (Smith *et al*., 2008). Through photosynthesis, sequestering carbon in the form of crop growth is a very effective approach for reducing atmospheric CO_2. However, the effectiveness of this method for long-term carbon sequestration is severely constrained since a significant amount of the collected carbon is unstable and will quickly (within months to years) return to the atmosphere as CO_2 through breakdown and respiration. To decrease carbon in the atmosphere and considerably increase long-term C sequestration, moving it into a passive pool is necessary and can be achieved through biomass pyrolysis. Biomass can be pyrolyzed to create a passive pool of stable or inert carbon, which can be used to transport carbon out of the atmosphere and significantly boost long-term C sequestration. A portion of the biomass is converted into a more stable form of carbon called biochar during pyrolysis, which also releases bio-energy. This allows for an easy movement of carbon from the active to the passive pool. The pyrolysis process produces significantly more energy than it uses, resulting in highly positive net energy. By combining the pyrolysis process with the application of biochar in soil, it is possible to sequester atmospheric CO_2 since more carbon is stored than is released. The pyrolysis process has a very positive net energy because substantially more energy is produced than is used. As recalcitrant carbon in biochar is exceptionally stable and long-lasting due to its resistance to microbial breakdown, its application will slow down the return of terrestrial organic carbon as CO_2 to the atmosphere and so reduce climate change.

In North western part of India, deliberate burying of crop residue *i.e.*, stubble burning is practised in order to remove agricultural crop residue from the field as a short period is available between the harvesting of *kharif* crop and preparing the land for the next winter crop. In India, it has been estimated that 93 million tonnes of crop waste are burned annually. Burning of the stubble not only resulted in the loss of a significant amount of biomass, or organic carbon and plant nutrients, but also had a negative impact on the chemical, biological, physical, and flora and fauna of the soil (Kannoj *et al*. 2023). Burning rice straw is estimated to produce 0.05% of India's overall greenhouse gas emissions (Gadde *et al.*, 2009). According to Lal (2005), India could generate almost 310 million tons of biochar per year from various sources, including crop residues, which could counterbalance about 50 per cent of carbon emissions from fossil fuels.

8.5.2 Greenhouse Gas Emissions:

Soil act as a significant source of nitrous oxide (N_2O) while both a source and sink of methane (CH_4). These gases absorb and emit radiant energy at thermal infrared wavelength, bringing a greenhouse effect. They are responsible for the greenhouse effect as they have a global warming potential of approximately 25 and 300 times more than CO_2. The contribution of agriculture to the overall amount of GHGs produced by anthropogenic actions was about 24% (Smith *et al*., 2007).

Heterotrophic denitrifying bacteria that thrive in anaerobic environments and chemotrophic bacteria that transform ammonium through mineralization processes into soluble NO_3^- are the principal sources of N_2O emission from soil. In the acidic soil of eastern Colombian plains, Rondon *et al*. (2005) reported a 50 per cent reduction in N_2O emissions and an almost complete reduction in CH_4 emissions from soybean plots with biochar application. The possible reason behind the decline of N_2O emission with the application of biochar might be due to slower N cycling, possibly as a result of an increase in the C: N ratio; an increase in soil pH enhances N_2O reductase activity and hence favours completion of NO_3^- reduction to N_2 (DeLuca *et al*., 2009). Increased soil aeration and adsorption of NH_4^+ from biochar addition reduce nitrification and denitrification and increase sink capacity for CH_4. Because N_2O and CH_4 have significantly higher potential for global warming than CO_2, reducing their emissions through biochar is of great interest. The effect of adding biochar on CH_4 and N_2O, however, was erratic and differed depending on the kind of crop and soil, the site and the source of the biochar. (Karhu *et al*., 2011; Kimetu and Lehmann, 2010).

8.6 Improvement of Crop Growth and Yield by Biochar Application:

The impact of biochar on crop yield, seed germination and crop growth depend on the type of soil and the amount of biochar used. Improvements in soil quality due to the use of biochar have often led to improved seed emergence and plant establishment (Solaiman *et al*., 2012; Van Zwieten *et al*., 2010). The plant's root system and the interface between biochar and soil (the rhizosphere) are crucial for crop growth due to their role in nutrient and water uptake, storage, and regulation. The rhizosphere is often larger in soils containing biochar (Zheng *et al*., 2013).

The benefits of biochar on yield and crop biomass have been observed to increase over time. In a multi-year experiment on a maize-soybean rotation system, Major *et al*. (2010) found that applying biochar at a rate of 20 t ha^{-1} did not increase maize yield in the first year, but a significant increase in yield was observed in the following three years compared to the control. Biochar-induced increases in soil specific surface area, CEC, porosity, water holding capacity, nutrient retention, and liming effect are key factors influencing improved crop growth and productivity, in addition to composts and fertilizers (Glaser *et al*., 2002; Lehmann *et al*., 2006). In a study on chickpea under rainfed conditions, Tomar *et al*. (2022) found that biochar application (supported by fertilizer) significantly improved the total nitrogen, phosphorus, and potassium uptake of chickpea compared to the control.

Biochar has been shown to increase the growth of maize plants in poor sandy soils by improving soil-plant water relations and photosynthesis (Haider *et al*., 2015). According to El-Naggar *et al*. (2019), biochar is generally more effective when applied to soils with low to medium fertility or degraded soils.

8.7 Remediation of Contaminated Soils:

Soil contamination with organic and inorganic toxins is a well-known problem, and there is an urgent need for sustainable, economically feasible, and environmentally friendly remediation methods.

Biochar has the potential to be an environmentally friendly and relatively cost-effective solution for treating contaminated soils due to its high sorption capacity, which can be 10-100 times greater than that of normal soil organic matter (Cornelissen *et al*., 2005).

Biochar through chemisorption and physisorption can alter the bioavailability of heavy metals in the soil. Its high aromatization and porosity allow it to generate a modest electric force when heavy metal ions are nearby, promoting their physisorption (Gomez-Eyles and Ghosh, 2018). The presence of surface functional groups such as carboxylic, alcohol, and hydroxyl groups on biochar allows it to chemisorb heavy metals and form complexes that reduce their bioavailability (Tang *et al*., 2013).

The alkaline properties of biochar can increase soil pH when added to soil, reducing zeta potential and increasing cation exchange capacity. This increases the negative charge on the soil surface, reducing the bioavailability of heavy metals and strengthening the electrostatic attraction between positively charged heavy metals and soil (Peng *et al*., 2011; Chintala *et al*., 2013). Biochar can also affect the soil's redox potential, moisture content, and aeration, altering the toxicity of some charge-sensitive toxic heavy metals such as cadmium (Bogusz *et al*. 2017). However, not all heavy metals are affected by biochar's ability to reduce their bioavailability.

Biochar can also adsorb several organic contaminants, including phenols, polychlorinated biphenyls, naphthalenes, and polycyclic aromatic hydrocarbons. Its ability to adsorb organic pollutants is influenced by factors such as its carbonaceous components, degree of aromatization, elemental composition, pH, pore structure, and surface chemistry (Chen *et al*., 2019). However, the mechanism by which biochar reduces the bioavailability of organic contaminants in soil is complex and involves intricate microbial metabolic activities (Zhu *et al*., 2017). In the present times, there is a lack of in situ or long-term experiments examining the role of biochar in the remediation of inorganic or organic pollutants.

8.8 Conclusion:

Biochar can have a variety of positive effects on crop growth, productivity and soil characteristics. These effects include increased growth and yield, adsorption of heavy metals, improved water holding capacity, and positive plant physiological responses. Biochar has great potential for use in large-scale agricultural production. Initial studies suggest that using biochar can increase crop productivity and soil fertility while mitigating the effects of climate change. However, further research, development, and demonstration of biochar production and use are essential to promote its use as a soil amendment and as a potential solution to combat climate change. Multidisciplinary and site-specific research is needed to better understand the long-term effects of biochar application on soil physical properties, nutrient availability, soil microbial activity, carbon sequestration capacity, crop production and greenhouse gas mitigation.

8.9 References:

1. Akhtar, S.S., Li, G., Andersen, M.N. and Liu, F. 2014. Biochar enhances yield and quality of tomato under reduced irrigation. *Agricultural Water Management* **138**:37-44.
2. Anton-Herrero, R., Garciadelgado, C., Alonsoizquierdo, M., Garciarodriguez, G., Cuevas, J. and Eymar, E. 2018. Comparative adsorption of tetracyclines on biochars and stevensite: looking for the most effective adsorbent. *Applied Clay Science* **160**:162-172.

3. Baldock, J.A. and Smernik, R.J. 2002. Chemical composition and bioavailability of thermally altered *Pinus resinosa* (Red pine) wood. *Organic Geochemistry* **33**:1093-1109.
4. Bansal, R.C., Donnet, J.B. and Stoeckli, F. 1988. Active carbon. Marcel Dekker, New York, pp-158.
5. Barrow, C.J. 2012. Biochar: potential for countering land degradation and for improving agriculture. *Applied Geography* **34**:21-28.
6. Bhinda, N. K., Yogi, A. K., Kumar, M., Choudhary, M. K. and Dhayal, S. 2022. Role of Biochar in Agriculture to Improve Soil Health and Climate Change Mitigation. In Jakhar, R. K., Kumawat, A., Sunda, S. L., Kumar, J., Choudhary, N. K. and Bhawariya, A. (Eds.), *Multifacted Agricultural Research And Extension*, pp. 85-97. Nation Press. India.
7. Bogusz, A., Nowak, K., Stefaniuk, M., Dobrowolski, R. and Oleszczuk, P. 2017). Synthesis of biochar from residues after biogas production with respect to cadmium and nickel removal from wastewater. *Journal of Environmental Management* **201**:268-276.
8. Brown, R.A., Kercher, A.K., Nguyen, T.H., Nagle, D.C. and Ball, W.P. 2006. Production and characterization of synthetic wood chars for use as surrogates for natural sorbents. *Organic Geochemistry* **37**(3):321-333.
9. Cantrell, K.B., Hunt, P. G., Uchimiya, M., Novak, J. M. and Ro, K. S. 2012. Impact of pyrolysis temperature and manure source on physicochemical characteristics of biochar. *Bioresource Technology* **107**:419-428.
10. Chen, Y., Jiang, Z., Wu, D., Wang, H., Li, J., Bi, M. and Zhang, Y. 2019. Development of a novel bio-organic fertilizer for the removal of atrazine in soil. *Journal of Environmental Management* **233**:553-560.
11. Cheng, C.H., Lehmann, J., Thies, J.E., Burton, S.D. and Engelhard, M.H. 2006. Oxidation of black carbon by biotic and abiotic processes. *Organic Geochemistry* **37**:1477-1488.
12. Chintala, R., Mollinedo, J., Schumacher, T.E., Malo, D.D. and Julson, J. 2014. Effect of biochar on chemical properties of acidic soil. *Archives of Agronomy and Soil Science* **60**(3):393-404.
13. Chintala, R., Schumacher, T.E., McDonald, L. M., Clay, D.E., Malo, D.D., Clay, S.A., Papiernik, S.K. and Julson, J. L. 2013. Phosphorus sorption and availability from biochars and soil biochar mixtures. *Clean Soil Air Water* **41**:1-9.
14. Cornelissen, G., Gustafsson, O., Bucheli, T. D., Jonker, M.T.O., Koelmans, A.A. and Van Noort, P.C.M. 2005. Extensive sorption of organic compounds to black carbon, coal, and kerogen in sediments and soils: mechanisms and consequences for distribution, bioaccumulation, and biodegradation. *Environmental Science and Technology* **39**: 6881-6895.
15. DeLuca, T.H., MacKenzie, M.D. and Gundale, M.J. 2009. Biochar effects on soil nutrient transformations. In Lehmann J, Joseph S (eds.) Biochar for Environmental Management: Science and Technology. *Earthscan*, London. pp. 251-270.
16. Dempster, D.N., Gleeson, D.B., Solaiman, Z.M., Jones, D.L. and Murphy, D.V. 2012. Decreased soil microbial biomass and nitrogen mineralisation with eucalyptus biochar addition to a coarse textured soil. *Plant and Soil* **354**:311-324.
17. El-Naggar, A., Sang, S.L., Jorg, R., Muhammad, F., Songe, H., Ajit, K.S., Andrew, R.Z., Mahtab, A., Sabry, M.S. and Yong, S.O. 2019. Biochar application to low fertility soils: a review of current status, and future prospects. *Geoderma* **337**:536-554.

18. Gadde, B., Menke, C. and Wassman, R. 2009. Rice straw as a renewable energy source in India, Thailand and the Philippines: Overall potential and limitations for energy contribution and greenhouse gas migration. *Biomass and Bioenergy* **33**:11.
19. Gaunt, J. and Cowie, A. 2009. Biochar greenhouse gas accounting and emission trading. In: *Biochar for environmental management* (J. Lehmann and S. Joseph eds.), Science and Technology, Earthscan, London. pp 317-340.
20. Glaser, B., Lehmann, J. and Zech, W. 2002. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal - a review. *Biology and Fertility Soils* **35**(4):219-230.
21. Gomez-Eyles, J.L. and Ghosh, U. 2018. Enhanced biochars can match activated carbon performance in sediments with high native bioavailability and low final porewater PCB concentrations. *Chemosphere* **203**:179-187.
22. Gul, S., Whalen, J.K., Thomas, B.W., Sachdeva, V. and Deng, H. 2015. Physico-chemical properties and microbial responses in biochar-amended soils: mechanisms and future directions. *Agriculture Ecosystems and Environment* **206**(1):46-59.
23. Haider, G., Koyro, H.W., Azam, F., Steffens, D., Muller, C. and Kammann, C. 2015. Biochar € but not humic acid product amendment affected maize yields via improving plantsoil moisture relations. *Plant and Soil* **395**:141-157.
24. Hester, R.E. and Harrison, R.M. 2005. Sustainability in Agriculture. Royal Society of Chemistry.
25. Kalinke, C., Oliveira, P.R.D., Oliveira, G.A.D., Mangrich, A.S., Marcolino-junior, L.H. and Bergamini, M.F. 2017. Activated biochar: preparation, characterization and electroanalytical application in an alternative strategy of nickel determination. *Analytica Chimica Acta* **983**:103-111.
26. Kannoj., Tomar, M., Choudhary. R. and Bhardwaj, S. 2023. Crop residue management Agriculture Science: Research and Review Volume XIV. Bhumi Publishing, India, pp 1-9.
27. Karhu, K., Mattila, T., Bergstrom, I. and Regina, K. 2011. Biochar addition to agricultural soil € increased CH_4 uptake and water holding capacity. Results from a short-term pilot field study. *Agriculture Ecosystems and Environment* **140**:309-313.
28. Khodadad, C.L.M., Zimmerman, A.R., Green, S.J., Uthandi, S. and Foster, J.S. 2011. Taxa-specific changes in soil microbial community composition induced by pyrogenic carbon amendments. *Soil Biology & Biochemistry* **43**:385-392.
29. Kimetu, J.M. and Lehmann, J. 2010. Stability and stabilisation of biochar and green manure in soil with different organic carbon contents. *Australian Journal of Soil Research* **48**: 577-585.
30. Laird, D.A. 2008. The charcoal vision: A win-win-win scenario for simultaneously producing bioenergy, permanently sequestering carbon, while improving soil and water quality. *Agronomy Journal* **100**:178-181.
31. Lal, M. 2005. Climate change-implications for India's water resources. In: Mirza, M.M.Q., Ahmad, Q.K., Balkema, A.A. (Eds.), Climate Change and Water Resources in South Asia. Taylor and Francis Group, UK, pp. 15-193.
32. Lee, J.W., Kidder, M. and Evans, B.R. 2010. Characterization of biochars produced from cornstovers for soil amendment. *Environmental Science and Technology* **44**(20):7970-7974.
33. Lehmann, J. 2007. A handful of carbon. *Nature* **447**:143-144.

34. Lehmann, J. and Rondon, M. 2006. Biochar soil management on highly weathered soils in the humid tropics. *Biological Approaches to Sustainable Soil Systems*, (N. Uphoff *et al*. eds), Boca Raton, FL: CRC Press. pp 517-530.
35. Lehmann, J., Gaunt, J. and Rondon, M. 2006. Biochar sequestration in terrestrial ecosystems-a review. *Mitigation and Adaptation Strategies Global Change* **11**:403-427.
36. Li, J.M., Cao, L.R., Yuan, Y., Wang, R.P., Wen, Y.Z. and Man, J.Y. 2018. Comparative study for microcystin-LR sorption onto biochars produced from various plant and animal-wastes at diferent pyrolysis temperatures: influencing mechanisms of biochar properties. *Bioresource Technology* **247**:794-803.
37. Liang, B., Lehmann, J., Solomon, D., Kinyangi, J., Grossman, J., O'Neill, B., Skjemstad, J.O., Thies, J., Luizao, F.J., Petersen, J. and Neves, E.G. 2006. Black carbon increases cation ~ exchange capacity in soils. *Soil Science Society of America Journal* **70**:1719-1730.
38. Lichtfouse, E., Navarrete, M., Debaeke, P., Souchere, V., Alberola, C. and Menassieu, J. 2009. Agronomy for sustainable agriculture: a review. *Agronomy for Sustainable Development* **29**:1-6.
39. Major, J., Rondon, M., Molina, D., Riha, S.J. and Lehmann, J. 2010. Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol. *Plant and Soil* **333**:117-128
40. Novak, J.M., Busscher, W.J., Laird, D.L., Ahmedna, M., Watts, D.W. and Niandou, M.A.S. 2009. Impact of biochar amendment on fertility of a southeastern coastal plain soil. *Soil Science* **174**:105-112.
41. Peng, X., Ye, L.L., Wang, C.H., Zhou, H. and Sun, B. 2011. Temperature and duration-dependent rice straw-derived biochar: characteristics and its effects on soil properties of an Ultisol in southern China. *Soil Tillage Research* **112**:159-166.
42. Pietika¨inen, J., Kiikkila¨, O. and Fritze, H. 2000. Charcoal as a habitat for microbes and its effect on the microbial community of the underlying humus. *Oikos* **89**:231-242.
43. Rondon, M., Ramirez, J.A. and Lehmann, J. 2005. Charcoal additions reduce net emissions of greenhouse gases to the atmosphere. In: *Proceedings of the 3rd USDA Symposium on Greenhouse Gases and Carbon Sequestration*, Baltimore, USA, March 21-24, 2005.
44. Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B. and Sirotenko, O. 2007. Agriculture, in: climate change 2007: mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, pp. 497-540.
45. Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Schneider, U., Towprayoon, S., Wattenbach, M. and Smith, J. 2008. Greenhouse gas mitigation in agriculture. Philosophical Transactions of the Royal Society B :Biology Science **363**:789-813.
46. Sohi, S.P., Krull, E., Lopez-Capel, E. and Bol, R. 2010. A review of biochar and its use and function in soil. *Advance Agronomy* **105**:47-82.
47. Solaiman, Z.M., Murphy, D.V. and Abbott, L.K. 2012. Biochars influence seed germination and early growth of seedlings. *Plant and Soil* **353**:273-287.
48. Srinivasarao, Ch., Vankateswarlu, B., Lal, R., Singh, A.K., Sumanta Kundu, Vittal, K.P.R., Balaguruvaiah, G., Vijaya Shankar Babu, M., Ravindra Chary, G., Prasadbabu,

M.B.B. and Yellamanda Reddy, T. 2012. Soil carbon sequestration and agronomic productivity of an Alfisol for a groundnut-based system in a semiarid environment in southern India. *European Journal of Agronomy* **43**: 40-48.

49. Suliman, W., Harsh, J.B., Fortuna, A., Garciaperez, M. and Abulail, N.I. 2017. Quantitative effects of biochar oxidation and pyrolysis temperature on the transport of pathogenic and nonpathogenic Escherichia coli in biochar-amended sand columns. *Environmental Science and Technology* **51**:5071-5081.
50. Tang, J.C., Zhu, W.Y., Kookana, R. and Katayama A. 2013. Characteristics of biochar and its application in remediation of contaminated soil. *Journal of Bioscience and Bioengineering* **116**:653-659.
51. Thies, E., and Rilling, M. C. 2009. Characteristics of biochar: Biological properties. In “Biochar for Environmental Management. Science and Technology” (J. Lehmann and S. Joseph, Eds.), Earthscan, London.
52. Tomar, M., Chaplot, P.C., Choudhary, J., Meena, R.H., Patidar, R. and Samota, A.K. 2022. Effect of Salicylic Acid and Biochar on Nutrient content and Uptake of chickpea (*Cicer arietinum* L.) under Rainfed Condition. *Biological Forum - An International Journal* **14**(3):613-616.
53. Van Zwieten, L., Kimber, S., Morris, S., Chan, K.Y., Downie, A., Rust, J., Joseph, S. and Cowie, A. 2010. Effects of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility. *Plant and* Soil **327**:235-246.
54. Wang, H. 2015. Removal of Pb (II), Cu (II), and Cd (II) from aqueous solutions by biochar derived from $KMnO_4$ treated hickory wood. *Bioresource Technology* **197**(9):356-362.
55. Warnock, D.D., Lehmann, J., Kuyper, T.W. and Rillig, M.C. 2007. Mycorrhizal responses to biochar in soil - concepts and mechanisms. *Plant and Soil* **300**:9-20.
56. Yanai, Y., Toyota, K. and Okazani, M. 2007. Effects of charcoal addition on N_2O emissions from soil resulting from rewetting air-dried soil in short-term laboratory experiments. *Soil Science and Plant Nutrition* **53**:181-188.
57. Yuan, J.H., Xu, R.K. and Zhang, H. 2011. The forms of alkalis in the biochar produced from crop residues at different temperature. *Bioresource Technology* **102**:3488-3497.
58. Zheng, H., Wang, Z., Deng, X., Herbert, S. and Xing, B. 2013. Impacts of adding biochar on nitrogen retention and bioavailability in agricultural soil. *Geoderma* **206**:32-39.
59. Zhu, X.M., Chen, B.L, Zhu, L.Z. and Xing, B.S. 2017. Effects and mechanisms of biochar-microbe interactions in soil improvement and pollution remediation: a review. *Environmental Pollution* **227**:98-115.

ISBN: 978-81-19149-59-9

9. Carbon and Water Footprint for Eco-Friendly Agriculture Practices

Babita

School of Basic, Applied Science,
RNB Global University,
Bikaner, Rajasthan, India

Anu Rani, Nivedan Bhardwaj

Department of Zoology,
Chaudhary Devi Lal University,
Sirsa, Haryana, India.

Bhumika Arora

Department of Botany,
Akal University,
Bathinda, Punjab, India

Abstract:

Around the world, 5% of all energy is utilized in agriculture. Agriculture consumes 5% of global energy, primarily for irrigation, machinery, and food processing. To reduce environmental impact and ensure long-term food security, sustainable practices and energy-efficient technologies are crucial. Thus, there must be a significant change in the agricultural production process. Currently, any agricultural growth must prioritize the sustainable use of water. Agricultural production effects freshwater wetlands and water quality and quantity. For agricultural production to be sustainable, it is essential to consider the carbon, and water footprints. In order to have the least possible impact on climate change, agricultural systems are crucial for lowering large inputs of greenhouse gas emissions, as well as for improving water use. Carbon emissions and water footprint can be used to analyze the production of agricultural systems.

Keywords:

Agriculture, Carbon footprint, Greenhouse gas, Water, Sustainable

9.1 Introduction:

The consumption of freshwater and global warming, both are severely affected by the food industry. The food industry has a significant impact on both freshwater consumption and global warming. The extensive use of water by the food industry for livestock production, processing, irrigation, and other purposes adds significantly to the use of freshwater resources. Additionally, the practices used in the food industry, such as methane emissions from livestock and deforestation for agricultural purposes, add to global warming. The urgent need for sustainable practices in the food industry to lessen its negative effects on freshwater resources and climate change is highlighted by these interconnected effects.

The sizeable contribution of AFOLU activities to greenhouse gas emissions worldwide. Deforestation, the raising of livestock, and agricultural soil management techniques are the main causes of these emissions. Water is crucial for crop growth and productivity in irrigation practices, which account for a large portion of agriculture's high water demand. Although it highlights the need for effective irrigation methods and conservation measures, this heavy reliance on freshwater resources poses significant challenges for sustainable water management.

India's population growth presents the country with the dual problem of boosting food production while reducing accompanying GHG emissions and giving the country's limited water resources.

Studies reveal the impact of India's crop production on greenhouse gas emissions. Accurate and trustworthy estimates require gathering primary data from the field and identifying regional variations and farming methods influencing emissions. Residue burning is a significant research gap in India, contributing to air pollution and greenhouse gas emissions.

Conducting an LCA-based study on CF accounting and assessing the environmental impact of residue burning could provide valuable insights for sustainable agricultural management. Agroclimatic zones and farm sizes significantly impact crop yields and agricultural practices. Understanding variations in CF across these factors is crucial for policymakers, farm can greatly and res to develop targeted interventions and strategies for sustainable agriculture in India.

Studies emphasize the need for specialized environmental interventions and policies considering regional farming methods and cultural contexts, emphasizing the importance of understanding these factors for effective environmental impact. Scallop crops like rice and wheat are grown in large quantities, significantly impacting global food security and livelihoods. This farming raises concerns about environmental sustainability and resource depletion, posing a significant threat to global food security.

Rice and wheat are the two crops with the largest blue water footprints (Mekonnen and Hoekstra, 2011). Rice is water-intensive due to its preference for flooded fields, while wheat requires significant irrigation in low-rainfall areas. Both crops contribute significantly to the ocean's water resources. Promoting effective irrigation methods and sustainable water management techniques like rainwater collection and recycling can reduce water use and GHG emissions.

Rice farming has expanded into porous and coarse soils, increasing food production and food security in areas with common soils. Irrigation enables farmers to grow rice year-round, even in regions with limited rainfall, enabling them to grow this crucial crop year-round.

As a result, CF and WF assessment based on farmer inputs can simultaneously provide significant insights like the discrepancy between theoretical and actual water use. This can aid in locating opportunities to increase water use efficiency and serve as a decision-making framework for sustainable water management techniques. Additionally, CF and WF assessments can offer insightful data on how agricultural activities generally affect the environment, enabling targeted interventions to lower carbon emissions and water pollution. Research on tomato and pumpkin yielded crucial information on the CF and WF of crop production. Expanding the analysis to other crops is essential for a comprehensive understanding of environmental impact.

Policymakers can develop targeted strategies to reduce GHG emissions and water use in agriculture by understanding CF variations across agroclimatic zones and farm sizes. Evaluating inputs and identifying successful mitigation strategies can help reduce environmental effects and support a more environmentally friendly and sustainable agricultural sector.

9.2 Environmental Footprint Indicators:

Relevant indicators of the environmental effects of agriculture and FSs are variables that depict both direct and indirect measurements of resource use as well as unfavourable changes in the quality and functionality of limited, important, and vulnerable natural resources.

The quality of the soil, water, air, and atmosphere are some of the crucial ecological indicators. Natural resources might be viewed as limited, fragile, and non-renewable instead of as a factor of production. Wiek and Tkacz (2013), proposed the term "ecological indicator" or EFP to denote ecological assets that a community requires, as well as the natural resources it uses to produce the necessary goods and services, and also to absorb or dispose of the waste or byproduct. This concept was based on life cycle analyses for a variety of products and services.

Therefore, EFP, which includes all components, including water and biodiversity, is a measure of GHG emissions during the production of products or services in relation to global warming and anthropogenic emissions.

The term "carbon footprint" or CFP refers to this indication, which is transformed to a carbon (C) equivalent for goods and services over their full life cycle, from conception to final disposition. The latter is frequently employed among the general public to highlight the danger posed by human-caused climate change (Chen et al., 2021).

As the primary element of EFP, CFP may account for more than half of the EFP of an agricultural commodity (Balogh, 2019). The EFP, however, consists of a variety of elements, including resources (RFP), food (FFP), nitrogen (NFP), biodiversity (BFP), and land (LFP) (Figure 9.1). The word CFP refers to a total numerical value expressed in terms of carbon dioxide equivalent for all EFP components (e.g., LFP, WFP, BFP, RFP, FFP, etc.). CFP is so commonly utilised in the context of identifying strategies for mitigating and coping with global climate change.

Figure 9.1: Environmental footprint indicators

9.3 Concept of Carbon and Water Footprint:

Farmers can optimize water use by implementing Conservation Farming (CF) techniques like crop rotation and cover cropping. Water Footprint Management (WF) focuses on analyzing and reducing water usage during production stages, including supply chain operations and irrigation systems. These methods enhance resource efficiency and promote sustainable water management in agricultural practices.

CF and WF are essential metrics for evaluating a product's environmental impact, with WF focusing on the water footprint and CF on greenhouse gas emissions. These metrics aid in making environmentally friendly decisions and understanding product sustainability. WF consists of green, blue, and grey footprints, with green referring to water stored in soil moisture and blue referring to surface or subsurface water used during manufacturing. Grey represents contamination of water during agricultural operations, as highlighted by Hoekstra (2017). This is a sign that agricultural practices have caused pollutants or other impurities to enter the water supply.

The CO2-equivalent is a crucial metric for comparing greenhouse gases and their impact on climate change. It accounts for gases like methane and nitrous oxide, as well as CO2's warming potential. This standardized unit helps researchers understand the impact of emissions and develop effective mitigation plans. Crop yield, demand, quality, and meteorological conditions are the main factors determining the cost of production (CF) and weight loss (WF) of agricultural products. These factors help farmers allocate resources effectively and minimize their environmental impact. Considering inputs like fertilizer and pesticides and meteorological factors like temperature and rainfall helps farmers understand crop production variability and adjust farming practices accordingly. The CF and WF evaluation of a product provides context for inputs and water usage.

Consumers, dealers, and the food industry can contribute to the logical management of inputs, resulting in more environmentally friendly production techniques and a smaller negative impact. This knowledge helps consumers make informed decisions, selecting goods that align with their values and support water conservation efforts. The environmental impact of a product is significantly impacted by its water and carbon footprints. Sustainable cultivation methods like organic farming and precision agriculture can reduce these footprints. Efficient transportation strategies and improved distribution networks can also reduce energy usage and environmental impacts. Businesses must consider these factors to maximize input management and minimize product environmental impact.

9.3.1 Agriculture and Carbon Footprint:

Greenhouse gas emissions are crucial metrics for evaluating agricultural sustainability, as they significantly impact ecosystems and contribute to climate change. Monitoring and reducing greenhouse gas emissions is essential for achieving global sustainability goals and minimizing the negative impact of agriculture on the environment. The term "carbon footprint" is defined and used in their analysis based on two methods for calculating the effects.: (a) the total greenhouse gas emissions per unit of farmland, measuring the overall emissions from crop production with an emphasis on environmental health, and (b) the amount of greenhouse gas emissions associated with each kilogram of grain produced, emphasizing both the products (i.e., grain yield) associated with each unit of emission as well as emissions during crop production. The latter strategy focuses on increasing crop production while reducing greenhouse gas emissions using sustainable farming techniques like organic and precision agriculture. It maximizes resource use and reduces chemical inputs, preserving the environment.

It is commonly acknowledged that humanity's current EFP cannot last. Humanity has significantly changed the earth's landscape, dramatically increased resource use, and produced a significant amount of garbage as a result of land conversion for agriculture and other anthropogenic activities. According to Hoekstra and Wiedmann (2014), the actual vs sustainable EFP of humanity was 10.5 vs. 8.0 Mg/capita of material footprint, 1000-1700 vs. 1100-4500 B m3 of blue water, and 18.2 vs. 12 B ha of land. In addition, Hoekstra and Wiedmann noted that the WFP for humanity (measured in B m3 year) was 1400 for grey water and 6700 for green water. The foundation of civilization, which started with the introduction of agriculture around 8000 BC, is food and agriculture. The majority of cultures and religion’s view soil and agriculture as integral to their legacy. In fact, establishing global peace and stability depends on sustainable soil and agricultural management (Lal, 2015). Natural resources are also heavily consumed by agriculture and FSs. Currently, 3.75 billion hectares (3.75 billion acres) of the ice-free area are used for agriculture, of which 1.5 billion hectares (3.50 billion acres) are used for crop cultivation.

Furthermore, irrigation uses 70% of all fresh water withdrawals. Despite being a problem that, according to a wide range of religions and cultures hunger and malnutrition are the unattractive sides of both agriculture and FSs that need to be addressed. The latter includes the effects of agriculture and FSs on the environment (such as soil, water, air, and biodiversity) as well as the maintenance of famine and hidden hunger. Agriculture and FSs account for a sizable portion of the total CFP, particularly in emerging nations.

For instance, five pillars for reducing CFP were identified at COP-26 in Glasgow (2021): (1) eliminate waste; (2) intelligently use power; (3) use bioenergy for circular economy; (4) employ hydrogen; and (5) sequester carbon (C). Agriculture, the majority of which have significantly depleted terrestrial carbon stores (Lal, 2018), rely on the final pillar of carbon sequestration since they have a high ability to store atmospheric CO_2 in biomass. The CFP of agricultural production is influenced by a variety of agricultural factors.

According to Balogh (2019), agricultural output factors including arable land, agricultural machinery, fertiliser use, irrigation, and other inputs which are dependent on economic growth. In order to reduce CFP of FSs, it is therefore necessary to identify factors affecting agricultural productivity and use-efficiency as well as site-specific technological options based on advised and scientifically supported best practises that can lower CFP of food products and other related commodities.

9.3.2 Agriculture's Water and Carbon Footprint:

Determining Crop Footprint (CF) and Water Footprint (WF) involves analyzing each crop species' life cycle within a region. This helps estimate the resources needed for growth and production, such as water and carbon. This analysis helps in determining CF and WF, aiding in sustainable agricultural practices, and reducing the environmental impacts of crops. Lower carbon and water footprint (CF) and water footprint (WF) products offer numerous advantages for consumers and the manufacturing process. These products reduce environmental impact, reduce climate change, and promote sustainable resource management. Traditional systems lack water efficiency compared to organic and integrated production methods, which prioritize effective irrigation and water conservation techniques. These methods, like rainwater collection and drip irrigation systems, aim to reduce water waste.

A combination of production system and farm site can reduce in and production costs, resulting in energy savproductivity. Strategically planning these elements maximizes resource utilization and minimizes waste, leading to higher profits and enterprise sustainability. Combination promotes nutritious food production, enabling consumers to measure and record the CF and WF of food.: (a) Choose items that genuinely fight climate change (b) Identify the product's competitive advantage versus other products and (c) By highlighting the use of products with lower CF and WF, promote the overall environmental advantages.

Producers should reduce inputs like fertilizers, gasoline, and irrigation equipment to reduce their carbon footprint. These compounds limit both N_2O emissions into the environment and leaching into deeper soil layers (Akiyama et al., 2010). Reduced input losses and sensible water management in cultivation procedures may make crops more tolerant of dry regions. In conclusion, agricultural production must employ environmentally friendly farming techniques that lower CF and WF.

Agricultural products' enhanced flavour, nutritional value, and desirability provide added value, giving farmers a competitive advantage and enabling higher market prices.

9.4 Conclusion:

Environmental indicators assess agricultural systems based on yield and water use, providing crucial information on their effectiveness and sustainability. These indicators enable informed decisions to support sustainable farming practices by considering both yield and water consumption. Implementing environmentally friendly farming methods like organic farming, crop rotation, and integrated pest management can reduce soil erosion, increase biodiversity, and reduce the use of synthetic fertilizers and pesticides in agriculture.

A sufficient number of farms can enable comparisons between farming methods, species, and environments, providing insights into efficiency and sustainability. Considering factors like soil quality, climatic conditions, and economic viability enhances the precision and applicability of these comparisons.

This strategy improves input rationalization by offering lower carbon footprint (CF) and water footprint (WF) products, meeting consumer preferences while using less energy. It encourages producers to innovate and create environmentally friendly production techniques, reducing waste and resource utilization. This not only benefits the environment but also encourages responsible energy use in the supply chain.

To stabilize agricultural production's resilience to climate change, farmers can adopt less intensive farming methods like crop rotation, agroforestry, and integrated pest management. These practices promote biodiversity and reduce chemical inputs. Precision agriculture methods like soil mapping and remote sensing maximize resource use and reduce environmental effects.

Agro-environmental indices are valuable for decision-makers seeking to balance agricultural productivity and climate change. These indices provide insights into the impact of agricultural practices on the environment, enabling sustainable farming practices. By considering these indices, decision-makers can make informed decisions that support productivity and environmental preservation in the face of climate change challenges.

9.5 References:

1. Akiyama, H., Yan, X., & Yagi, K. (2010). Evaluation of effectiveness of enhanced-efficiency fertilizers as mitigation options for N2O and NO emissions from agricultural soils: meta-analysis. *Global Change Biology*, *16*(6), 1837-1846.
2. Balogh, J. M. (2019). Agriculture-specific determinants of carbon footprint. *Studies in Agricultural Economics*, *121*(3), 166-170.
3. Benbi, D. K. (2018). Carbon footprint and agricultural sustainability nexus in an intensively cultivated region of Indo-Gangetic Plains. *Science of the Total Environment*, *644*, 611-623.
4. Cambridge University Press: Cambridge, UK, 2014.

5. Chauhan, B. S., Mahajan, G., Sardana, V., Timsina, J., & Jat, M. L. (2012). Productivity and sustainability of the rice–wheat cropping system in the Indo-Gangetic Plains of the Indian subcontinent: problems, opportunities, and strategies. *Advances in Agronomy*, *117*, 315-369.
6. Chen, R., Zhang, R., & Han, H. (2021). Where has carbon footprint research gone? *Ecological Indicators*, *120*, 106882.
7. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.
8. Ercin, E., & Hoekstra, A. Y. (2012). Carbon and water footprints: Concepts, methodologies and policy responses. *World Water Assessment Programme*, (4).
9. FAO, 2017. Water for Sustainable Food and Agriculture: A Report Produced for the G20 Presidency of Germany. Food and Agricultural Organization (FAO).
10. Ghosh, B., & Chakma, N. (2019). Composite indicator of land, water and energy for measuring agricultural sustainability at micro level, Barddhaman District, West Bengal, India. *Ecological Indicators*, *102*, 21-32.
11. Gómez-Limón, J. A., & Sanchez-Fernandez, G. (2010). Empirical evaluation of agricultural sustainability using composite indicators. *Ecological Economics*, *69*(5), 1062-1075.
12. Hoekstra, A. Y. (2017). Water footprint assessment: evolvement of a new research field. *Water Resources Management*, *31*(10), 3061-3081.
13. Hoekstra, A. Y., & Wiedmann, T. O. (2014). Humanity's unsustainable environmental footprint. *Science*, *344*(6188), 1114-1117.
14. Intergovernmental Panel on Climate Change (IPCC). Climate Change 2014: Mitigation of Climate Change.
15. Kaltsas, A. M., Mamolos, A. P., Tsatsarelis, C. A., Nanos, G. D., & Kalburtji, K. L. (2007). Energy budget in organic and conventional olive groves. *Agriculture, Ecosystems and Environment*, *122*(2), 243-251.
16. Lal, R. (2015). The soil–peace nexus: our common future. *Soil Science and Plant Nutrition*, *61*(4), 566-578.
17. Lal, R. (2018). Digging deeper: A holistic perspective of factors affecting soil organic carbon sequestration in agroecosystems. *Global Change Biology*, *24*(8), 3285-3301.
18. Litskas, V. D., Karaolis, C. S., Menexes, G. C., Mamolos, A. P., Koutsos, T. M., & Kalburtji, K. L. (2013). Variation of energy flow and greenhouse gas emissions in vineyards located in Natura 2000 sites. *Ecological Indicators*, *27*, 1-7.
19. Mays, K. L., Shepson, P. B., Stirm, B. H., Karion, A., Sweeney, C., & Gurney, K. R. (2009). Aircraft-based measurements of the carbon footprint of Indianapolis. *Environmental Science and Technology*, *43*(20), 7816-7823.
20. Mekonnen, M. M., & Hoekstra, A. Y. (2010). A global and high-resolution assessment of the green, blue and grey water footprint of wheat. *Hydrology and Earth System Sciences*, *14*(7), 1259-1276.
21. Michos, M. C., Menexes, G. C., Kalburtji, K. L., Tsatsarelis, C. A., Anagnostopoulos, C. D., & Mamolos, A. P. (2017). Could energy flow in agro-ecosystems be used as a "tool" for crop and farming system replacement? *Ecological Indicators*, *73*, 247-253.
22. Page, G., Ridoutt, B., & Bellotti, B. (2012). Carbon and water footprint tradeoffs in fresh tomato production. *Journal of Cleaner Production*, *32*, 219-226.
23. Pathak, H., Jain, N., Bhatia, A., Patel, J., & Aggarwal, P. K. (2010). Carbon footprints of Indian food items. *Agriculture, Ecosystems and Environment*, *139*(1-2), 66-73.

24. Schäfer, F., & Blanke, M. (2012). Farming and marketing system affects carbon and water footprint–a case study using Hokaido pumpkin. *Journal of Cleaner Production*, *28*, 113-119.
25. Smith, P., Bustamante, M., Ahammad, H., Clark, H., Dong, H., Elsiddig, E. A., et al. (2014). Agriculture, forestry and other land use (AFOLU). In E. Ottmar (Eds.), *Climate change 2014: mitigation of climate change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 811-922). Cambridge University Press.
26. Tahmasebi, M., Feike, T., Soltani, A., Ramroudi, M., & Ha, N. (2018). Trade-off between productivity and environmental sustainability in irrigated vs. rainfed wheat production in Iran. *Journal of Cleaner Production*, *174*, 367-379.
27. Taxidis, E. T., Menexes, G. C., Mamolos, A. P., Tsatsarelis, C. A., Anagnostopoulos, C. D., & Kalburtji, K. L. (2015). Comparing organic and conventional olive groves relative to energy use and greenhouse gas emissions associated with the cultivation of two varieties. *Applied Energy*, *149*, 117-124.
28. Więk, A., & Tkacz, K. (2013). Carbon Footprint: an Ecological Indicator in Food Production. *Polish Journal of Environmental Studies*, *22*(1).
29. WRI, 2014. Available at. https://www. wri.org/blog/2014/11/6-graphs-explain-world-s-top-10-emitters.
30. Zhang, D., Shen, J., Zhang, F., Li, Y. E., & Zhang, W. (2017). Carbon footprint of grain production in China. *Scientific Reports*, *7*(1), 1-11.

10. Millet for Food Security

Mrs. Dhaneshwari Karnavat, Mr. Akash Khorde

M. Tech. Food Technology
MIT School of Food Technology, Pune
MIT ADT University
Pune.

Mrs. Deepti Chaudhari

Department of Food Safety, Quality and Nutrition (FSQN)
MIT School of Food Technology, Pune,
MIT ADT University
Pune.

Abstract:

Millets, known as coarse cereals, belong to the grass family (Gramineae/Paniceae) and encompass a range of 13 diverse varieties. These include Job's tears, fonio, pearl millet, finger millet, sorghum, little millet, proso millet, barnyard millet, brown top millet, foxtail millet, Guinea millet, and Kodo millet. These millet varieties originate from semi-arid tropical regions in Asia and Africa and offer various medicinal and nutritional benefits. Despite their rich content of vitamins, fiber, minerals, and phytochemicals, millets remain underutilized in many developed countries. However, their cultivation is relatively uncomplicated, and they have a short growth cycle, allowing farmers to obtain multiple harvests within a year.

Keywords:

Millets, food security, farmers, nutrition

10.1 Introduction:

Millets, commonly known as minor millets, belong to a category of cereal crops cultivated for their small-sized grains obtained from grassy plants in the Poaceae family. These millets hold great significance owing to their nutritional value, medicinal benefits, and utilization as animal feed, despite being categorized as minor crops. Moreover, they have historically served as crucial food sources during periods of food scarcity. (Kumar *et al.*, 2021).

Millets encompass a wide range of varieties originating from Asia and Africa, making them suitable for the challenging semi-arid tropical climates of these regions. In these areas, where other crops struggle to thrive, millets have historically served as a primary food source for the local populations. With approximately 6,000 different millet varieties currently cultivated worldwide, these crops have been domesticated since ancient times. Despite their nutritional advantages and adaptability, millets remain underutilized in many developed countries, failing to reach their full potential. (Karuppasamy 2015).

Millet holds a significant position among cereal grains, with over a third of the global population including it in their diets. It stands as the sixth most important cereal crop worldwide in terms of production. The millet family includes several varieties such as Jowar (sorghum), Sama (little millet), Ragi (finger millet), Korra (foxtail millet), and Variga (proso millet). Among them, Ragi has the lowest fat content, while Bajra and Sama contain higher-than-average amounts. Millets are predominantly consumed as food in rural areas and primarily cultivated for that purpose. (Kimeera Ambati and Sucharitha K.V.V, 2019).

Millets have gained the reputation of being "super grains" owing to their remarkable nutritional profile, making them highly beneficial for individuals dealing with obesity, diabetes, and cardiovascular diseases. These crops are not only considered intelligent due to their photo-insensitivity, drought tolerance, and resilience to various climates but are also regarded as intelligent foods due to their rich content of vitamins, fiber, and minerals.

Recognizing their importance, the FAO designated 2023 as the International Year of Millets, while India declared 2018 as the National Year of Millets. Despite their significance, millet production currently represents only 2 percent of the global cereal production, with Asia accounting for 40 percent of it. (Gutha *et al.,* 2021).

Millets offer not only fiber, minerals, and vitamin B complex but also serve as a rich source of phytochemicals. These organic compounds possess antioxidant and detoxifying properties, adding to the nutritional value of millets. For instance, finger millet (ragi) stands out for its high calcium content, a vital mineral for maintaining strong bones and teeth. With their diverse phytochemical composition, millets make an excellent inclusion in a well-rounded diet, providing additional health benefits beyond their basic nutritional components. (Raju *et al.,* 2018).

Millets play a significant role as a prominent source of essential nutrients and rank as the sixth-largest producer of cereal grains globally. They continue to be a staple in many regions, offering the added advantage of addressing nutrient deficiencies in developing nations. As a health food, millets boast several desirable qualities.

They feature gluten-free proteins, a substantial amount of fiber, a low glycemic index, and bioactive compounds that match or even surpass those found in major cereal grains in terms of nutritional value. Carbohydrate content in millets typically ranges from 56.88 to 72.97 g per 100 g, with barnyard millet displaying the lowest levels. Except for finger millet, which varies between 4.76 and 11.70 g/100 g across different studies, the protein contents of millets are generally comparable, averaging around 10 to 11%. (Ashwani *et al.,* 2018).

10.2 Types of millets:

Millets, a diverse group of small-seeded grasses, are cultivated and consumed worldwide. There are 13 known types of millets, including sorghum, finger millet, kodo millet, barnyard millet, brown top millet, foxtail millet, Guinea millet, Job's tears, fonio, and teff.

Among these, only Job's tears, fonio, and teff are not commonly grown in India. The remaining ten varieties of millets are widely available and consumed throughout India.

A. Sorghum or Jowar:

Sorghum (Sorghum bicolor) holds the position of being the fifth-most important cereal crop globally. It is primarily cultivated as a rain-fed crop across more than 42 million hectares of land by subsistence farmers in the semi-arid tropics (SAT) of Africa, Asia, and Latin America.

Sorghum serves as an excellent alternative for individuals with celiac disease, as it is a gluten-free ancient cereal grain that serves as a staple food in India and Africa, offering excellent gastrointestinal safety. India, in particular, witnessed a significant cultivation area dedicated to sorghum, exceeding 16 million hectares in 1981. However, this area gradually decreased to 7.8 million hectares by 2007-2008. Nonetheless, it still accounted for approximately 20% of the global sorghum cultivation area in recent years (Pragya *et al.*, 2021).

B. Finger Millet:

As highlighted by Pragya Singh and Rita Singh (2011), millets, known as coarse cereals, constitute a diverse group of small edible grasses belonging to the grass family (Gramineae/Paniceae). Among the various millet varieties, finger millet stands out as a highly nutritious cereal. It is rich in essential nutrients such as iron, calcium, fiber, protein, and the amino acid methionine. Finger millet proves particularly beneficial for individuals who have experienced multi-generational deficiencies in these crucial nutrients due to heavy reliance on starchy staples. Recent research emphasizes the significance of finger millet in combating malnutrition and addressing food insecurity in several regions worldwide.

C. Pearl millet:

Pearl millet (Pennisetum glaucum) is a versatile cereal crop widely cultivated in African and Asian countries for various purposes, including food, feed, and forages. It possesses remarkable resilience to drought and high temperatures, making it well-suited for regions where other cereal crops like wheat and maize face challenges. With a cultivation area exceeding 29 million hectares globally, pearl millet holds the largest share among millet varieties. While it is primarily concentrated in Africa, covering around 15 million hectares, it also holds significant cultivation area in Asia, accounting for approximately 11 million hectares. (Savita *et al.,* 2017).

D. Foxtail millet:

Foxtail millet (S. italica) serves as a significant crop in various regions worldwide. It is a staple food in arid and semi-arid areas of China, certain parts of India, and Japan. Additionally, foxtail millet is cultivated in North and South America for purposes such as hay and silage production. Foxtail millet is rich in essential nutrients including iron, calcium, potassium, zinc, magnesium, and vitamins. It also contains raw edible fibers. Notably, foxtail millet has a low glycemic index (GI) and is gluten-free, making it an excellent dietary choice for individuals with specific nutritional requirements or health conditions. (Roshan *et al.,* 2017).

E. Kodo millet:

Kodo millet, known for its origins in India, is believed to have been domesticated around 3000 years ago. It is scientifically known as Paspalum scrobiculatum L. and is extensively found in arid and semi-arid regions of India and various African countries. One of the notable characteristics of Kodo millet is its ability to thrive in less fertile soils, making it suitable for cultivation in subpar agricultural conditions. (Durga *et al.*, 2021).

F. Barnyard Millet:

Barnyard millet, scientifically known as Echinochloa crusgalli (L.) P. Beauvois, is a versatile crop cultivated for both food and fodder purposes. It is referred to by various names, including Japanese barnyard millet, ooda, oodalu, sawan, sanwa, and sanwank. Nutritionally, barnyard millet is a valuable source of highly digestible protein and dietary fiber, offering a balanced combination of soluble and insoluble fractions. Its low and slow digestible carbohydrate content makes it particularly beneficial for modern individuals leading sedentary lifestyles. Barnyard millet is thus considered a valuable natural resource in terms of its nutritional composition. (Dayakar *et al.,* 2017).

G. Proso millet:

Proso millet, scientifically known as Panicum miliaceum L., is believed to have been domesticated approximately 10,000 years ago in China. The domestication of proso millet is associated with the beginning of the Holocene period, a time characterized by rising temperatures and the interaction of hunter-gatherers with new plant species and environments, as suggested by current archaeological theories (Cedric et al., 2017). Over time, proso millet has become a vital source of nutrition for populations worldwide.

H. Little millet:

Little millet, scientifically known as Panicum sumatrense, originated in India as a domesticated cereal crop. It is primarily cultivated in specific regions of India up to an altitude of 2100 meters and holds lesser significance in other parts of the world. Little millet is characterized by its smaller seeds compared to common millet and shares visual similarities with proso millet. This annual herbaceous plant grows upright or with folded blades, reaching heights ranging from 30 cm to 1 m. The linear leaves of little millet occasionally feature hairy lamina and membranous hairy ligules. The panicles of the plant bear awns measuring 2 to 3.5 mm in length and range from 4 to 15 cm in size. The grain of little millet is round and smooth, typically measuring 1.8 to 1.9 mm in length. (Dayakar *et al.,* 2017).

10.3 Millets Production and Consumption:

According to FAOSTAT (2021), global millet production in 2019-20 reached 84.17 million metric tonnes, cultivated on an area of 70.75 million hectares. India contributed approximately 20.50% of the total production. Millet consumption is significant in Africa and Asia, with around 90 million people in these regions relying on millet as a staple food.

Africa holds the majority share, producing over 55% of the world's millet, while Asia accounts for nearly 40%. Europe, on the other hand, constitutes only about 3% of the global millet market. (Alam and Reddy, 2023).

The primary producers of millet crops in India were the southern states of Karnataka, Maharashtra, Gujarat, and Tamil Nadu. Among these states, Karnataka was the leading producer, followed by Maharashtra, Gujarat, and Tamil Nadu. In terms of consumption, Karnataka and Maharashtra had relatively higher consumption rates, with urban consumers typically consuming millet crops "once or twice a week." In Gujarat, despite being the largest producer of pearl millet, the consumption of these crops was comparatively lower, suggesting that the high production had limited impact on urban consumption patterns. In Delhi, where production levels were modest, millet crops were consumed moderately, typically once a month. (Joanna *et al.,* 2021).

The production and consumption of millets are predominantly concentrated in developing countries, accounting for over 97% of the global total. However, the global area dedicated to millet cultivation has decreased by approximately 25.71% between 1961 and 2018 across all continents. Despite this, the overall productivity of millets has increased worldwide, with yields rising from 575 kg/ha in 1961 to 900 kg/ha in 2018.

While millet production has significantly increased in Africa, experiencing substantial growth, most other regions have witnessed a decline over the past 58 years. West Africa, in particular, has observed the largest increase, with production nearly doubling in the 1960s. In Asia, although the land area allocated for millet cultivation has reduced, productivity has steadily improved, leading to increased production.

India, with a significant share of 37.5% in global millet production, holds the top position, followed by Sudan and Nigeria. However, millet production in India reached its peak in the 1980s and has gradually declined as cultivated land has diminished. (Meena *et al.*, 2021).

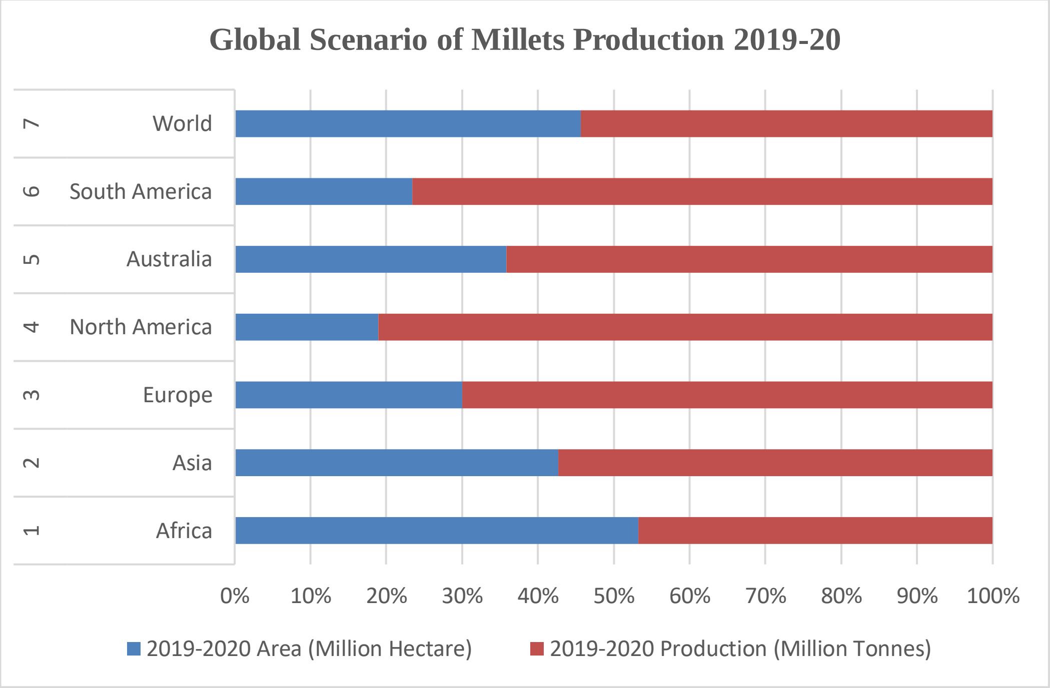
Minor millets, also known as coarse grains, are crucial sources of nutrition for tribal communities in areas with low yields of primary cereals. They contain high concentrations of micronutrients like vitamin B complex, calcium, iron, and sulfur, offering higher nutritional value than cereals. Despite being less expensive sources of dietary calories, their consumption has declined. Promoting the inclusion of minor millets in diets can address nutritional needs and improve overall health. (Junaid *et al.,* 2022).

Millet crops are predominantly cultivated in semi-arid regions of Asia and Africa, covering approximately 32.12 million hectares and yielding 28.76 million tonnes in 2013. These crops possess a short growth cycle of 60 to 90 days, making them well-suited to thrive in environments with limited moisture, high temperatures, and nutrient-depleted soils. Millets play a vital role in subsistence farming, particularly in areas with unpredictable rainfall and poor soil fertility, as they exhibit adaptability to such challenging environmental conditions.

Moreover, millets are cost-effective for small-scale farmers as they require minimal inputs. Additionally, millets offer excellent nutritional value due to their high protein, mineral, and dietary fiber content. (Umanath *et al.*, 2018).

Studies have revealed that the consumption of millet protein, particularly UCE and UCEE FM protein, can have beneficial effects on weight loss and liver health. Furthermore, research indicates that the inclusion of millet protein, specifically UCE and UCEE millet protein, can mitigate the increased impact of D-galactosamine on certain liver enzymes in the bloodstream, such as AST, ALT, and LDH.

Additionally, the intake of UCE and UCEE millet protein has been associated with reduced levels of plasma TC, TG, and LDL-C, as well as TC and TG in the liver. Interestingly, it also leads to increased levels of HDL-C, which may contribute to improved cardiovascular well-being. (Ashfak *et al.*, 2023).



(Source: FAOSTAT, 2021)

10.4 Nutritional Importance and Health Benefits of Millets:

A. Sorghum:

Sorghum, a nutrient-rich cereal crop, offers a wide range of vitamins and minerals, predominantly present in the aleurone layer and germ. It is notably abundant in various B vitamins, except for B12. Yellow sorghum grain, in particular, exhibits high levels of beta-carotene, lutein, and zeaxanthin, although this can vary based on genetics and environmental factors. While sorghum is not a significant source of vitamin C, it can be produced through soaking and germination. Sorghum grain also contains detectable amounts of vitamins E, K, and D. Research suggests that sorghum may have potential health benefits for conditions such as celiac disease, obesity, diabetes, and coronary heart disease, as indicated by a study conducted by Dayakar et al. in 2017.

B. Finger Millet:

Finger millet is a highly nutritious cereal grain with a protein content ranging from 5-8%, ether extractives of 1-2%, carbohydrates of 65-75%, dietary fiber of 15-20%, and minerals of 2.5-3.5%. It stands out with its exceptional calcium content of 344 mg per 100 grams, surpassing other cereals. Previously labeled as "anti-nutrients," finger millet contains substances like phytates (0.48%), polyphenols, tannins (0.61%), and trypsin inhibitory factors, which possess metal-chelating and enzyme-inhibiting properties, as reported in a study by Palanisamy et al. in 2011.

Finger millet has shown potential health benefits due to its anti-mutagenic, anti-estrogenic, anti-carcinogenic, anti-inflammatory, and antiviral properties. These findings, derived from various studies, establish finger millet as a beneficial addition to a nutritious diet, as highlighted by (Palanisamy *et al.*, 2011).

C. Pearl millet:

According to a study conducted by Ragaee et al. in 2006, pearl millet is a highly nutritious grain with abundant resistant starch, soluble and insoluble dietary fibers, minerals, and antioxidants. It contains approximately 2.1% ash, 2.8% crude fiber, 7.8% crude fat, 13.6% crude protein, and 63.2% starch, making up about 92.5% of its dry matter content. The energy value of pearl millet is reported to be 361 Kcal per 100g, as stated by (Patni and Agrawal 2017).

Multiple epidemiological studies have indicated that diets rich in plant-based foods can contribute to the prevention of various degenerative diseases, including cancer, heart conditions, diabetes, metabolic syndrome, and Parkinson's disease. These findings were presented in the study conducted by Patni and Agrawal (2017) in their study.

D. Foxtail millet:

Foxtail millet is a highly nutritious grain known for its low glycemic index (GI) and high fiber content. Compared to other cereals, it has a higher protein content and more fiber. A study has shown that foxtail millet contains glucans, which can enhance the metabolism of sugar and cholesterol. As a result, foxtail millet has hypoglycemic and hypocholesterolemic effects, making it beneficial for preventing diabetes and cardiovascular diseases. This research finding highlights the potential of foxtail millet as an ingredient for low-GI foods. (Hariprasanna 2016).

E. Kodo millet:

Kodo millet is a nutritious grain known for its protein content of 8%. Glutelin is the predominant protein fraction in kodo millet. It is also an excellent source of dietary fiber, with a high content of 9%, surpassing wheat (1.2%) and rice (0.2%). The carbohydrate content in kodo millet is 66.6g per 100g, providing 353 kcal. It contains minerals at a level of 2.6% and fat at 1.4%. Kodo millet is also notable for its iron concentration, ranging from 25.86 to 39.60 ppm. (Deshpande *et al.*, 2015).

Scientific studies have suggested that incorporating millet into one's diet can provide several health benefits. These benefits include the prevention and management of conditions such as heart attacks, atherosclerosis, migraines, high blood pressure, and diabetic heart disease. Additionally, the high fiber content of millet has been associated with a reduced risk of gallstone formation. (Deshpande *et al.,* 2015).

F. Barnyard Millet:

Grains are recognized for their nutritional value due to their rich content of protein, carbohydrates, fiber, and essential micronutrients such as iron (Fe) and zinc (Zn). Compared to commonly consumed cereals like rice, wheat, and maize, grains are often more affordable, making them a cost-effective and beneficial option for meeting dietary needs. (Vellaichamy *et al.,* 2020).

Barnyard millet has been associated with various medicinal benefits, including its anti-inflammatory, anti-carcinogenic, antioxidant, and antimicrobial properties. It also possesses wound-healing properties and has shown effectiveness in managing biliousness and constipation-related ailments. (Vellaichamy *et al.,* 2020).

G. Proso millet:

Proso millet is rich in essential amino acids such as methionine, phenylalanine, tryptophan, and valine. However, it has a relatively lower content of lysine, which is considered a limiting amino acid. Despite this, Proso millet has a higher essential amino acid index (51%) compared to wheat (45%). It is a nutritious grain, similar to other popular cereals like rice and wheat, containing significant amounts of protein, carbohydrates, and energy. With approximately 11% protein content per 100g, Proso millet provides essential micronutrients like iron, zinc, and copper. Additionally, due to its lower glycemic index (GI), Proso millet is suitable for individuals with type-2 diabetes and cardiovascular disease. Products made entirely from Proso millet have a GI of 50-65, which is notably lower than refined corn- and wheat-based products (Saurav *et al.,* 2019).

H. Little millet:

Little millet is a nutritious grain known for its high fiber content and can be a healthy alternative to rice in various dishes such as pongal and kheer. It not only provides ample fiber but also contains significant amounts of phosphorus (220 mg/100g) and iron (9.3 mg/100g). Ankita et al. (2020) state that little millet can be particularly beneficial for individuals with low body mass and those dealing with conditions like cancer, diarrhea, and cardiovascular diseases. It is considered a wholesome grain with potential health advantages.

10.5 Millet and Food Security:

Millet, a highly nutritious and drought-resistant crop, has been cultivated for centuries in various regions of the world. It belongs to the Poaceae family, which includes major food crops like wheat, rice, and maize. Millet serves as a vital source of food and livelihood for millions of people in arid and semi-arid regions of Africa and Asia. This versatile crop has multiple uses, including ethanol production, animal feed, and as a staple food. It can be consumed as porridge, flatbread, or ground into flour for baking.

Millet stands out for its high protein, dietary fiber, vitamins (such as magnesium, phosphorus, and potassium), and essential amino acids like lysine and tryptophan, which are often deficient in other cereal grains like wheat and rice. It is also gluten-free, making it suitable for individuals with celiac disease or gluten intolerance. Millet plays a crucial role in food security, providing a reliable food source and income for farmers in regions prone to drought and challenging conditions. Despite its advantages, millet has often been overlooked due to the dominance of other crops and limited awareness of its nutritional value and versatility. However, there is a growing interest in promoting millet as a sustainable and nutritious food crop, with various initiatives underway to support its cultivation and consumption.

10.6 Challenges and Opportunities:

Small millets, including finger millet, foxtail millet, proso millet, barnyard millet, kodo millet, little millet, teff, fonio, job's tears, guinea millet, and browntop millet, are coarse cereal grains that serve as staple foods in various regions. They belong to the Poaceae family, which also includes major cereals like rice, wheat, maize, and sorghum. However, small millets offer several advantages over large cereals.

One significant advantage is their agroecological adaptability. Small millets can thrive in diverse agroecological conditions, including drylands and low-fertility soils, where other crops may struggle to grow. They require less water and fertilizer, making them more environmentally friendly and sustainable compared to major cereals.

In terms of nutrition, small millets have a superior profile. They are rich in protein, fiber, and essential micronutrients such as calcium, iron, and zinc. This makes them a valuable dietary choice for individuals seeking a nutrient-dense food source. Moreover, small millets are gluten-free, making them suitable for individuals with gluten intolerance.

Overall, small millets offer a combination of adaptability, sustainability, and nutritional value, making them a promising option for food security and sustainable agriculture. Their cultivation and consumption can contribute to diverse and resilient food systems reduce the plagarism.

Small millets have additional benefits when it comes to addressing immediate food security needs. One advantage is their ability to provide multiple harvests within a single year. Due to their fast maturation and short growth cycles, small millets can be harvested more frequently compared to major cereals. This characteristic makes them a valuable resource for meeting immediate food requirements.

Furthermore, small millets exhibit resilience in challenging environmental conditions. They are well adapted to withstand drought, low-fertility soils, and other harsh conditions. This resilience ensures a stable food supply even during periods of environmental stress.

Their capacity to provide multiple harvests and withstand adverse conditions makes them valuable for ensuring food availability and resilience in communities. However, there are various challenges that affect millet food security.

These challenges include inadequate investment in research and development, limited market access, the impact of climate change, and insufficient awareness of millet's nutritional benefits. Insufficient investment in developing new millet varieties and protecting against pests, diseases, and extreme weather leads to low yields and crop failures in regions prone to drought and flooding. Additionally, small-scale farmers often face difficulties in obtaining fair prices and accessing markets, which discourages them from investing in millet production. Climate change further exacerbates these challenges by causing unpredictable weather patterns and crop failures. Furthermore, the underutilization of millet beyond traditional production regions limits its market potential, despite its high nutritional value. Addressing these challenges is crucial for promoting millet's role in food security (Source: Fetene et al., 2011).

There are various strategies that can be employed to enhance the food security of millet. One key aspect is the increasing demand for nutritious and sustainable food among health-conscious consumers, which provides farmers with new markets and income opportunities. Implementing new technologies and innovations, such as improved seeds, precision farming techniques, and efficient irrigation systems, can increase millet yields and mitigate the risks posed by climate change. Governments and non-governmental organizations (NGOs) can support millet farmers by implementing policy interventions such as facilitating access to credit, providing training, and disseminating market information.

Furthermore, there is potential to transform millet into high-value products like millet flour, which could drive demand and create additional income streams for farmers. By investing in research and development, expanding market access, and implementing supportive policies, it is possible to ensure that millet remains a significant source of food and nutrition for communities worldwide. These measures can contribute to improving the overall food security of millet and the well-being of millet farmers. (Source: Adapted from Fetene et al., 2011).

10.7 Conclusion:

Millet continues to be a prevalent staple food in numerous regions, particularly in developing countries, and it holds great potential in combating malnutrition. The versatility of millet is noteworthy, as it can be utilized for various purposes such as ethanol production and animal feed. Its resilience to adverse conditions and ease of cultivation make it a reliable source of both food and income for farmers. Millet's nutritional value and sustainability further enhance its appeal as a crop.

Recognizing its significance, several initiatives have been established to support the cultivation and consumption of millet. These initiatives aim to capitalize on its nutritional benefits, sustainability, and ability to address immediate food security needs. The cultivation and consumption of millet are being promoted as a means to improve nutrition and enhance food security.

10.8 References:

1. Ambati, K., & Sucharitha, K. V. (2019). Millets-review on nutritional profiles and health benefits. *International Journal of Recent Scientific Research*, *10*(7), 33943-33948.
2. Anitha, S., Kane-Potaka, J., Tsusaka, T. W., Botha, R., Rajendran, A., Givens, D. I., ... & Bhandari, R. K. (2021). A systematic review and meta-analysis of the potential of millets for managing and reducing the risk of developing diabetes mellitus. *Frontiers in nutrition*, 386.
3. Bunkar, D. S., Goyal, S. K., Meena, K. K., & Kamalvanshi, V. (2021). Nutritional, functional role of kodo millet and its processing: a review. *Int. J. Curr. Microbiol. App. Sci*, *10*(01), 1972-1985.
4. Bunkar, D. S., Goyal, S. K., Meena, K. K., & Kamalvanshi, V. (2021). Nutritional, functional role of kodo millet and its processing: a review. *Int. J. Curr. Microbiol. App. Sci*, *10*(01), 1972-1985.
5. Das, S., Khound, R., Santra, M., & Santra, D. K. (2019). Beyond bird feed: Proso millet for human health and environment. *Agriculture*, *9*(3), 64.
6. Dayakar Rao, B., Bhaskarachary, K., Arlene Christina, G. D., Sudha Devi, G., Vilas, A. T., & Tonapi, A. (2017). Nutritional and health benefits of millets. *ICAR_Indian Institute of Millets Research (IIMR), Rajendranagar, Hyderabad*, *112*, 33.
7. Deshpande, S. S., Mohapatra, D., Tripathi, M. K., & Sadvatha, R. H. (2015). Kodo millet-nutritional value and utilization in Indian foods. *Journal of grain processing and storage*, *2*(2), 16-23.
8. Devi, P. B., Vijayabharathi, R., Sathyabama, S., Malleshi, N. G., & Priyadarisini, V. B. (2014). Health benefits of finger millet (Eleusine coracana L.) polyphenols and dietary fiber: a review. *Journal of food science and technology*, *51*, 1021-1040.
9. Fetene, M., Okori, P., Gudu, S., Mneney, E. E., & Tesfaye, K. (2011). Delivering new sorghum and finger millet innovations for food security and improving livelihoods in Eastern Africa.
10. Habiyaremye, C., Matanguihan, J. B., D’Alpoim Guedes, J., Ganjyal, G. M., Whiteman, M. R., Kidwell, K. K., & Murphy, K. M. (2017). Proso millet (Panicum miliaceum L.) and its potential for cultivation in the Pacific Northwest, US: a review. *Frontiers in plant science*, 1961.
11. Habiyaremye, C., Matanguihan, J. B., D’Alpoim Guedes, J., Ganjyal, G. M., Whiteman, M. R., Kidwell, K. K., & Murphy, K. M. (2017). Proso millet (Panicum miliaceum L.) and its potential for cultivation in the Pacific Northwest, US: a review. *Frontiers in plant science*, 1961.
12. Hariprasanna, K. (2023). Foxtail millet: Nutritional importance and cultivation aspects.
13. Kane-Potaka, J., Anitha, S., Tsusaka, T. W., Botha, R., Budumuru, M., Upadhyay, S., ... & Nedumaran, S. (2021). Assessing millets and sorghum consumption behavior in urban India: A large-scale survey. *Frontiers in sustainable food systems*, *5*, 680777.
14. Kane-Potaka, J., Anitha, S., Tsusaka, T. W., Botha, R., Budumuru, M., Upadhyay, S., ... & Nedumaran, S. (2021). Assessing millets and sorghum consumption behavior in urban India: A large-scale survey. *Frontiers in sustainable food systems*, *5*, 680777.
15. Karuppasamy, P. (2015). Overview on Millets. *Trends in Biosciences*, *8*(13), 3269-3273.
16. Kumar, A., Tomer, V., Kaur, A., Kumar, V., & Gupta, K. (2018). Millets: a solution to agrarian and nutritional challenges. *Agriculture & food security*, *7*(1), 1-15.

17. Kumar, A., Tripathi, M. K., Joshi, D., & Kumar, V. (Eds.). (2021). *Millets and Millet Technology* (p. 438). Springer Singapore.
18. Malik, S. (2015). Pearl millet-nutritional value and medicinal uses. *International Journal of Advance Research and Innovative Ideas in Education*, *1*(3), 414-418.
19. Meena, R. P., Joshi, D., Bisht, J. K., & Kant, L. (2021). Global scenario of millets cultivation. *Millets and Millet Technology*, 33-50.
20. Muthamilarasan, M., & Prasad, M. (2021). Small millets for enduring food security amidst pandemics. *Trends in Plant Science*, *26*(1), 33-40.
21. Palai, J. B. Role of Minor Millets in Malnutrition Elevation in India.
22. Patni, D., & Agrawal, M. (2017). Wonder millet–pearl millet, nutrient composition and potential health benefits-a review. *Int J Innov Res Rev*, *5*, 6-14.
23. Poshadri, A., Deshpande, H. W., & Kshirsagar, R. B. (2023). The International Year of Millets-2023, Millets as Nutri-cereals of 21st Centenary for Health and Wellness.
24. Pragya Mishra, H. G. Prakash, Suman Devi, SeemaSonkar, Shweta Yadav, H. C. Singh and Singh, D. R. 2021. Nutritional Quality of Millets and their Value Added Products with the Potential Health Benefits: A Review.Int.J.Curr.Microbiol.App.Sci. 10(10): 163-175.
25. Prashanthi, A., & Geetha Reddy, R. (2023, January 23). Millet Status in India Production and Consumption.
26. Praveen, B., & Nagaraja, A. (2021). In vitro Efficacy of Plant Extracts against Bipolaris setariae causing Brown Top Millet Leaf Blight. *Int. J. Curr. Microbiol. App. Sci*, *10*(02), 1884-1889.
27. Raju, S., Rampal, P., Bhavani, R. V., & Rajshekar, S. C. (2018). Introduction of millets into the public distribution system: lessons from Karnataka. *Review of Agrarian Studies*, *8*(2369-2020-1990).
28. Rani, S., Singh, R., Sehrawat, R., Kaur, B. P., & Upadhyay, A. (2018). Pearl millet processing: a review. *Nutrition & Food Science*, *48*(1), 30-44.
29. Rao, D. B., Ananthan, R., Hariprasanna, K., Bhatt, V., Rajeswari, K., Sharma, S., & Tonapi, V. A. (2018). Nutritional and Health Benefits of Nutri Cereals. *Rajendranagar, Hyderabad: ICAR_Indian Institute of Millets Research (IIMR)*.
30. Reddy, B. V. S., Ramesh, S., & Reddy, P. S. (2004). Sorghum breeding research at ICRISAT-goals, strategies, methods and accomplishments. *International Sorghum and Millets Newsletter*, *45*, 5-12.
31. Renganathan, V. G., Vanniarajan, C., Karthikeyan, A., & Ramalingam, J. (2020). Barnyard millet for food and nutritional security: current status and future research direction. *Frontiers in genetics*, *11*, 500.
32. Sabuz, A. A., Rana, M. R., Ahmed, T., Molla, M. M., Islam, N., Khan, H. H., ... & Shen, Q. (2023). Health-Promoting Potential of Millet: A Review. *Separations*, *10*(2), 80.
33. Sharma, A., Tiwari, V. K., Suman, S., & Nagaraju, M. Nutritional and Neutraceutical Importance of Minor Millets: A Review.
34. Singh, P., & Raghuvanshi, R. S. (2012). Finger millet for food and nutritional security. *African Journal of Food Science*, *6*(4), 77-84.
35. Singh, R. K., Muthamilarasan, M., & Prasad, M. (2017). Foxtail millet: an introduction. *The foxtail millet genome*, 1-9.
36. Thapliyal, V., & Singh, K. (2015). Finger millet: potential millet for food security and power house of nutrients. *International or Research in Agriculture and Forestry*, *2*(2).

ISBN: 978-81-19149-59-9

11. Crop Residue Management: Recent Initiatives

Ancy G. Martin, Chinmaya Sahoo

M.Sc. Scholar, Department of Agronomy,
College of Agriculture, Vellayani,
Kerala Agricultural University,
Thrissur.

Atul Jayapal

Assistant Professor,
Kerala Agricultural University,
Thrissur.

Ankit Saini

Ph.D. Scholar,
Department of Agronomy,
CSKHPKV, Palampur, Himachal Pradesh.

Abstract:

Food production in India between 1947 and 1960 was not sufficient. During this time, Dr. M.S. Swaminathan, the main architect of India's Green Revolution, brought India out of the status of beggar's bowl. As the green revolution continues, there are some weaknesses. One of them is the large amount of agricultural waste associated with crop production. In India, farmers destroy crops by burning to prepare the soil for the next crop. The consequences of burning crops are now felt in the lungs of the people of Delhi.

Therefore, proper management of crop residue has become most important. Earning income from this waste is a good option to prevent farmers from burning the waste. There are many ways to use crop residues for sustainable agriculture and income. Different assets can be created from waste to generate income, making it an essential part of mixed farming. Thus, while the income increases, the agricultural waste problem is also solved. Plant-based fibres have the potential for commercial use in the manufacture of tissue, textiles, pulp and paper, building materials and other composite materials. It has become important to raise awareness among the farming community regarding the importance of crop residues for conservation agriculture and to generate income by adding value. There is no waste in the world unless we treat it as waste.

Keywords:

Crop residue, Surface retention, Mulch, Residue incorporation, Livestock feed, Soil less planting media, Mushroom Cultivation, Sustainable Agriculture.

11.1 Introduction:

The global population is anticipated to reach 8.5 billion by 2030, 9.7 billion by 2050, and over 11 billion by the end of the century [1]. Population growth has led to increased demand for food [2, 3], which has placed enormous pressure on agriculture. In India, food grain production was inadequate in the post-independence era. Dr. M.S. Swaminathan led the Green Revolution during this time [4]. It began in the 1960s and contributed to a rise in the country's food production. The fundamental goal of the Green Revolution was to develop high-yielding cereal varieties (HYVs) to combat poverty and malnutrition [5].

Not to be denied, the Green Revolution was able to alleviate hunger and malnutrition in short term [6]. However, there are also some weaknesses after the green revolution. The most significant of them is the massive production of agricultural waste along with crop production.

Agricultural wastes are waste materials generated from various agricultural operations. Agricultural waste typically includes harvest waste, other farm manure, hazardous waste such as pesticides and insecticides, and processing waste such as packaging material [7]. Crop residues comprise both field residues left in an agricultural field or orchard after harvesting a crop and process residues remaining after the crop has been processed into a marketable resource. Field residues include things like stalks and stubble (stems), leaves, and seed pods. Process residues include sugarcane bagasse and molasses, to name a few [8].

Crop leftovers are produced in vast quantities during crop cultivation. Crop residue recycling offers the advantage of transforming agricultural waste into a usable product that may be used to meet the fertiliser requirements of future crops. Crop residues include a substantial amount of plant nutrients, and their appropriate use will benefit the nutrient management system. Because of the scarcity of plant nutrients in crop fields, the high cost of synthetic fertilisers, and the low efficiency of chemical fertilisers, recycling crop wastes to supply plant nutrients is becoming increasingly important in order to replenish plant nutrients, maintain soil health, and reduce pollution [9].

To maintain sustainable agricultural productivity, it is essential to recycle nutrients from crop residues after harvest. Adoption of effective crop residue management practices is a necessity today.

11.2 Generation of Crop Residues:

According to the Indian Ministry of New and Renewable Energy (MNRE), India produces 500 million tonnes (Mt) of crop leftovers each year on average. According to the National Policy for Management of Crop Residues (NPMCR), the state of Uttar Pradesh produces the most crop residues (60 Mt), followed by Punjab (51 Mt), and Maharashtra (46 Mt), for a total of 500 Mt every year. Cereals (352 Mt) produce the most residues, followed by fibres (66 Mt), oilseeds (29 Mt), pulses (13 Mt), and sugarcane (12 Mt). Cereals (rice, wheat, maize, millet) account for 70% of crop wastes, with rice alone accounting for 34%. The accumulation of massive amounts of agricultural waste is becoming a problem as a result of ineffective crop residue management.

11.3 On Farm Burning of Crop Residues:

Around 93 Mt of plant residues are burned on-farm in the country out of 500 MT of residues produced [10]. According to the IPCC, over 25% of total crop residues were burned on the farm. Paddy fields in Kuttanad, Kerala's rice bowl, are dark today, with some spewing plumes of smoke. In many parts of the world, burning agricultural residues is the most common practice in preparing land for growing another crop [11].

A large amount of crop residues after the harvest of the first crop remained in the field for a long time, and their management is a big challenge for farmers. Therefore, it is very important to look for alternative management practices to use discarded crop residues in a way that does not affect the environment or soil fertility [12].

Crop residue burning is a cause for worry, because it causes air pollution, greenhouse gas emissions, negative health consequences, nutrient loss, increased soil erosion and runoff, negative effects on soil quality, and depletion of soil organic carbon [13].

Burning plant residues on the soil surface degrades the physical, chemical, and biological aspects of the soil, resulting in a deterioration of the soil nutrient budget. They are necessary nutrients for long-term soil fertility.

During the formulation of the National Policy for Crop Residue Management (NPMCR) in 2014, it was anticipated that burning one tonne of rice straw would result in the loss of 5.5 kg of nitrogen (N), 2.3 kg of phosphorus (P), 25 kg of potassium (K), and 1.2 kg of sulphur (S) in addition to organic carbon.

In general, crop residue combustion consumes 80 percent of the N, 25 percent of the P, 50 percent of the S, and 20 percent of the K present in crop residues. The burning of rice, wheat, and sugarcane crop leftovers alone resulted in a loss of around 0.4 MT of nitrogen, 0.01 MT of phosphate, and 0.3 MT of potassium, according to India's main policy-making agency, NITI Aayog. Paddy residue includes 6.1 kg N, 0.8 kg P, and 11.4 kg K per tonne. The intact loss from burning paddy straw is approximately 79.38 kg ha^{-1} N, 183.71 kg ha^{-1} P, and 108.86 kg ha^{-1} K [14]. Crop leftovers must therefore be managed in a sustainable manner to prevent farmers from incurring financial losses.

11.4 Management of Crop Residues:

Crop residue management is possible either by on-farm (in-situ) residue management or off-farm (ex-situ) residue management.

11.4.1 On Farm Residue Management:

In this situation, farm residues are managed directly in the farm field by residue retention, residue integration, or by the use of machinery such as the happy seeder and turbo happy seeder [15]. All of these are in-situ residue management techniques that will improve soil structure, reduce weed intensity, and increase production over farmer methods [16].

A. Surface Retention as Mulch:

Mulching is the practice of covering the soil surface with organic or inorganic materials [17, 18]. This provides a longer time for surface water to be retained, reducing leaching and evapotranspiration. Mulching with organic materials adds organic matter to the soil and will also reduce nutrient losses [19, 20]. Covering topsoil positively regulates soil temperature and thereby increases crop production. After using rice straw as mulch, 15-20% of direct fertilizers can be saved in the subsequent crop [21].

Zero tillage and crop residue mulching were found to reduce input costs with slight yield improvements [22]. 1 kg m^{-2} of organic mulch with a thickness of 10 to 15 cm is sufficient to cover the soil and reduce weed density [23]. The retention of residues in the field will support the organic matter present in the soil and improve the physical properties of the soil [24].

B. Residue Incorporation:

Here, crop residues are completely or partially incorporated into the soil. The above-ground part can be chopped into small pieces and can also be incorporated using machines. Crop residue incorporation increased 1000-grain weight, grain yield, straw yield, harvest index, and benefit cost ratio in the following rice crop [25]. Incorporating plant residues strengthens the soil, helps in nutrient recycling and also improves soil health by increasing soil organic matter [26]. Similarly, residual effect of forage cowpea grown in summer improved the yield of succeeding rice [27]. Rice straw incorporation along with N treatment considerably increased rice and wheat grain production in sandy loam soil in a rice-wheat cropping system. [28]

C. Pusa Decomposer:

Recently, a team of scientists from IARI led by Dr. Livleen Shukhar has developed a bio-degradable capsule called "Pusa decomposer" that has the ability to turn crop stubble into compost in less than one month. These capsules contain crop-friendly fungi that can be dissolved in water before spraying. It is a cost-effective, achievable and practical method to prevent farmers from stubble burning. The capsules cost around Rs. 5, which is feasible for the common man. No negative effects caused by this fungus have been reported yet. It will improve soil fertility, soil productivity and also reduce the need for fertilizer for the succeeding crop. This potential decomposer is being tested in Punjab and Uttar Pradesh. It is an environmentally friendly and beneficial technology that can help to achieve a clean environment [29].

The effect of four residue management practices, viz. residue burning, residue removal, residue treated with PUSA Decomposer and residue treated with *Trichoderma* along with five weed control options namely , two hand weedings @ 30 & 45 DAS, sulfosulfuron @ 25 gm a.i. ha^{-1}, fenoxaprop-p-ethyl + metsulfuron methyl @ 100 g + 4 g a.i. ha^{-1} and brown fertilization fb chlodinofop @ 60 g a.i. ha^{-1} were evaluated on the weed dynamics of late-sown wheat. They reported that the application of PUSA decomposer significantly suppressed the weed flora at 60 DAS and at 90 DAS in the wheat stand.[30]

11.4.2 Off-Farm Residue Management:

Here crop residues are taken off the farm for safe disposal. Packaging and transporting crop residues from the field for safe disposal is only feasible if alternative, efficient and economically viable uses are identified. Off-farm residue management will only be cost-effective, if transported residues can be converted into items that are more profitable.

A. Livestock Feed:

Livestock is essential to poor farmers' livelihoods because it provides economic, social, and food security. In India, plant residues are traditionally used as animal feed. Using these alternative feed sources, replacing part of conventional feed ingredients is a wise way for sustainable animal production. Some of these potential feeds are discussed.

During processing, potato pulp, peels, culls, chips, and pieces, among other things, are created. During processing, around 35% of the total processed potato crop is discarded as waste. The total annual global potato waste is estimated to be 12 million tonnes. In India, around 2 million tonnes of potato waste are produced. The feasibility of using this potato waste to create cow feed combinations were evaluated [31]. A feed made from waste potato chips and pulp was compared to feed available locally. It was shown to have the lowest moisture content (10.07 percent) and could be preserved for a longer amount of time. The feed also has a high pellet durability index because the potato is also used as a binder which identifies the possibility of potato processing waste to partially replace the grain component in feed pellets. In areas where arecanut is grown, the sheaths are usually left unused. Due to their higher lignin content, they will take some time to decompose. The potential of using areca pods as dry fodder for farm animals were evaluated [32]. The dried areca sheaths were cut up and used along with the concentrated mixture as a total mixed ration. It has been found that areca sheaths can completely replace paddy straw because the nutritional value is higher and can improve milk yield.

Cassava peels are a waste product of the tapioca flour industry that is usually thrown away during processing. Supplementing these discarded cassava husks with feed, cattle population were grouped and fed a discarded cassava peel-based feed and milk quality was evaluated [33]. The control group was fed grass and a commercial ration dietary. The results of the study showed significant positive effects for the treatment group in terms of percent protein (2.87%), lactose (4.40%), fat-free dry matter (8.49%) and total dry matter (12.23%) versus control. Therefore, they have a high potential as a feed source to reduce production costs and thereby increase the income of farmers.

Pineapple is a commercially important fruit crop, and its waste disposal is a serious concern because of its high moisture and sugar content, which makes it susceptible to fungus development and deterioration. Converting them into silage can successfully solve this problem. The lactation performance in cows and lambs after feeding pineapple and maize silage were evaluated [34]. The nutritional value of pine apple silage in terms of energy and minerals was found to be superior to maize silage. Milk yield and quality were also found to be improved with pineapple silage, indicating the potential of converting crop residues into silage.

B. Bedding Material:

In Western countries, crop residues are generally not fed to livestock, but are used as bedding, especially wheat straw. While in developing countries, these carbohydrate-rich straws are a valuable resource for farmers as cheap animal feed because there is a shortage of fodder [35].

C. Production of Mushrooms:

Mushroom cultivation is an important source of protein and income for rural meat.

ICAR-CIRCOT has discovered a method for producing oyster mushrooms (*Pleurotus florida and P. ostreatus*) on cotton stalks. In thirty days, one kilogramme of dry cotton stalks can yield around 300 g of fresh oyster mushrooms. In general, two to three mushroom harvests occur each year [36].

A low-cost system for growing oyster mushrooms has been devised using coconut debris such as leaves, stems, bunch waste, leaflets, and so on. Coconut waste is cut into 5-7 cm pieces and steeped in water overnight. The surplus water is drained away, and the substrates are disinfected by steam pasteurisation before being placed in polybags and inoculated with spawn at a rate of 100 g per bag containing 3-3.5 kg of substrate. As an organic supplement, 5 percent sterilised rice bran is added. For 15-20 days, the bags are incubated for spawn run in a mushroom house. After spawning, the plastic cover is ripped and the compact cylinder bed is sprinkled with water two to three times every day. The initial flush of mushroom fruiting bodies appears 5-10 days after opening the bag. Each bed can yield three to four crops. This technology provides work and revenue to many women's self-help groups, unemployed youngsters, and rural residents [37].

The effect of different substrates on the yield of *Pleurotus florida* were reported a high potential for mushroom production using different agricultural plant wastes as substrate material [38]. Oyster mushroom could grow on all substrates used for different treatments. The highest yield (1037.72 g) was achieved with mushrooms grown from sesame crop residue substrates. So, in areas where sesame plant residues are generated in large quantities and pose a threat to the environment, they can be converted as a food source by using them for oyster mushroom production.

D. Biochar from Agricultural Waste Material:

The pyrolysis method is used to create biochar from agricultural waste and weeds. Using a customised portable metal furnace, agricultural biomass may be turned to biochar in two hours with a conversion efficiency of 25-35 percent depending on the kind of biomass. They have the ability to improve soil fertility and agricultural productivity, as well as the efficiency of fertiliser application, water retention, aeration, and soil slope. It also has a large and favourable effect on soil pH. The influence of biochar on bunch yield and bunch features of banana were studied and discovered that biochar application greatly increased banana growth and yield. Biochar @ 10 kg plant^{-1} leads in higher bunch weight, number of hands per bunch, and number of fingers per bunch [39].

E. Banana Fiber from Pseudostem Sheath:

Banana pseudostem is waste material after harvest. Banana cultivation produces 30 million tons of biomass annually, from which 1.5 million tons of fiber can be extracted. Banana pseudostem is the main proportion of banana waste biomass and provides high-quality fiber. The waste generated in the banana pulp extraction plant can be used in hand-made paper production, which will alleviate the problem of pollution along with creating employment opportunities in rural areas [40].

Additionally, it has the potential to be used industrially in the manufacture of food, textiles, pulp and paper, sanitary napkins, reinforced composite materials for automobiles, structural materials for the aerospace industry, and other composite materials [41]. Banana pseudostem fiber had the highest tensile strength, flexural strength and lowest elongation percentage among various natural fibres [42].

F. Bio-Brick:

Rice straw can also be used to make lightweight cement bricks called biobricks that can be used in building construction. Biobricks are an alternative and sustainable building material made from agricultural waste. Biobricks have the potential to generate a new economic model for farmers and contribute to the growth of agriculture-based companies. The biobricks are a carbon-negative, sustainable, and economically viable construction material [43].

G. Soilless Planting Media:

The effect of different growth media on yield and yield characteristics of bhindi were evaluated and reported that different soil less growth media had significant effect on growth and yield characteristics of bhindi. Coirpith compost + FYM (2:1) recorded maximum yield and B:C ratio for bhindi.[44] A similar study was conducted on the effect of different growth media on tomato and coir pith compost + FYM (2:1) reported maximum fruits per plant (23.41), fruit weight (35.43 g) and yield per plant. (883.46 g) [45]. Press mud, a by-product of the sugar industry that is commonly accessible at 2% crushed cane, has physical qualities similar to soil and gives good root anchoring. Because composted press mud supplies critical nutrients to plants, mixing composted and powdered press mud makes a soilless planting media. This soilless planting medium is composed of 50% composted press mud, 25% coirpith, and 25% dry cow dung powder. Dolomite is added to the mixture to balance off its acidity, and neem cake and biocontrol chemicals are also used. Soilless planting media are regularly produced at the ICAR-Krisi Vigyan Kendra in Ernakulam.

H. Briquets:

It is a process in which harvested crop residues are densely compacted, allowing for the replacement of wood as a fuel. Agricultural residues can be managed by converting them into thickened solid biofuels using briquetting technology. By briquetting plant residues, it will be easier for agricultural waste to be transported, stored and used as biofuel [12].

The possibilities of using agricultural waste in the production of briquettes were evaluated. The major generated wastes were used as treatments, viz. rice husks, ground nut shells, cotton husks, coconut husks, coir pith, sunflower stalk, soybean husks, sugarcane bagasse, paddy straw and tea waste for energy production in the form of briquettes. The results show that the calorific value of the briquettes is higher than the calorific value of the raw materials. The input-output ratio was observed to be cost-effective and profitable for the farmers in all parameters.[46]

I. Bio-Waste Utilization for Crop Production:

Kerala Agricultural University has developed feasible technologies for waste utilization. Suchita, created at the College of Agriculture, Vellayani, and Bio-bin, developed at the College of Agriculture, Vellanikkara, have both been established as commercially viable methods for converting bio-waste into bio-manure. These technologies can help manage garbage at its source.

- **Suchitha- Thermochemical Organic Fertilizer:**

"Suchitha" technology is a thermochemical process that can convert biodegradable waste into organic fertilizer. This patented technology of rapid thermochemical processing of biowaste [47] enables the processing of solid waste into organic fertilizer in less than one day in an environmentally friendly manner.

The effect of 'Suchitha' in combination with various organic and inorganic fertilizers on growth and yield of vegetables, viz. tomatoes and okra were evaluated and it was found that regardless of the organic nitrogen source used, the enriched thermochemical organic fertilizer imparted a high total organic carbon status to the growing medium. It was found that irrespective of the organic source of nitrogen used, the fortified thermochemical organic fertilizer imparted a high status of total organic carbon to the growing media. Container grown okra in a growing media with 'Suchitha' fortified with farmyard manure out yielded urea-based fortification by 55.96%. Tomatoes grown in growing medium enriched with coirpith compost increased yield by 27.37 percent compared to growing medium enriched with peanut cake.[48]

11.5 Conclusion:

Crop wastes are highly valuable economically as fuel, animal feed, and industrial raw materials. However, crop residue issues vary by region and are linked to socioeconomic requirements. Crop residues are essential for improving soil quality and crop productivity. They contain a large amount of nutrients, so returning plant residues to the soil can save a significant amount of fertilizer. Using plant residues as an important resource for better productivity is a good solution to challenges. The remainder of the crop should be partially or fully used in conservation agriculture to ensure food security in the country, make agriculture sustainable and improve soil quality. Using conservation agriculture practices such as zero tillage and crop residue management such as biochar, incorporating crop residues into the soil and using crop residues as mulch will improve soil quality. In this case, it will increase the productivity of these inputs and help maintain agricultural production levels. A lot of technologies are available for creating wealth from agricultural waste which is generated during agricultural activities, crop harvesting, crop processing, product synthesis etc. The need of the hour is to raise awareness among agricultural communities so that they comprehend the value of crop leftovers in conservation agriculture for the resilience and sustainability of Indian agriculture.

11.6 References:

1. UN [United Nations]. 2022. World population prospects 2022 [on-line]. Available: https://www.un.org/development/desa/pd/content/World-Population-Prospects-2022 [12 Jun 2023].
2. Brahmachari, K., Sarkar, S., Santra, D.K. and Maitra, S., 2019. Millet for food and nutritional security in drought prone and red laterite region of Eastern India. *Int. J. Plant Soil Sci. 26*(6), pp.1-7.
3. Laik, R., Singh, S.K., Pramanick, B., Kumari, V., Nath, D., Dessoky, E.S., Attia, A.O., Hassan, M.M. and Hossain, A., 2021. Improved method of boron fertilization in rice (Oryza sativa L.)–mustard (Brassica juncea L.) cropping system in upland calcareous soils. *Sustain. 13*(9), p.5037.
4. Somvanshi, P. S., Pandiaraj, T., and Singh, R. P. (2020). An unexplored story of successful green revolution of India and steps towards ever green revolution. *J. Pharmacogn. Phytochem.* 9, 1270–1273.
5. Eliazer Nelson, A.R.L., Ravichandran, K. and Antony, U., 2019. The impact of the Green Revolution on indigenous crops of India. *J. Ethnic Foods* 6(1), pp.1-10.
6. Davis, K.F., Chhatre, A., Rao, N.D., Singh, D., Ghosh-Jerath, S., Mridul, A., Poblete-Cazenave, M., Pradhan, N. and DeFries, R., 2019. Assessing the sustainability of post-Green Revolution cereals in India. *Proc. Natl. Acad. Sci. 116*(50), pp.25034-25041.
7. Agamuthu, P. 2009. Challenges and opportunities in agro-waste management: An Asian perspective. In Inaugural meeting of first regional 3R forum in Asia (pp. 11-12).
8. Obi, F. O, Ugwuishiwu, B. O. and Nwakaire, J. N. 2016. Agricultural waste concept, generation, utilization and management. *Nigerian J. Technol.* 35(4):957-64.
9. Chatterjee, R., Gajjela, S., and Thirumdasu, R. K. 2017. Recycling of organic wastes for sustainable soil health and crop growth. *Int. J. Waste Resour*. 7(3): 296-303.
10. Pathak, H., Bhatia, A., Jain, N. and Aggarwal, P.K. 2010. Greenhouse Gas Emission and Mitigation in Indian Agriculture – A Review, *In ING Bulletins on Regional Assessment of Reactive Nitrogen, Bulletin No. 19,(Ed. Bijay-Singh)*, New Delhi, pp: 34.
11. McCarty, J. L., Krylov, A., Prishchepov, A. V., Banach, D. M., Tyukavina, A., Potapov, P. and Turubanova, S. 2017. Agricultural fires in European Russia, Belarus, and Lithuania and their impact on air quality, 2002–2012. *In Land-Cover and Land-Use Changes in Eastern Europe after the Collapse of the Soviet Union in 1991* (pp. 193-221).
12. Setter, C., Silva, F. T. M., Assis, M. R., Ataíde, C. H., Trugilho, P. F., and Oliveira, T. J. P. 2020. Slow pyrolysis of coffee husk briquettes: characterization of the solid and liquid fractions. *Fuel 261*:116420 [on-line]. Available: https://doi.org/10.1016/j.fuel.2019.116420 [08 Jun.2023]
13. Mittal, S. K, Singh, N, Agarwal, N, Awasthi, A. and Gupta, P. K. 2009.Ambient air quality during wheat and rice crop stubble burning episodes in Patiala. *Atmos Environ* 43:238–44.

14. Jat, M. L, Gathala, M. K, Saharawat, Y. S, Tetarwal, J. P, Gupta, R. and YadvinderSingh. 2013. Double no-till and permanent raised beds in maize-wheat rotation of northwestern Indo-Gangetic plains of India: effects on crop yields, water productivity, profitability and soil physical properties. *Field Crops Res* 149:291–299.
15. Singh, R., Yadav, D. B., Ravisankar, N., Yadav, A., and Singh, H. 2020. Crop residue management in rice–wheat cropping system for resource conservation and environmental protection in north-western India. *Environ. Dev. Sustain. 22*(5): 3871-3896.
16. Lal, R. 2004. World crop residues production and implications of its use as a biofuel. *Environ. Inter*. 31: 575–584.
17. Ghousepeera, P. S. K., Debnath, S., and Maitra, S. 2020. Mulching: materials, advantages and crop production, In: Maitra, S., Dinkar, J., Gaikwad, D. J., and Shankar, T. (Eds). Protected cultivation and smart agriculture, New Delhi Publishers, India, pp. 55-66.
18. Santosh D. T. and Maitra, S. 2022. Effect of drip irrigation and plastic mulch on yield and quality of ginger (*Zingiber officinale*), *Res. Crops* 23 (1): 211-219.
19. Anand, D. D., Singh, M. S., Lhungdim, J., Devi, N. S., and Sing, N. G., 2020. Effect of mulching on growth and yield of soybean (*Glycine max* (L.) Merrill). *Int. J. Curr. Microbiol. Appl.* 9(9): 3313-3318.
20. Singh, L. and Brar, B.S., 2021. A Review on Rice Straw Management Strategies. *Nat. Environ. Pollut. 20*(4), pp.1485-1493.
21. Kumar, P., Kumar, S., and Joshi, L. 2015. The extent and management of crop stubble. In: *Socioeconomic and Environmental Implications of Agricultural Residue Burning*. New Delhi, pp. 13-34.
22. Wu, G., Wei, K., Chen, Z., Jiang, D., Xie, H., Jiang, N. and Chen, L., 2021. Crop residue application at low rates could improve soil phosphorus cycling under long-term no-tillage management *Biol. Fertil. Soils, 57*(4), pp.499-511.
23. Anzalone, A., Cirujeda, A., Aibar, J., Pardo, G., and Zaragoza, C., 2010. Effect of biodegradable mulch materials on weed control in processing tomatoes. *Weed Technol.* 24(3): 369-377.
24. Hiel, M. P., Barbieux, S., Pierreux, J., Olivier, C., Lobet, G., Roisin, C., Garré, S., Colinet, G., Bodson, B., and Dumont, B. 2018. Impact of crop residue management on crop production and soil chemistry after seven years of crop rotation in temperate climate, loamy soils. *PeerJ* [on-line]. Available: https://10.7717/peerj.4836. [08.Jun.2023]
25. Singh, G., Bhattacharyya, R., Das, T. K., Sharma, A. R., Ghosh, A., Das, S., and Jha, P. 2018. Crop rotation and residue management effects on soil enzyme activities, glomalin and aggregate stability under zero tillage in the Indo-Gangetic Plains. *Soil Tillage Res.* 184: 291-300.
26. Nawaz, A., Farooq, M., Nadeem, F., Siddique, K. H. M., and Lal, R. 2019. Rice-wheat cropping systems in South Asia: issues, options and opportunities. *Crop and Pasture Sci*. 70(5): 395-427.
27. Reshma, M. R., Pillai, P. S., John, J., and Thampatti, K. C. M. 2019. Effect of crop diversification and fish integration in productivity enhancement of rice. *Int. J. Curr. Microbiol. App. Sci.* 8(11): 382-387.
28. Sharma, S., Singh, P., and Kumar, S. 2020. Responses of soil carbon pools, enzymatic activity, and crop yields to nitrogen and straw incorporation in a rice-wheat cropping system in north-western India. *Front. Sustain. Food Syst,* 4: 203-222.

29. Rai, U. 2020. A microbial spray could be the game changer against crop residue burning. *Mongabay Series: Environment and Health* [on-line]. Available: https:// https://india.mongabay.com/2020/11/commentary-a-microbial-spray-could-be-the-game-changer-against-crop-residue-burning/ [08 Jun. 2022].
30. Pachauri, R. K., Yadav, R. B., Naresh, R. K., Kumar, M., Dhyani, B. P., Singh, A., and Nath, A. 2022. Influence of rice residue and weed management on weed dynamics in late sown wheat (*Triticum aestivum* L.). *Pharma Innov. J.* 11(8): 1622-1626.
31. Dhingra, D., Michael, M., Rajput, H., and Chopra, S., 2013. Utilization of potato processing waste for compound cattle feed. *Agric. Eng. Today* 37(4): 40-45.
32. Gowda, N. K. S., Anandan, S., Pal, D. T., Vallesha, N. C., Swathi, V., and Sampath, K. T. 2012. Technology to use areca sheath as an alternative dry fodder for dairy animals. *Indian Dairyman* 64(10): 58-61.
33. Pertiwi, H., Maharsedyo, Y. N, Amaro, L., and Dadi, B. T. 2019. Nutritional evaluation of cassava (*Manihot esculenta*) peels as a dietary supplement in tropical Friesian Holstein cross breed dairy cattle. *Vet. Med. Int.* [on-line] Available: https://doi.org/10.1155/2019/6517839 [08 Jun. 2023]
34. Gowda, N. K. S., Vallesha, N. C., Awachat, V. B., Anandan, S., Pal, D. T., and Prasad, C. S. 2015. Study on evaluation of silage from pineapple (*Ananas comosus*) fruit residue as livestock feed. *Trop. Anim. health and prod.* 47(3): 557-561.
35. Goswami, S.B., Mondal, R., and Mandi, S.K. 2020. Crop residue management options in rice–rice system: a review. *Arch. Agron. Soil Sci.* 66(9): 1218-1234.
36. Mageshwaran, V., Varsha, S., Hamid, H., Shukla, S.K. and Patil, P.G., 2017. Compost production and oyster mushroom cultivation-a potential entrepreneurship for cotton growing farmers. *International Journal of Forestry and Crop Improvement*, *8*(2), pp.149-156.
37. Thomas, G. V., Prabhu, S. R., Reeny, M. Z., and Bopaiah, B. M. 1998. Evaluation of lignocellulosic biomass from coconut palm as substrate for cultivation of *Pleurotus sajor*-caju (Fr.) Singer. *World J. Microbiol. Biotechnol.* 14(6): 879-882.
38. Resmi, A. R., Lovely, B., Jayapal, A., Anila, S., Athira, A., Raj, G. S., Ruma, S., and Megha, G.K. 2021. Growth and yield of oyster mushroom (*Pleurotus florida*) as influenced by different ligno cellulosic materials as substrates. *Green Farming* 12(1&2): 68-71.
39. Sainath, N., Usha, P. B., Manorama, K. C., and Joseph, B. 2020. Tender coconut husk derived biochar influence on nutrient use efficiency, yield and economics of banana (*Musa spp*.). *J. Pharmacogn. Phytochem.* 9(4): 1457-1461.
40. Arafat, K., Nayeem, J., Quadery, A.H., Quaiyyum, M.A. and Jahan, M.S., 2018. Handmade paper from waste banana fibre. *Bangladesh Journal of Scientific and Industrial Research*, *53*(2), pp.83-88.
41. Ghosh, I., Rakholia, D., Shah, K., Bhatt, D. and Das, M., 2020. Environmental Perspective on Menstrual Hygiene Management Along with the Movement towards Biodegradability: A Mini-Review. *Journal ISSN*, *2766*, p.2276.
42. Balda, S., Sharma, A., Capalash, N., and Sharma, P., 2021. Banana fibre: a natural and sustainable bioresource for eco-friendly applications. *Clean Technol. Environ.* 23(5): 1389-1401.
43. Rautray, P., Roy, A., Mathew, D. J., and Eisenbart, B. 2019. Bio-brick - development of sustainable and cost effective building material. In: *Proceedings of the 22nd International Conference on Engineering Design,* 5-8 August 2019, Delft, The Netherlands, pp. 3171-318.

44. Cuckoorani, M. and Thomas, C.U., 2015. Standardization of media and organic nutrient scheduling for bhindi in soilless cultivation. *Trends in Biosciences*, *8*(15), pp.3915-3918.
45. Soumya, A. and Usha, C., 2015. Impact of different growth media, nutrient sources and nutrient levels on yield and quality of tomato. *Trends in Biosciences*, *8*(15), pp.3953-3958.
46. Patil, G. 2019. The possibility study of briquetting agricultural wastes for alternative energy. *Indones. J. For. Res.* 6(2): 133-139.
47. Sudharmaidevi, C. R., Thampatti, K. C. M., and Saifudeen, N. 2017. Rapid production of organic fertilizer from degradable waste by thermochemical processing. *Int. J. Recycl. Org. Waste Agric.* 6(1): 1-11.
48. Leno, N., Jacob, G., Jayakrishna, J., Kavya, S. R., Krishnapriya, M. K., Taki, L., Sreelakshmi, M. M., Rehana, M. R., and Vijay, A. B. 2021. Carbon fractions of fortified thermochemical organic fertilizers and their response on the yield of okra and tomato. *J. Environ. Biol.* 42(6): 1544-1553.

12. Pulse-Based Crop Diversification in Indo-Gangetic Conditions

Priyanka Dubey

Department of Plant Physiology,
College of Agriculture,
J.N.K.V.V. Jabalpur M.P.

Nidhi Pathak

Department of Plant Breeding and Genetics,
College of Agriculture,
J.N.K.V.V. Jabalpur M.P.

Abstract:

In India's Gangetic Plain, 44 million hectares are predominantly cereal crops. Rice-wheat and rice-crop systems are the main cropping systems, with rice-wheat rotations accounting for about 10 million ha. Legumes are grown on about 5 million ha, accounting for about 14% of the country's total area. This region has wide spatial variation in rainfall patterns (268 mm in the far north to 1600 mm in the far east) and is largely dominated by Inceptisol soils. There are also large differences in other agroclimatic characteristics such as temperature regime, length of growing season, and evapotranspiration. Despite these major differences, chickpea, lentils, and pigeon pea are the main legumes grown throughout the region. Their production is severely affected by many diseases, pests, and abiotic stresses in this diverse part of the country. Socioeconomic constraints are also a major reason hindering cultivation. The Indian government has increased research spending to develop improved technologies to increase legume production in the country. The results of government investments have been promising, and some improved varieties and technological options have been developed to mitigate biotic and abiotic constraints. The government also initiated several policy measures to alleviate socioeconomic constraints to increase legume production. Available trends show that the area under legumes is gradually increasing in some regions. The region has tremendous potential for legume production (either as an intercrop, summer crop, or sole crop in a variety of cropping systems), provided that appropriate crop varieties/technologies reach farmers' fields.

Keywords:

cropping system, food security, Indo-gangetic plains, intercropping, Pulse.

12.1 Introduction:

The backbone of our Indian economy is Agriculture. The first prime minister of India Pandit Jawaharlal Nehru said, "If agriculture in this country fails, we fail, the government fails and the nation fails, there is no help for us but to succeed in agriculture". Our world faces the tough challenges of climate change, which makes life difficult on our planet. Millions of people are suffering from severe hunger and malnutrition. The economic systems of many developed countries where agriculture contributes a considerable share of the economy are directly influenced by climate change, population explosion, and food insecurity. The world is longing for a solution that can tackle the situation. The solution should be inexpensive, easy to access, requires minimum input and management practices that have a high amount of nutritive valuable food. Pulses are the best source of all these requirements. Pulses have a prominent and very good source of protein in human beings. It has qualities like a low glycemic index (FAO, 2016), is gluten-free, and even acts as a functional food (Rao, 2002). The diet of Type 2 diabetes patients can be included pulses in their regular diet because of having a low glycemic index and pulses are gluten-free so including it in the diet will not cause chances of Celiac disease. Pulses have important and cheap sources of plant dietary proteins having various amino acids. These are consumed in split form and prepared as a curry called ‘dhal’ or ‘dal' which is an important source of dietary proteins for Indian masses. These superfoods have double the protein in wheat and three-fold in rice. Besides, they are also rich in complex carbohydrates, micro-nutrients, protein, and vitamins B and minerals like calcium, iron, magnesium, zinc potassium, and folate. Long shelf life without loss of nutritional value, low prices coupled with wider availability make pulses an affordable source of protein and minerals and contribute to food security at all levels of society in India. Besides adding to human nutrition, pulse crops serve as a source of fodder and fuel for farm families.

Several pulse crops are grown in India and all over the world. Among the crops, the major ones are Gram, Pigeonpea, Lentil, Fieldpeas, etc. According to history, the origin of Gram is in South West Asia probably Afghanistan and Persia, Pigeonpea in Africa, Lentil in Turkey to South Iran and Field peas in the Mediterranean Region of Southern Europe and Western Asia. Pulse crops are cultivated in the Kharif, Rabi and Zaid seasons of the Agricultural year. Rabi crops require a mild cold climate during the sowing period, the vegetative stage to pod development stage requires a cold climate and the maturity stage requires a warm climate. Similarly, Kharif pulse crops require a warm climate throughout their cropping seasons from the sowing to the harvesting stage. Summer pulses crops are habitants of hot climate. Seed is required to pass many stages to produce seed like germination, seedling, vegetative, flowering, fruit setting, pod development and grain maturity or harvesting.

The Indo-Gangetic Plains of India, spreading about 44 million ha area, is over 185 districts in the states of Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal. The IGP in India can be divided into four major sub-regions, viz. Trans-Gangetic Plains (Punjab, Haryana, Chandigarh and Delhi), Upper-Gangetic Plains (Western and Central Uttar Pradesh) Middle-Gangetic Plains (Eastern Uttar Pradesh and Bihar) Lower-Gangetic Plains (West Bengal).

The Indo-Gangetic Plains also known as the North Indian River Plain is a 700-thousand km2 (172-million-acre) fertile plain encompassing northern regions of the Indian subcontinent, including most of northern and eastern India, around half of Pakistan, virtually all of Bangladesh and southern plains of Nepal. The region is named after the Indus and the Ganges rivers and encompasses several large urban areas. The plain is bound on the north by the Himalayas, which feed its numerous rivers and are the source of the fertile alluvium deposited across the region by the two river systems. The southern edge of the plain is marked by the Deccan Plateau. On the west rises the Iranian Plateau. Many developed cities like Delhi, Dhaka, Kolkata, Lahore and Karachi are located in the Indo-Gangetic Plains. Pulse crops are part of the legume family, with common varieties including a diversity of species such as fava beans, lentils, field peas and common bean. Corteva Agriscience is seeking new cropping systems that incorporate a pulse crop to increase the amount of protein-rich food grown on existing farmland while reducing agricultural inputs. Crop Diversification refers to a shift from the regional dominance of one crop to the regional production of many crops, to meet the ever-increasing demand for cereals, pulses, vegetables, fruits, oilseeds, fibers, fodder, grasses etc. The importance of crop diversification lies in the fact that it effectively increases soil fertility and controls pest incidences. The boost in rural employment impacts the overall economy of the nation, as agriculture in India falls into the primary sector of the country. A shift in crop preferences is visible since the 1990s. The farmers of the Indo-Gangetic belt who grew pulses earlier, have shifted to wheat where yields range from 3,000 to 4,000 kg per hectare compared to only about 800 kg in the case of pulses. Over the past two decades the production of pulses has largely shifted from northern India to central and southern parts. Today, >90% of total pulses production is realized in 10 states namely, MP, MS, Rajasthan, UP, Karnataka, AP, Gujarat, Jharkhand, CG and Telangana. Both area and productivity of chickpea significantly increased over decades.

12.2 Area and Distribution of Pulse Crops in India:

From 1980–1981 to 2020–2021, the total cropped area under pulses in India increased from 22.46 to 28.83 m ha with a peak of 26.40 m ha in 2010–2011. Due to stagnant production and an increase in population, the per capita availability of pulses has declined in the range of 35.4 g to 47.2 g/capita/day during 2009–2020. The total world acreage under pulses is about 93.18 (Mha) with the production of 89.82 (Mt) at a 964 kg/ha yield level. India, with >28 Mha pulses cultivation area, is the largest pulse producing country in the world. It ranks first in area and production with 31 percent and 28 percent respectively. In India pulses covers an area of 28.78 m ha with production of 25.46 m t. Among the pulses, chickpea contributed 48 percent and then comes pigeon pea, black gram, green gram and other pulses (GOI, 2016). During 2020-21 our productivity at 885 kg/ha, has also increased significantly over the last five years. Under the pro-active pulse program implementation strategies and robust monitoring mechanism of the government of India, significant growth in the area, production and productivity of pulses has been recorded. More visible and significant increasing trends during 2016-17, 2017-18 and 2020-21, whereby the pulses production reached 23.13 Mt, 25.42 and 25.46 Mt respectively, is a grand success story in itself. The productivity of pulses has increased by 13 percent at 885 kg/ha during 2020-21 and 9 percent at 853 kg/ha during 2017-18 from the level of 786 kg/ha during 2016-17. The production growth has been 10 percent highest over 2016-17. Major pulses producing states in India are Rajasthan, Madhya Pradesh, Maharashtra, Uttar Pradesh and Karnataka. Rajasthan was a leading producer of pulse in India with a production of 4821.84 tonnes in 2020-21. India is the grower of pulses in huge quantities. Some government programs like National Food Security Mission (NFSM) - Pulses program are highly useful to make it ever-increasing. The government of India has initiated an NFSM-Pulses program to support the production of different types of pulses in India. The program is being initiated in around 644 districts across 28 States and the Union Territories of Jammu & Kashmir and Ladakh.

Under the NFSM-Pulses program, the government focuses on:

- Distribution of incentives to farmers.
- Distribution of high-yielding varieties of seeds (HYVs).
- And, Production of certified seeds.
- Distribution of efficient farm machinery/tools.
- Distribution of water-saving devices, plant protection chemicals, and soil ameliorants (substances that helps improve/grow the physical condition of the soil).
- Training is also given to farmers to improve crop production and yield.
- And Central seed agencies get assistance to produce certified and latest seed varieties.
- Free of cost, mini kits of various pulses are distributed to farmers.

12.3 Importance of Pulses in India:

The Pulses crops belong to the family Fabaceae or Leguminosae, which is the world's third largest group of plant life after Orchidaceae and Asteraceae. The word ‘pulse’ has its origin from the Latin word ‘Puls’ meaning thick soup or potage (FAO, 2016). According to FAO, pulses are annual leguminous crops yielding, one to twelve grains or seeds of variable size, shape and color within a pod. Only legumes harvested for dry grain are classified as pulses. Legume species used for oil extraction (e.g. soybean and groundnut) and sowing purposes (e.g. clover and alfalfa) are not considered as pulses. Likewise, legume species are not considered pulses when they are used as vegetables (e.g. green peas and green beans) (FAO, 1994). Therefore, all pulses are legumes, but not all legumes are pulses.

Pulses are part of traditional offerings in many temples e.g. Green gram powder as Prasada in Mookambika Temple, boiled cowpea in Parassini Muthappan Temple and ‘Chana sundal’, a special preparation during Ganesh Puja. Pulses are an important component of diets in many countries and can help to provide balanced nutrition. They can also be grown as a palatable and nutritious feed for animals, as a green manure crop, as a fuel source, or even for medicinal use. Pulses are sources of high-quality protein. They act as a good fodder crop. Due to its drought-tolerant properties, it can be grown on marginal and wastelands. It even finds a suitable crop of summer fallows of cereals and areas where rain-fed agriculture is practiced. It has a comparatively short duration than other crops, so it can fit into the gap between the two main crops. It fixes atmospheric nitrogen efficiently through its root nodules. Thus, it not only reduces the fertilizer input of it but also reduces the fertilizer input of the succeeding crop to an extent of 25 to 30 percent. It is also a good green manuring crop. Thus, it enhances the physical, chemical and biological properties of the soil. As it requires less input, less management practices and less labor requirements the cost of cultivation of pulses is very less. Pulses also play a key role in soil and water conservation. They are important crops for food security, combating malnutrition, alleviating poverty, improving human health and enhancing agricultural sustainability. Despite its importance to man, pulses are usually regarded as 'orphan crops'. 'Orphan crops' are crops that are not part of the main crops that are traded internationally and are often considered staple crops, such as rice, wheat or maize. However, the Food and Agriculture Organization of UN (FAO) identified these orphan crops as a solution to global food system risks and an investment opportunity for future agricultural research (GPC, 2016).

12.4 Different Cropping Systems in Indo-Gangetic Regions:

Crop diversification refers to the addition of new crops or cropping systems to agricultural production on a particular farm taking into account the different returns from value-added crops with complementary marketing opportunities. The major cropping systems in western IGP are rice-wheat, maize-wheat, sugarcane-wheat, pearl millet-mustard, rice-chickpea, cotton-wheat, pigeon pea-wheat, rice/maize-potato/mustard-urban/mungbean and rice wheat-mungbean. In the eastern IGP, rice-wheat, rice-chickpea/lentil, rice rice, maize-wheat, sugarcane-wheat, rice-mustard, groundnut-wheat, rice-mustard/potato-urdbean/mungbean and rice-mustard-jute/vegetables are important cropping systems. However, rice-wheat is the predominant cropping system occupying about 10.5 million ha. The main crops are grown in IGP cereals - rice, maize, pearl millet, sorghum, wheat and barley, pulses- chickpea, lentil, fieldpea, pigeonpea, urdbean and mungbean, oilseeds- rapeseed and mustard, soybean, groundnut, sunflower and linseed and cash crops like cotton, sugarcane and potato among. Crop rotations with pulses enhance the productivity of systems. We should focus on the cropping system approach for increasing pulse production by giving more emphasis to increased production per unit of time and space. Reddy and Reddy (2013), the Cropping system consists of a "pattern of crops taken up for a given piece of land or order in which the crops are cultivated on a piece of land over a fixed period and their interaction with farm resources". The advantages of cropping systems include using resources more efficiently, enhancing crop growth, increasing the soil cover of the cultivated area, maintaining and enhancing soil fertility, minimizing the spread of pests and diseases, controlling weeds and reducing the risk of crop failure.

12.5 Deterioration of Natural Resources in Indo-Gangetic Regions:

Pulses in crop rotations increase the systems' production. Continuous use of the rice-wheat or rice-rice cropping systems in IGP resulted in a noticeable depletion of natural resources. According to the National Bureau of Soil Survey and Land Use Planning, the IGP contains 22,84 million ha of degraded land. The main concerns for improved and sustainable agricultural production are growing salt dangers, lowering water table due to over-exploitation of groundwater, particularly in the western region, poor soil health, pest outbreaks, weed threat, and diminishing Total Factor Productivity. Ramesh Chand and T. Haque (1998) expressed that the apprehension emergence of rice-wheat rotation crop system in Indo- Gangetic plains as a post-green revolution phenomenon has resulted in waterlogging, soil salinity and over-exploitation of the natural resource base. Moreover, it is argued that the short time duration between rice-wheat crop rotation has led to sub-optimal land preparation and sub-optimal use of other inputs, causing a reduction in the yield of rice and wheat.

12.5.1 Crop management:

Generally, pulses are grown under low input management and therefore, the yield is realized only 60-65 %. The yield of the pulse crop is a 30-35 % increase with better management practices attainable. Some of the major practices for increasing the pulse crops yields under IGP's are given below:

A. **Plant population:** For ensuring optimum plant stand, the seed rate should be worked out with due consideration to seed viability and purity, seed size, no. of plants required per sq m area, soil moisture status, planting time and planting method. Raise bed/ ridge-furrow planting is a must for kharif pulses, especially in eastern IGP where water stagnation/poor drainage often leads to the mortality of plants. Seed treatment with fungicides like carbendazim protects young plants against seed-borne diseases and therefore should invariably be followed.

B. **Nutrient management:** Pulses have an intrinsic ability to trap atmospheric nitrogen to meet their requirements and also leave some amount for succeeding crops. To augment the process, seed inoculation with appropriate Rhizobium culture should be done. Similarly, PSB inoculation enhances the availability of soil phosphorus. Besides biofertilizers, soil placement of N, P, K, S, and Zn as per soil nutrient status should be done. Foliar application of 2 % urea at flower bud formation and 15 days thereafter is quite beneficial for late-planted and rainfed crops.
C. **Integrated pest management:** For containing diseases, resistant/ tolerant varieties should be chosen. Seed dressing with appropriate fungicides, crop rotation, soil solarization and soil application of Trichoderma contributes to reducing the spread of disease. IPM, which uses a combination of plant-based insecticides, biopesticides, cultural methods, and a little quantity of chemical insecticides, should be used to control insect pests. Spraying pre-emergence herbicides like pendimethalin and postemergence herbicides like imazethapyr, as well as cultural measures, can effectively manage weeds that may reduce crop output by 15–30%. Nematodes also significantly reduce yield in light-textured soils. Neem cake or phorate granules applied to the soil efficiently reduce plant nematodes connected to pulse crops.
D. **Soil and water management:** Pulses are typically farmed in rainfed environments, where insufficient soil moisture and unpredictable rainfall frequently cause intermittent droughts that cause significant crop loss. The soil moisture status is improved via laser leveling, field bundling, in-situ moisture conservation, mulching, etc. It is advised to collect water in agricultural ponds and community reservoirs for come-up irrigation and life-saving purposes. Pulses are chronically lacking in the Indo-Gangetic Plains, which contribute more than 50% of the food grains to the national food basket. IGP only produces 3.30 million tonnes of pulse compared to the 10.62 million tonnes total required. Pulses' area under cultivation shrank dramatically from 7.10 million ha in 1970–1975 to 3.37 million ha in 2010–14, posing a severe danger to the region's ability to produce crops sustainably.

12.6 Conclusion:

Pulses are sources of high-quality protein. India is the largest pulses producer globally, accounting for 27-28% of the world's total production. Moreover, India imports 14% of pulses globally. In India, total food grain production only accounts for pulses 7-10%. Pulses are well suited to grow well in both Rabi and Kharif seasons. The problem of malnutrition and inadequate supply of protein poses an enormous task to increase pulse production in many countries. This comprehensive book chapter has been designed to provide sequential development and generation of information in the science and technology of growing pulse crops. It aims to equip the students and researchers with the knowledge of research results to put those into practice for higher crop production in Indo-Gangetic Plains.

Sustainable efforts are needed to end hunger and provide food security. However, one concrete, promising, sustainable and cost-effective opportunity lies within the tiniest of seeds found in a multitude of plants: Pulses-Seeds for a sustainable future (FAO, 2016).

Pulses are the most efficient primary producers of proteins harnessing natural elements like sunlight, soil nutrients and water. While pulses are already relatively climate-hardy, they are being developed. These specific roles of pulses in the cropping system are of greater importance and thus contribute to the cropping system's productivity. to be more tolerant to these conditions. Pulses contribute towards sustainability by mitigating and adapting climate change, reducing poverty and hunger, improving health by providing nutrition and helping to promote economic stability. Pulses are an important component to sustain agriculture production as the pulse crops possess wide adaptability to fit into various cropping systems, improve the soil fertility being leguminous in nature and physical health of soil while making the soil more porous due to the tap root system. Introducing pulses into farm production can be a key to increasing resilience to climate change. It is clear that pulses are an incredible food and deserve greater attention in both our consumption and production. Thus, due attention is required to enhance the production of pulses not only to meet the dietary requirement of protein but also to raise awareness about pulses for achieving nutritional, food security and environmental sustainability. Pulses are good for people, good for soils and good for the planet.

During the Green Revolution period, Indo-Gangetic Plains witnessed a sea change in cropping pattern, with rice-wheat covering over 10 million ha As a consequence of this, pulses were marginalized. Whereas wheat area increased by 58.6 % during 1970-75 to 2010-14, the pulse area decreased by 52.4% during the same period. The share of pulses in food grain acreage of IGP decreased from 16.7% to 7.0 %. This is posing a serious threat to nutritional security and sustainable crop production. The low yield of pulses coupled with high instability in production led to the gradual decline in its area which is alarming and needs to be reversed. Three-pronged strategies (a) expanding area under pulses through intercropping, catch cropping and introduction in rice fallows, (b) improving genetic yield potential through widening the genetic base and employing transgenic technology and (c) improving crop management practices need to be adopted to address the emerging challenges.

12.7 References:

1. FAO [Food and Agricultural Organization of United Nations]. Pulses- Nutritious Seeds for Sustainable Future. Food and Agricultural Organization of United Nations, Rome, Italy, 2016, 189.
2. GOI [Government of India]. Pulses Estimates for India. Directorate of Economics and Statistics, Department of Agriculture and Cooperation and Department of Commerce, Ministry of Agriculture, New Delhi, 2016, 9.
3. Rao BSN. Pulses and legumes as functional foods. Bull. Nutr. Foundation India. 2002; 23(1):1-9.
4. Ramesh Chand and T. Haque "Rice-Wheat Crop System in Indo-Gangetic Region: Issues concerning Sustainability" *Economic and Political Weekly* 1998; 33 (26): 108-112.
5. Reddy TY, Reddy GHS. Principles of Agronomy. Kalyani Publishers, Ludhiana, 2013, 527.
6. FAO (Food and Agricultural Organization of United Nations). Definition and Classification of Commodities, 1994. Available: http://www.fao.org/es/faodef/ fdef04e.htm 2016.

ISBN: 978-81-19149-59-9

13. Soil Management Practices in Conservation Agriculture

Mohini R. Punse

Assistant Professor of Agronomy,
College of Agriculture, Mul.

Devanand T. Kusumbe, Dr. Sharad. K. Nayak

Assistant Professor of Agronomy,
SSSM College of Agriculture,
Pimpalkhuta.

Abstract:

Conservation agriculture (CA) has emerged as a sustainable approach to address the challenges of modern agriculture, such as soil degradation, erosion, and declining soil fertility. This abstract explores various soil management practices within the framework of conservation agriculture. The primary focus is on techniques that promote the enhancement and preservation of soil health, while simultaneously improving agricultural productivity and minimizing environmental impacts. Key soil management practices discussed include minimum tillage, cover cropping, and crop rotation. These practices contribute to reduced soil disturbance, maintenance of organic matter content, and the prevention of soil erosion. The adoption of minimum soil disturbance practices, such as no-till or reduced tillage, is a cornerstone of conservation agriculture. These practices help preserve soil structure, minimize soil erosion, and maintain organic matter content. Cover cropping, another integral component of CA, involves planting cover crops between cash crop cycles to prevent soil erosion, enhance nutrient cycling, and suppress weeds. Cover crops contribute to increased soil organic matter, microbial diversity, and overall soil fertility.

13.1 Introduction:

Conservation agriculture is an innovative farming approach aimed at preventing the depletion of arable land and revitalizing degraded lands. It revolves around three key principles: the maintenance of a continuous soil cover, minimal disturbance of the soil, and the diversification of plant species. By adhering to these principles, conservation agriculture contributes to sustainable farming practices and the preservation of the environment.

Conservation agriculture principles are universally applicable to all agricultural landscapes and land uses, with locally adopted practices. The aim is to minimize or completely avoid mechanical soil disturbance and optimize the application of external inputs, including agrochemicals and plant nutrients of mineral or organic origin, so as not to disrupt biological processes. The soil is a vital repository of nutrients essential for plant growth, animal life, and millions of microorganisms. However, its life cycle is compromised if it becomes unhealthy due to various factors and techniques. Committed individuals dedicated to soil conservation play a crucial role in maintaining soil fertility and productivity while safeguarding it from erosion and degradation.

13.2 Soil Conservation (Management):

Soil conservation, also known as soil management, encompasses a range of strategies aimed at safeguarding soil from degradation. The fundamental principle of soil conservation lies in viewing soil as a thriving ecosystem, wherein various organisms play vital roles in maintaining a fertile and healthy environment. These organisms contribute to the decomposition of organic matter, nutrient release, and facilitation of air and water circulation. By adopting these practices, we ensure the sustainable preservation of soil health and productivity.

Figure 13.1: Soil Conservation (Management)

As a crucial aspect of soil conservation, the sustenance of various organisms within the soil heavily relies on the presence of deceased plant and animal materials, serving as their primary source of sustenance and energy. Therefore, to ensure effective soil conservation, it becomes imperative to consistently reintroduce organic matter back into the soil. This organic matter plays a vital role in establishing favorable soil structure and enhancing water retention capacity. Moreover, it facilitates efficient water infiltration while shielding the soil from erosion and compaction threats.

Besides safeguarding soil life and organic matter, soil conservation is guided by several other principles, which include:

- Ensure effective surface runoff management by implementing appropriate strategies to prevent erosion and sedimentation.
- Protect bare exposed soil areas, especially on steep slopes and highly vulnerable sites.
- Additionally, take measures to protect downstream watercourses from potential pollution and sedimentation issues.

Soil conservation is an ongoing and dynamic process that requires unwavering dedication from practitioners. The initial and essential step is acquiring a comprehensive understanding of the land resource. This entails identifying areas where the soil is highly permeable and at risk of groundwater contamination due to excessive pesticide use, as well as recognizing regions prone to water erosion due to a combination of slope and soil texture.

This crucial knowledge forms the foundation for devising an effective and tailored conservation strategy. Without such insight, developing an appropriate plan for soil conservation becomes unattainable.

The subsequent stages involve the identification or anticipation of problematic areas, selection, and application of soil conservation methods, along with the maintenance of control structures. The ultimate phase revolves around consistently monitoring the plan's efficacy and making appropriate adjustments when needed.

13.3 Good Reasons to Practice Soil Conservation:

- The primary objective is to maintain an optimal level of organic matter and biological activity within the soil. These fundamental components contribute significantly, accounting for 90 to 95 percent of the overall soil productivity.
- Another crucial goal is to secure a stable food supply at reasonable prices. Soil conservation has been scientifically proven to enhance both the quality and quantity of crop yields in the long run by preserving topsoil and sustaining the soil's productivity over time.
- Additionally, the aim is to produce enough food not only to meet our own needs but also to address food shortages in third-world countries.
- Lastly, promoting soil conservation serves to save farmers money. The detrimental effects of erosion currently lead to an annual loss of over $90 million in farmers' income due to decreased crop yields and nutrient depletion from the soil. By implementing soil conservation practices, farmers can mitigate these financial losses and ensure more sustainable agricultural practices.
- Soil conservation efforts aim to save citizens money by addressing the costly impact of soil erosion, which currently amounts to an additional $9.1 million annually. Recent research suggests that the actual cost might be even higher, making soil conservation all the more vital for financial savings.
- One of the critical goals is to enhance water quality. Clean water is essential for all forms of life to thrive. Soil erosion from agricultural and urban areas contributes

significantly to sedimentation and water contamination, making soil conservation crucial for safeguarding water supplies.

- Soil conservation practices play a crucial role in improving wildlife habitat. By implementing measures such as buffer strips, windbreaks, and restoring soil organic matter, the overall environment becomes more favorable for various wildlife species.
- Soil conservation efforts are also motivated by aesthetic reasons, as they contribute to the creation of more attractive and picturesque landscapes. Preserving and restoring healthy soils can enhance the visual appeal of the surroundings.
- An important objective is to establish an environment free of pollution, providing a safe and healthy place for human habitation. Soil conservation contributes to overall environmental protection, ensuring cleaner air, water, and surroundings.
- Protecting and conserving soil resources is essential for the future of our children. By maintaining healthy soil, we secure a foundation that can sustain life for generations to come. As the saying goes, the land is not solely inherited from our forefathers; instead, it is borrowed from our children, emphasizing the responsibility to preserve it for their benefit.

13.4 Soil Management Techniques:

Soil serves as the foundation for agriculture, making its proper management crucial for maintaining long-term agricultural productivity. Regrettably, soil erosion often goes unnoticed until it reaches severe levels, where deep channels impede cultivation practices.

However, the reality is that soil erosion starts to occur at unsustainable levels even when small rills become visible in the fields.

Identifying and addressing erosion at its early stages is essential to safeguard this valuable resource and ensure the sustainable growth of agriculture.

Indeed, soil stands as the fundamental resource upon which agriculture relies. To ensure sustainable long-term agricultural productivity, it is imperative to exercise proper management of this invaluable asset. Regrettably, soil erosion often comes to attention only when its impact becomes visibly drastic, such as channels cutting deeply through fields, impeding cultivation practices. However, it is crucial to recognize that soil erosion reaches unsustainable levels even when small rills become noticeable in the fields.

Thus, proactive measures and early identification are essential to effectively combat soil erosion and preserve the productivity of agricultural lands. By addressing erosion concerns at their early stages, we can safeguard the health and resilience of the soil, promoting a more sustainable and prosperous agricultural future.

There are two distinct approaches to soil conservation, namely mechanical measures and biological measures. Mechanical measures encompass the construction of enduring or semi-permanent structures, such as terracing, bunding, trenching, and check dams. On the other hand, biological measures consist of vegetative strategies, including forestry, agroforestry, horticulture, and agricultural or agronomic practices.

13.4.1 Biological Measures (Agronomic/Agricultural and Agroforestry):

Agronomic measures are applicable in the landscape of ≤2% slope. Agronomic measures reduce the impact of raindrops through the covering of soil surface and increasing infiltration rate and water absorption capacity of the soil which results in reduced runoff and soil loss through erosion. These measures are cheaper, sustainable, and may be more effective than structural measures. Important agronomic measures are described below.

A. Contour Farming:

Contour farming is a highly effective agronomic measure for soil and water conservation, particularly in hilly and sloping landscapes. It involves carrying out all agricultural operations, such as plowing, sowing, and inter-culturing, along the contour lines of the land. The formation of ridges and furrows across the slope creates a series of small barriers that slow down the flow of water, reducing the velocity of runoff and minimizing soil erosion and nutrient loss. The benefits of contour farming are significant and vary depending on the specific environmental conditions of a particular area:

- **Reduced soil erosion**: By slowing down runoff, contour farming prevents the rapid removal of soil particles, reducing erosion and conserving the fertile topsoil.
- **Enhanced infiltration**: The ridges and furrows improve water infiltration by increasing the time of concentration, allowing water to seep into the soil rather than running off the surface. This is particularly valuable in regions with low rainfall, as it helps conserve soil moisture and improves plant water availability.
- **Improved soil moisture retention**: In low rainfall areas, contour farming helps to trap and store rainwater, making it available for plant uptake over an extended period.
- **Minimized nutrient loss**: As the soil is better retained on the field, the loss of valuable nutrients, such as nitrogen and phosphorus, is reduced, benefiting crop productivity.
- **Increased crop productivity**: Conserving soil fertility, moisture, and nutrients ultimately improves overall crop productivity.

Contour farming is a valuable agronomic measure that offers numerous benefits for soil and water conservation in hilly agro-ecosystems and sloping lands. Proper implementation and adaptation to local conditions can greatly enhance its effectiveness and contribute to sustainable agriculture and improved crop productivity.

B. Choice of Crops:

Choosing the appropriate crop plays a vital role in soil conservation. Several factors should be taken into account, including the intensity and critical period of rainfall, market demand, climate, and the farmer's available resources. Opting for a crop with excellent biomass, ample canopy cover, and an extensive root system is crucial as it aids in safeguarding the soil against erosive rainfall impact and obstructing runoff, ultimately reducing soil and nutrient loss. Certain crops, like sorghum, maize, and pearl millet, which grow in rows or tall structures, may promote erosion by exposing the soil and facilitating the erosion process. On the other hand, crops that grow closely together, with a dense canopy cover and vigorous root system, such as cowpea, green gram, black gram, and groundnut, are better suited for mitigating soil erosion. To maximize canopy density, it is advisable to use a higher seed rate while planting the chosen crop. This practice encourages a more comprehensive coverage, further enhancing soil protection and erosion reduction.

Figure 13.2: Choice of Crops

F. Crop Rotation:

Figure 13.3: Crop Rotation

Crop rotation is a beneficial agricultural practice that involves cultivating different types of crops successively on the same field. The primary aim is to maximize profits with minimal investment while preserving soil fertility. In contrast, monocropping, which involves planting the same crop repeatedly, can lead to soil nutrient depletion and reduced fertility over time. Incorporating legume crops into the crop rotation brings several advantages, such as reducing soil erosion, restoring soil fertility, and conserving soil and water resources. Additionally, when crop residues are integrated into the soil after harvest, it enhances the organic matter content, overall soil health, and helps in reducing water pollution.

An appropriately planned crop rotation that includes high canopy cover crops can significantly contribute to sustaining soil fertility. These rotations effectively suppress weed growth, decrease pests and disease infestation, improve the efficiency of resource utilization, and enhance overall system productivity while simultaneously reducing soil erosion. By adopting crop rotation practices, farmers can achieve sustainable and profitable agricultural production while safeguarding the long-term health and productivity of their soil.

D. Cover Crops:

Figure 13.4: Cover Crops

Cover crops, also known as close-growing crops with high canopy density, play a crucial role in protecting the soil from erosion. Among cover crops, legume crops are particularly effective in safeguarding soil health due to their good biomass and dense canopy. The success of cover crops in erosion control depends on their crop geometry and the development of a robust canopy, which helps intercept raindrops and minimize soil surface exposure to erosion.

Studies have indicated that legume cover crops outperform other options like cultivated fallow and sorghum in providing better cover and protection against runoff and soil loss.

Among the legume cover crops, cowpea, green gram, black gram, and groundnut have been found to be particularly effective in reducing erosion and preserving soil integrity. By strategically incorporating these cover crops into crop rotations or leaving them on the field during periods of fallow, farmers can greatly enhance soil conservation efforts, reduce erosion-related issues, and promote sustainable agricultural practices.

Advantages:

Cover crops offer a range of valuable benefits that contribute to soil conservation and agricultural productivity

- Protection from Erosion: Cover crops shield the soil surface from the erosive impact of raindrops and the forces of wind, reducing soil erosion.
- Obstacle to Water Flow: They act as barriers in water flow, slowing down its velocity, which helps in decreasing runoff and soil loss during heavy rainfall events.
- Increased Organic Matter: Cover crops contribute to soil organic matter content through the incorporation of their residues into the soil. This enhances soil fertility and overall soil health.
- Biological Nitrogen Fixation: Legume cover crops have the unique ability to fix atmospheric nitrogen through symbiotic relationships with nitrogen-fixing bacteria in their root nodules. This process enriches the soil with available nitrogen, benefiting not only the cover crop but also subsequent crops in the rotation.
- Improved Water Holding Capacity: The presence of cover crops helps improve the soil's ability to retain moisture, reducing water loss through evaporation and ensuring better water availability for the crops.
- Enhanced Soil Properties: Cover crops can positively influence soil structure, aeration, and nutrient availability, leading to improved overall soil properties.
- Weed Suppression: A well-established cover crop can effectively suppress weed growth, reducing competition for resources and promoting the growth of desired crops.
- Increased Crop Productivity: By providing a favorable environment for the main crop and subsequent crops, cover crops can lead to increased agricultural productivity.
- Overall, incorporating cover crops into agricultural practices can bring multiple advantages, making them a valuable tool for sustainable soil conservation and farming. Protection of soil from the erosive impact of raindrops, runoff, and wind.
- Act as an obstacle in water flow, reduce flow velocity, and thereby reduce runoff and soil loss.
- Increase soil organic matter by residue incorporation and deep root system.
- Improve nutrients availability to the component crop and succeeding crops through biological nitrogen fixation.
- Improve water holding capacity of the soil.
- Improve soil properties, suppress weed growth, and increase crop productivity.

E. Intercropping:

Figure 13.5: Intercropping

Intercropping refers to the practice of cultivating two or more crops simultaneously in the same field, often arranged in definite or alternate row patterns. The classification of intercropping can be based on the types of crops used, soil type, topography, and prevailing climatic conditions. Common types of intercropping include row intercropping, strip intercropping, and relay intercropping, each offering specific benefits based on its configuration.

The primary goal of intercropping is to make efficient use of resources, space, and time dimensions. By combining erosion-permitting and erosion-resisting crops, farmers can optimize soil conservation efforts. Selecting crops with different rooting patterns is essential to ensure effective soil coverage, which reduces the direct impact of raindrops and minimizes soil erosion.

Overall, intercropping provides significant advantages in terms of better soil coverage, reduced soil erosion from the direct impact of raindrops, and improved soil protection. By strategically planning and implementing intercropping practices, farmers can enhance soil health, maximize productivity, and promote sustainable agricultural practices.

F. Strip Cropping:

Figure 13.6:

Strip cropping is a farming practice that involves growing alternating strips of erosion-permitting and erosion-resistant crops in the same field. This technique is employed to reduce soil erosion, control runoff, and maintain soil fertility. The erosion-resistant crops, which typically have deep root systems and high canopy density, act as natural barriers, protecting the soil from the impact of raindrops and slowing down the velocity of runoff. By implementing strip cropping, the runoff velocity is reduced, which allows more time for water to infiltrate into the soil, resulting in increased soil moisture. This additional soil moisture can enhance crop production, as it provides a more favorable environment for plant growth. In addition to mitigating soil erosion and nutrient loss, strip cropping can also be beneficial in preserving soil structure, preventing sedimentation in water bodies, and supporting biodiversity in the agricultural landscape. Overall, it is a sustainable practice that contributes to the long-term health and productivity of the soil.

Types of Strip Cropping:

Contour strip cropping: Contour strip cropping is indeed a farming practice where alternating strips of erosion-permitting and erosion-resistant crops are grown along the contour lines of the sloping land.

The main objectives of contour strip cropping include:

A. **Reducing the direct impact of raindrops on the soil surface**: By growing erosion-resistant crops in alternate strips, the force of raindrops hitting the soil is reduced, minimizing soil detachment and erosion.
B. **Reducing the length of the slope**: The contour strips act as barriers to slow down the flow of water down the slope, effectively dividing the long slope into shorter segments. This reduces the potential for concentrated flow, which can lead to soil erosion.
C. **Slowing down runoff flow**: Contour strip cropping helps to control and disperse runoff water, preventing it from gaining high velocity and causing erosion.
D. **Enhancing rainwater absorption into the soil profile**: By slowing down the flow of water and reducing surface runoff, more water can infiltrate into the soil, increasing soil moisture and promoting better plant growth.

Overall, contour strip cropping is an effective soil conservation practice, especially on sloping terrains, as it helps to minimize soil erosion, retain soil fertility, and improve water availability for crops. It is a sustainable agricultural approach that contributes to the long-term health and productivity of the land.

Figure 13.7: Strip Cropping

- **Field strip cropping -** The specialized strip cropping you described, where crops are planted in parallel bands across a slope but do not follow contour lines, with alternating bands of grass or other close-growing species and cultivated crops, is known as "alley cropping" or "agroforestry strip cropping.".

Figure 13.8: Field Strip Cropping

- **Wind strip cropping:** Wind strip cropping is a conservation technique used to control soil erosion caused by wind., it involves planting tall-growing row crops (like maize, pearl millet, and sorghum) along with close or short growing crops in alternating strips across the direction of the prevailing wind, without regard to the contour of the land.

Figure 13.9: Wind Strip Cropping

- **Permanent or temporary buffer strip cropping:** It is the growing of permanent strips of grasses or legume or a mixture of grass and legume in highly eroded areas or in areas that do not fit into regular rotation, i.e. steep or highly eroded, slopes in fields under contour strip cropping. These strips are not practiced in normal strip cropping and generally planted permanent or temporary basis.

Figure 13.10: Permanent or Temporary Buffer Strip Cropping

Purposes:

- Reduce soil erosion from water and wind.
- Strip Cropping reduces the rate of soil erosion and the runoff velocity.
- Increasing the infiltration rate of the soil under cover condition.
- Reduce the transport of sediment and other waterborne contaminants.
- Protect growing crops from damage by windborne soil particles.
- Improve water quality.

G. Mulching:

Figure 13.11: Mulching

Mulch is any organic or non-organic material that is used to cover the soil surface to protect the soil from being eroded away, reduce evaporation, increase infiltration, regulate soil temperature, improve soil structure, and thereby conserve soil moisture.

Mulching prevents the formation of hard crust after each rain. The use of blade harrows between rows or inter-culture operations creates “dust mulch” on the soil surface by breaking the continuity of capillary tubes of soil moisture and reduces evaporation losses. Mulching also reduces the weed infestation along with the benefits of moisture conservation and soil fertility improvement.

Hence, it can be used in high rainfall regions for decreasing soil and water loss, and in low rainfall regions for soil moisture conservation. Organic mulches improve organic matter and consecutively improving the water holding capacity, macro and micro fauna biodiversity, their activity, and fertility of the soil .Inorganic mulches have a longer life span than organic mulches and can reduce soil erosion, water evaporation losses, suppress weeds but cannot improve soil health.

This practice is costly and labor intensive therefore, suitable for cash crops such as fruits and vegetables. Polyethylene mulch is commonly used for the conservation of soil and water resources to increase crop productivity.

H. Conservation tillage:

Conservation tillage is an important agricultural practice that involves leaving a significant amount of crop residue on the soil surface before and after planting the next crop. The main goal is to reduce soil erosion and promote other beneficial effects, such as carbon sequestration and improved soil health.

Benefits of Conservation Tillage:

- **Reduced soil erosion**: Crop residue cover protects the soil from water and wind erosion.
- **Carbon sequestration**: The presence of crop residues contributes to increased soil organic carbon content**.**
- **Improved infiltration**: Conservation tillage improves water infiltration into the soil, reducing runoff.
- **Soil moisture conservation**: Crop residue cover reduces evaporation losses and helps retain soil moisture.
- Enhanced soil health: Conservation tillage improves soil structure, organic matter content, and nutrient cycling.
- **Increased productivity**: Better soil health and fertility lead to improved crop yields.
- **Soil compaction reduction**: Reduced soil disturbance can alleviate compaction issues.

Figure 13.12: Soil Compaction Reduction

I. Organic Farming:

Organic farming in relation to soil erosion and overall environmental friendliness. Organic farming practices focus on enhancing soil health and fertility through the use of natural, organic sources for plant nutrient supply, such as farmyard manure (FYM), compost, vermicompost, green manure, and residue mulching. These practices lead to several positive effects on soil erosion:

- **Continuous soil surface cover**: Organic farmers often use cover crops, green manure, and residue mulch, which help maintain a protective cover on the soil surface. This cover acts as a barrier against raindrop impact and water runoff, reducing the erosive forces that lead to soil erosion.

- **High organic matter content:** Organic farming relies on the addition of organic materials, which increase the organic matter content in the soil. Higher organic matter content improves soil structure and stability, reducing the disintegration of soil particles and making the soil less susceptible to erosion.
- **Improved water infiltration**: Organic matter-rich soils have better water retention capacity and improved water infiltration. This helps prevent surface runoff and allows rainwater to penetrate the soil, reducing the potential for erosion.
- **Enhanced soil aggregation**: The presence of organic matter fosters the development of soil binding agents, such as polysaccharides. These agents help stabilize and strengthen soil aggregates, which further contributes to erosion reduction.
- **Reduced soil erodibility**: By improving soil structure, organic farming reduces soil erodibility, which refers to the soil's susceptibility to erosion under specific conditions.
- organic farming practices can significantly reduce soil erosion rates compared to conventional farming methods. The use of synthetic fertilizers and pesticides in conventional agriculture can lead to adverse environmental impacts, including soil degradation and erosion. On the other hand, organic farming focuses on sustainable and eco-friendly practices, which prioritize soil health and long-term crop productivity while minimizing negative environmental consequences.

J. Land Configuration Techniques:

Adoption of appropriate land configuration and planting techniques according to crops, cropping systems, soil type, topography, rainfall, etc. help in better crop establishment, intercultural operations, reduce runofff, soil and nutrient loss, conserve water, efficient utilization of resources and result in higher productivity and profitability. Ridge and furrow, raised bed and furrow, broad bed and furrow, and ridging the land between the rows are important land configuration techniques.

- **Ridge and furrow system:** Raising rainy season crops on ridges and *rabi* season crops in furrows reduces the soil crusting and ensures good crop stand over sowing on flat beds. Moreover, inter-row rainwater can be drain out properly during the monsoon period and collected in farm ponds, for life-saving irrigations and profile recharging for the establishment of *rabi* crops. It leads to the increased moisture content in soil profile which reduces moisture stress on plants during the drought period. This method is most suitable for wide-spaced crops viz. cotton, maize, vegetables, etc.

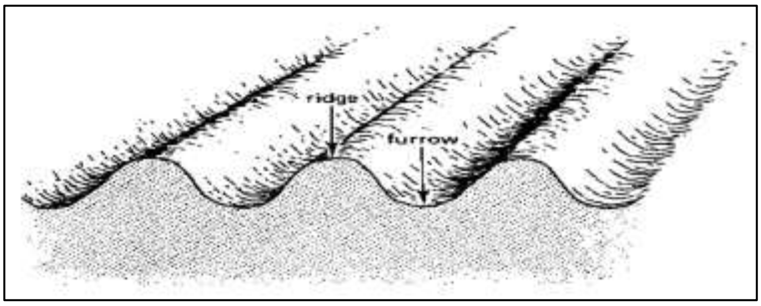


Figure 13.13: Ridge and Furrow System

- **Broad bed and furrow system:** This system has been developed by the ICRISAT in India. It is primarily advocated for high rainfall areas (>750 mm) having black cotton soils (Vertisols). Beds of 90–120 cm width are formed, separated by sunken furrows of about 50–60 cm wide and 15 cm depth. The preferred slope along the furrow is between 0.4 and 0.8% on Vertisols. Two to four rows of the crop can be grown on the bed, and the width and crop geometry can be adjusted to suit the cultivation and planting equipment.

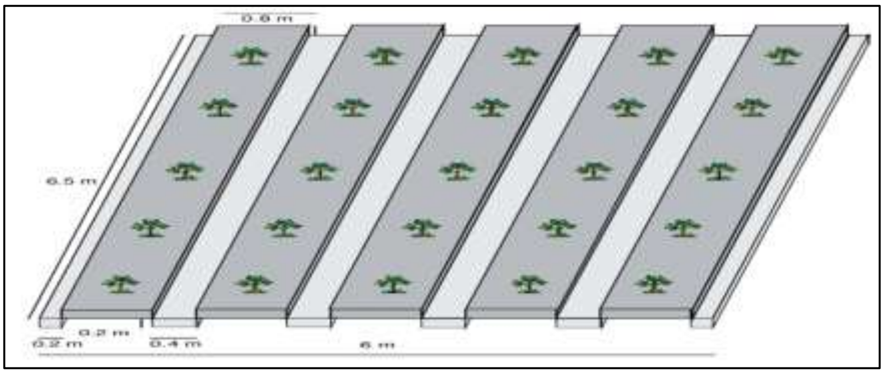


Figure 13.14: Broad Bed and Furrow System

Advantages:

- Increase *in-situ* soil moisture conservation
- Safely dispose of excess runoff without causing erosion
- Improved soil aeration for plant growth and development
- Easier for weeding and mechanical harvesting
- It can accommodate a wide range of crop geometry.

13.5 Agroforestry Measures:

Figure 13.15: Agroforestry Measures

Agroforestry is indeed a sustainable land management system that integrates the cultivation of trees or shrubs with agricultural crops and livestock on the same piece of land. This practice has gained attention for its numerous benefits, including effective soil conservation and sustainable agricultural production.

A. **Soil conservation**: Agroforestry systems help control soil erosion by providing a protective layer through the addition of leaf litter and organic matter from tree and shrub canopy. The leaf litter acts as a mulch, reducing the impact of raindrops on the soil surface and minimizing surface runoff, thus protecting against erosion.
B. **Soil health and moisture retention**: The incorporation of trees and shrubs in agroforestry systems improves soil health by enhancing organic matter content and microbial activity. This, in turn, enhances the soil's moisture retention capacity, reducing the risk of drought stress on crops.
C. **Crop productivity**: Agroforestry practices can positively impact crop productivity due to improved soil health, reduced erosion, and better water availability. The interaction between trees and crops can also create beneficial microclimates for certain crops, providing shade or wind protection.
D. **Environmental benefits**: Agroforestry helps mitigate environmental pollution by reducing the need for synthetic fertilizers and pesticides, thereby promoting a more sustainable and eco-friendly agricultural system.
E. **Economic benefits**: Apart from its environmental advantages, agroforestry also offers economic benefits to farmers. Trees in agroforestry systems can produce marketable products like fruits, nuts, timber, medicinal plants, and other non-timber forest products, contributing to farm income diversification.
F. **Soil erosion reduction:** Studies have shown that various agroforestry practices can reduce soil erosion rates by up to 10% compared to conventional agriculture. This is an essential contribution to land conservation and protection of natural resources. agroforestry is a multifaceted approach that offers a range of benefits, including soil conservation, improved soil health, increased crop productivity, and economic diversification through the production of marketable tree-based products. Its potential to reduce soil erosion and its positive impact on the environment and farm economy make it an attractive and sustainable land management system.

Types of Agroforestry Systems:

A. **Agri- Silviculture:** It is the growing of agricultural crops as a primary component with the secondary component of multipurpose trees (MPTs) on the same managed land unit. The tree species bind soil particles in the root zone and increase water infiltration, and reduce runoff.
B. **Agri-Horticulture:** Growing of agricultural crops and fruit trees on the same managed land unit is known as agri-horticulture. Fruit tree species like lemon (*Citrus limon*), mango (*Mangifera indica*), ber (*Ziziphus mauritiana*), and aonla (*Phyllanthus emblica*) can be successfully planted in agricultural fields and on degraded and low fertile lands with some restoration measures.
C. **Alley Cropping:** Growing of agricultural crops in the alley formed between the hedge rows of leguminous nitrogen-fixing tree species. This system is one of the effective measures for soil and water conservation in hilly areas.

D. **Silvi -Pasture System:** Raising grasses or livestock with MPTs on the same managed land unit is known as silvi-pasture system. This system has the potential to reclaim eroded and degraded lands. Mechanical measures combined with grass species cultivation are more effective for controlling soil erosion processes. The grass species such as, *Dichanthium annulatum (marvelgrass), Panicumantidotale (bluepanicgrass), Panicummaximum (Guineagrass), Brachiariamutica (para grass)* and *Pennisetum purpureum* (elephant grass) are important in ravine restoration.

13.6 Mechanical Measures:

Mechanical measures or engineering structures are designed to modify the land slope, to convey runoff water safely to the waterways, to reduce sedimentation and runoff velocity, and to improve water quality. These measures are either used alone or integrated with biological measures to improve the performance and sustainability of the control measures. In highly eroded and sloppy landscape biological measures should be supplemented by mechanical structures. A number of permanent and temporary mechanical measures are available such as terraces, contour bunding, check dams. The mechanical measures are preferred based on the severity of erosion, soil type, topography, and climate.

A. Bunding:

- **Contour bunding:** Contour bunding is used to conserve soil moisture and reduce erosion in the areas having 2–6% slope and mean annual precipitation of <600 mm with permeable soils. The vertical interval between two bunds is known as the spacing of bunds. The spacing of bund is dependent on the erosive velocity of runoff, length of the slope, slope steepness, rainfall intensity, type of crops, and conservation practices.

Figure 13.16: Contour Bunding

- **Graded bunding:** Graded bunds are made to draining out of excess runoff water safely in areas having 6–10% land slope and receiving rainfall of >750 mm with the soils having infiltration rate < 8 mm/h.

- **Peripheral bunds:** Peripheral bunds are constructed around the gully head to check the entry of runoff into the gully. It protects the gully head from being eroded away through erosion processes. It creates a favorable condition for the execution of vegetative measures on gully heads, slopes, and beds.

B. Contour trenching:

Trenches are constructed at the contour line to reduce the runoff velocity for soil moisture conservation in the areas having <30% slope. Bunds are formed on the downstream side of trenches for the conservation of rainwater. Trenches are of two types:

Figure 13.17: Contour Trenching

- **Continuous contour trenches:** Continuous contour trenches are constructed based on the size of the field in the low rainfall areas with the 10–20 cm trench length and 20–25 cm equalizer width without any discontinuity in trench length (10–20 m).
- **Staggered contour trenches (STCs)** Generally, these trenches are constructed in alternate rows directly beneath one another in a staggered manner in the high rainfall areas, where the risk of overflow is prominent. SCTs are 2–3 m long with 3–5 m spacing between the rows. Planting of tree species is done based on the land slope. It is highly effective in forestalling extension of gully head, soil loss, and arrest the overflow.

C. Terracing:

Figure 13.18: Terracing

Terraces are earthen embankments built across the dominant slope partitioning the field in uniform and parallel segments. Generally, these structures are combined with channels to convey runoff into the main outlet at reduced velocities. It reduces the degree and length of slope and thus reduced runoff velocity, soil erosion and improves water infiltration. It is recommended for the lands having a slope of up to 33%, but can be adopted for lands having up to 50–60% slope, based on socio-economic conditions of a particular region. Where plenty of good-quality stones are available, stone bench terracing is recommended. Sometimes, semi-circular type terraces are built at the downstream side of the plants, known as half-moon terraces. Based on the slope of benches, the bench terraces are classified into the following categories:

- **Bench terraces sloping outward:** These types of terraces are used in low rainfall areas having permeable soils. A shoulder bund is provided for stability of the edge of the terrace and thus has more time for rainwater soaking into the soil.
- **Bench terraces sloping inward (hill-type terraces):** These types of bench terraces are suitable for heavy rainfall areas where a higher portion of rainfall is to be drained as runoff. For this, a suitable drain should be provided at the inward end of each terrace to drain the runoff. These are also known as hill-type terraces.
- **Bench terraces with level top:** These types of terraces are suitable for uniformly distributed medium rainfall areas having deep and highly permeable soils. These are also known as irrigated bench terraces because of their use in irrigated areas.

D. Conservation Bench Terrace:

In the conservation bench terrace system, the land is divided into 2:1 ratio along the slope in which the upper 2/3 area (Donor area) contributes runoff to the lower 1/3 runoff collecting area (recipient area). The donor area is left in its natural slope condition. It is also known as the zing terrace and developed by Zing and Hauser in 1959. The runoff contributing area is used for cultivation of *kharif* while the lower 1/3 area with conserved soil moisture is used to cultivate rabi zcrops. This mechanical measure can be successfully applied in a semi-arid climate on mild sloppy lands (2–5%) for erosion control, water conservation, and improvement of crop productivity. This system can be used in silty loam to silty clay loam soils. CBT system resulted in the reduction of runoff from 36.3 to 7.4% and soil loss from 10.1 to 1.19 Mg ha^{-1} as compared to the conventional system of sloping border. An average reduction of 78.9 and 88.0% in runoff and soil loss, respectively reported in the CBT system over the conventional system.

13.7 Conclusion:

The land is finite and diminishing gradually due to the increasing rate of varied kinds of degradation and thus there is no alternative to expend cultivable land area. The only way is either increasing agricultural productivity per unit resource available or restoring the degraded lands. Healthy soil and availability of water are vital for productivity in all kinds of terrestrial ecosystems because plants require fertile soil with improved Biological-Physical-Chemical properties and good quality of water for their growth and development. Use of soil and water conservation measures including biological (agroforestry and agricultural) and mechanical measures (terracing, bunding, trenching, check dams, etc.) is imperative to reduce runoff, soil erosion and to improve soil quality, water quality, moisture conservation, and overall crop productivity in a sustainable way. Biological measures are economically feasible and environmental friendly; also improve soil properties along with the conservation of soil and water resources. Further, the combined use of biological and mechanical measures will help in improving and sustaining agricultural productivity.

Future Perspectives for Soil Conservation:

The burgeoning world population, food insecurity and natural resource degradation are the major issues in the present era of climate change. It has been projected that the world population will be ~10 billion in 2050. Further, the rapid industrial growth and intensive farming practices are expected to increase the pressure on land and water resources in near future. Therefore, a paradigm shift in soil and water conservation, and its management is needed for agricultural sustainability. The some of the future concern for soil and water conservation and sustainable agriculture are the following:

- Formulation of new policies and development of new technologies based on social, economic and cultural aspect of a particular regional.
- Implementation and adoption of effective conservation measures for sustaining agricultural productivity.
- Existing soil and water conservation practices should be improved and developed based on the level of natural resources degradation.
- Greater emphasis should be given on participatory approach for effective soil and water conservation.
- Post impact assessment and monitoring of soil and water conservation measures should be done to evaluate their efficacy in increasing productivity, monetary returns, and livelihood of the stakeholders.
- Development of cost effective conservation practices to restore the degraded lands and to sustain agricultural productivity.
- The efficient technologies for soil and water conservation should be demonstrated on farmers' fields with their active participation.
- Emphasis on research, education and extension of soil and water conservation effective technologies to the stakeholders.
- Adoption of efficient management practices and judicious use of soil and water resources.

13.8 References:

1. Shinde R, Sarkar PK, Thombare N, Naik SK. Soil conservation: Today's need for sustainable development. Agriculture & Food: e-Newsletter. 2019;1(5):175-183
2. Sarvade S, Upadhyay VB, Kumar M, Khan MI. Soil and water conservation techniques for sustainable agriculture. In: Sustainable Agriculture, Forest and Environmental Management. Singapore: Springer; 2019. pp. 133-188.
3. Manivannan S, Thilagam VK, Khola OP. Soil and water conservation in India: Strategies and research challenges. Journal of Soil and Water Conservation. 2017;16(4):312-319

4. Gachene CK, Nyawade SO, Karanja NN. Soil and water conservation: An overview. In: Zero Hunger. Encyclopedia of the UN Sustainable Development Goals. Cham: Springer; 2019
5. Blanco H, Lal R. Principles of Soil Conservation and Management. Dordrecht: Springer; 2008. pp. 167-169
6. Singh RK, Chaudhary RS, Somasundaram J, Sinha NK, Mohanty M, Hati KM, et al. Soil and nutrients losses under different crop covers in vertisols of Central India. Journal of Soils and Sediments. 2020;20(2):609-620
7. Bhattacharyya R, Ghosh BN, Mishra PK, Mandal B, Rao CS, Sarkar D, et al. Soil degradation in India: Challenges and potential solutions. Sustainability. 2015;7(4):3528-3570
8. Indian Council of Agricultural Research (ICAR). In: Trivedi TP, editor. Degraded and Wastelands of India: Status and Spatial Distribution. New Delhi, India: Directorate of Information and Publications of Agriculture; 2010. p. 24
9. Lal R. Restoring soil quality to mitigate soil degradation. Sustainability. 2015;7(5):5875-5895.
10. Samra JS, Sharma UC. Soil erosion and conservation. In: Sekhon GS, Chhonkar PK, Das DK, Goswami NN, Narayanasamy G, Poonia SR, Rattan RK, Sehgal JK, editors. Fundamental of Soil Science. New Delhi: Indian Society Soil Science; 2002. pp. 159-170
11. Vanwalleghem T. Soil erosion and conservation. International Encyclopedia of Geography: People, the Earth, Environment and Technology: People, the Earth, Environment and Technology. 2016;12:1-10
12. Young A. Agroforestry for Soil Conservation. Wallingford: CAB International; 1990. p. 318
13. Santra P, Mertia RS, Kumawat RN, Sinha NK, Mahla HR. Loss of soil carbon and nitrogen through wind erosion in the Indian Thar Desert. Journal of Agricultural Physics. 2013; 13(1):13-21.
14. Lal M, Mishra SK. Characterization of surface runoff, soil erosion, nutrient loss and their relationship for agricultural plots in India. Current World Environment: An International Research Journal of Environmental Sciences. 2015;10(2):593-601
15. Singh AK, Kumar AK, Katiyar VS, Singh KD, Singh US. Soil and water conservation measures in semi-arid regions of South-Eastern Rajasthan. Indian Journal of Soil Conservation. 1997;25(3):186-189
16. Shinde R, Sarkar PK, Thombare N, Naik SK. Soil conservation: Today’s need for sustainable development. Agriculture & Food: e-Newsletter. 2019;1(5):175-183
17. Meena RS, Lal R, Yadav GS. Long term impacts of topsoil depth and amendments on soil physical and hydrological properties of an Alfisol in Central Ohio. USA. Geoderma. 2020;363:1141164.

ISBN: 978-81-19149-59-9

14. Conservation Agriculture in India, History, Status, Implications and Sustainability Uses

Buriga Teja Swaroop, Kobagapu Mani Ratnam,

Palli Susan Grace, Yalamala Prasanghi

Abstract:

Conservation agriculture (CA) technologies involve minimal soil disturbance, permanent soil cover through crop residues or cover crops, and crop rotations to increase productivity. Efforts in India to develop, refine, and disseminate conservation-based agricultural technologies have been ongoing for nearly two decades and have made significant progress since then, despite several constraints that impede CA adoption. In particular, tremendous efforts have been made in the Indo-Gangetic plains to achieve no-till wheat under a rice-wheat rotation. There are more payoffs than tradeoffs for CA adoption, but the balance between the two was understood by both adopters and promoters.

CA technologies offer opportunities to reduce production costs, save water and nutrients, increase yields, diversify crop production, improve resource efficiency, and benefit the environment. However, there are still barriers to CA technology promotion, such as a lack of appropriate seeders, particularly for small and medium-scale farmers, crop residue competition between CA use and livestock feeding, crop residue burning, the availability of skilled and scientific manpower, and overcoming the bias or mindset about tillage.

To promote CA in the region, it is critical to develop a policy framework and strategies. This article examines the emerging concerns caused by the continued adoption of conventional agriculture systems, as well as the constraints, prospects, policy issues, and research needs for conservation agriculture in India.

Keywords:

Conservation agriculture, Conventional agriculture, Principles, Constraints, Prospects, Implications and Sustainability uses.

14.1 Introduction:

The concept of conservation agriculture is relatively using of new and modern cultivation practices. Conventional agricultural practices promote the extensive soil tillage, burning of crop residues and external inputs. Such practices lead to soil degradation through loss of organic matter, soil erosion and compaction.

In India more than 70-75% farmers are small land holding farmer they are still using traditional farm practices and are major contributor in total food production. Yet, for many, farming is a struggle often with only rudimentary tools and implements available.

Conservation Agriculture is a method of planning and managing sustainable and resource-conserving agricultural systems (CA). It aims to improve, preserve, and make better use of natural resources through integrated management of soil, water, crops, and other biological resources in conjunction with selected external inputs. Agriculture could be resource-saving and effective, while also improving production in a sustainable manner, with such a technological setup.

Conservation agriculture includes direct planting through crop residue, minimum tillage, organic soil cover, improved on-farm water management, and appropriate crop rotations to prevent disease and pest issues. Burning crop wastes (as in the rice-wheat cropping system) contributes to pollution, greenhouse gas emissions, and the loss of important plant nutrients. Initiating processes that improve soil quality and boost resource quality when crop residues are left on the soil surface and no tillage is used. In order to fulfil the goals of sustainable agriculture production, Conservation agriculture has evolved as a new approach. It's a significant step in the direction of sustainable agriculture.

Therefore, there are major benefits to Conservation agriculture. Direct advantages to farmers include i) lower cultivation costs due to manpower, (ii) time, and farm power savings, and (iii) increased input usage efficiency. More importantly, CA techniques stop the depletion of resources. By increasing nitrogen balance and availability, soil infiltration and retention, lowering water loss due to evaporation, and enhancing the quality and availability of ground and surface water, CA results in long-term gains in the effective use of water and nutrients.

14.2 Conservation Agriculture Definition and Goals:

Conservation agriculture is a management system that maintains a soil cover through surface retention of crop residues with no till/zero and reduced tillage.

It is described as a concept for resource saving agricultural crop production which is based on enhancing the natural and biological processes above and below the ground. Conservation agriculture (CA), is not "business as usual," based on optimizing yields while utilizing the resources of the land and agro-ecosystem. A balance of agricultural, economic, and environmental benefits is achieved by CA by optimizing yields and profitability. It argues that the social and economic benefits of both production and environmental preservation-including lower input and labour costs—are larger than those of production alone. By using pesticides, fossil fuels, and other harmful substances, as well as by preserving the integrity of the environment and its services, farming communities may provide a wider population with better hygienic living conditions.

As per FAO definition CA is to i) achieve acceptable profits ii) high and sustained production levels, and iii) conserve the environment. It aims at reversing the process of degradation inherent to the conventional agricultural practices like intensive agriculture, burning/removal of crop residues. Hence, it aims to conserve, improve and make more efficient use of natural resources through integrated management of available soil, water and biological resources combined with external inputs. It can also be referred to as resource efficient or resource effective agriculture.

Table 1: Distinguishing features of conventional and conservation agriculture systems

Sr. No	Parameters	Conventional Agriculture (CT)	Conservation Agriculture (CA)
1.	Practice	Disturbs the soil and leaves at a bare surface	Minimal soil disturbance and soil surface is permanently coverd
2.	Cropping system	Monocropping / less efficient rotations	Diversified farming / more efficient rotations
3.	Residue management	Burning or removal	Retention on the soil surface
4.	Erosion	Maximum wind and water erosion	Less erosion
5.	Soil health	Poor	Good
6.	Water infiltration	Infiltration will be lowest after soil pores clogged	Good infiltration
7.	Organic matter content	Low	High
8.	Weeds	Control weeds and also produce more weed seeds to germinate	Weeds are problem only during early stages of adoption, later good control of weeds
9.	Timeliness	Operations can be delayed	Optimal timeliness
10.	Yield	Lower due to delayed operation	More yield when timely planting done

How is conservation agriculture different from sustainable intensification?

Sustainable intensification is a process to increase agriculture yields without adverse impacts on the environment, taking the whole ecosystem into consideration. It aims for the same goals as conservation agriculture.

Conservation agriculture practices lead to or enable sustainable intensification.

How is conservation agriculture differing from organic agriculture?

Conservation agriculture and organic farming both use crop rotation to maintain a balance between agriculture and resources and to protect the organic matter in the soil. The main distinction between these two types of farming is that organic farmers use soil tillage, whereas conservation farmers use natural principles and do not till the soil. Tillage is used by organic farmers to remove weeds without the use of inorganic fertilisers.

Farmers who practise conservation agriculture use a permanent soil cover and plant seeds through it. They may initially use inorganic fertilisers to control weeds, particularly in low fertility soils. Agrichemical use may be reduced or phased out gradually over time.

How is conservation agriculture differing from climate-smart agriculture?

While conservation agriculture and climate-smart agriculture are similar, their goals are not. Conservation agriculture seeks to use natural processes to sustainably intensify smallholder farming systems while also having a positive impact on the environment. It enables farmers to adapt to and increase profits in the face of climate risks. Climate-smart agriculture aims to adapt to and mitigate the effects of climate change by sequestering soil carbon and reducing greenhouse gas emissions, and finally to increase the productivity and profitability of farming systems to ensure farmers' livelihoods and food security in a changing climate. Conservation agriculture systems can be considered climate-smart because they meet the goals of climate-smart agriculture.

14.2.1 Principles of Conservation Agriculture:

Conservation agriculture practices used in many parts of the world are built on ecological principles making land use more sustainable. Adoption of Conservation Agriculture for enhancing Resource use efficiency (RUE) and crop productivity is the need of the hour as a powerful tool for management of natural resources and to achieve sustainability in agriculture. Conservation agriculture basically follows 3 principles, which must be considered together for appropriate design, planning and implementation processes. These are:

A. Minimal Mechanical Soil Disturbance:

The biological activity of the soil creates very solid soil aggregates and holes of different sizes that enable the infiltration of air and water. This method, which is sometimes referred to as "biological tillage," is incompatible with mechanical tillage. The biological health and life processes of the soil will be destroyed by mechanical soil disturbance. A minimum amount of soil disturbance promotes/maintains ideal levels of respiration gases in the rooting zone, moderate organic matter oxidation, porosity for water transport, retention, and release, and restricts re-exposure of weed seeds and their germination.

B. Permanent Organic Soil Cover:

It is imperative in conservation agriculture to protect the soil from harmful effects resulting from exposure to rain and sun; to provide constant food supply to the soil; micro and macro -organisms, together with the plant roots. Soil cover is attained with biomass obtained from crop residues and cover crops.

C. Diversified Crop Rotations:

Crop rotation is essential not just to provide a variety of "food" for soil microorganisms, but also to search through different soil levels for nutrients that have leached to deeper layers and can be "recycled" by the crops in rotation. Rotation produces a variety of soil flora and fauna. By disruption of life cycles, biological nitrogen fixing, reduction of off-site pollution, and enhancement of biodiversity, the sequence and rotation of cropping with legumes contributes to the lowest rates of population build-up of pest species.

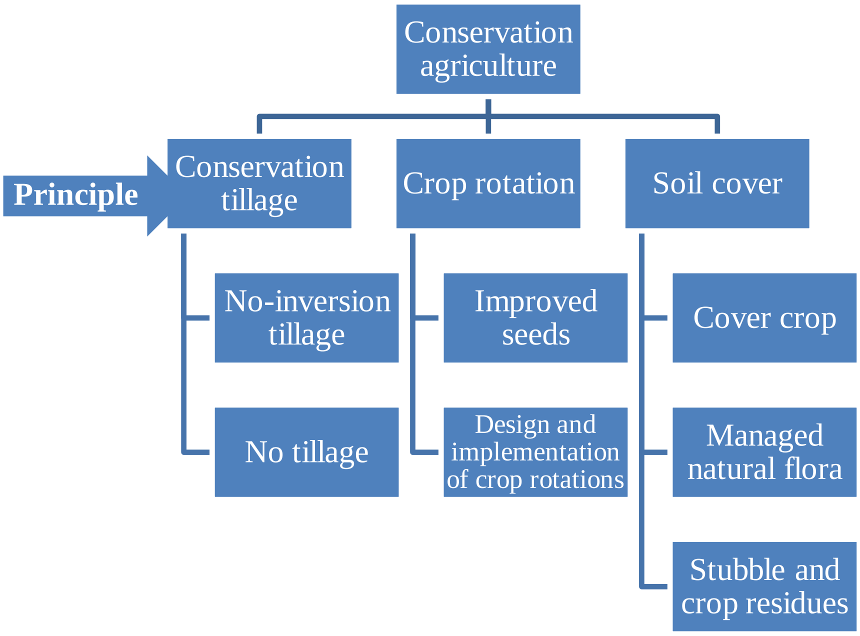


Figure 14.1: Principles of Conservation Agriculture

14.2.2 History and Status of Conservation Agriculture in India and World:

The term “conservation agriculture” was coined in the 1990s, but the idea to minimize soil disturbance has its origins in the 1930s, during the Dust Bowl in the United States of America. CIMMYT began work with conservation agriculture in Latin America and South Asia in the 1990s and in Africa in the early 2000s. Today, these efforts have been scaled up and conservation agriculture principles have been incorporated into projects such as CSISA, FACASI, MasAgro, SIMLESA, and SRFSI. Farmers worldwide are increasingly adopting conservation agriculture. In the 2015/16 season, conservation agriculture was practiced on about 180 mega hectares of cropland globally, about 12.5% of the total global cropland — 69% more than in the 2008/2009 season. In approximately 125 million ha. of high-potential environments worldwide, CA is used. USA (26.5 M ha), Brazil (25.5 M ha), Argentina (25.5 M ha), Canada (13.5 M ha), and Australia are the top CA-practicing nations (17.0 M ha). The adoption of CA is still in its early stages in India. Over 1.5 million hectares have adopted zero tillage and CA over the past few years (Jat et al., 2012; www.fao.org/ag/ca/6c.html). In the rice-wheat (RW) system of the Indo-Gangetic plains, zero-till (ZT) wheat is one of the main CA-based technologies being used (IGP).In other crops and cropping systems, the conventional agriculture based crop management systems are gradually undergoing a paradigm shift from intensive tillage to reduced/zero-tillage operations. In addition to ZT, other concept of CA needs to be infused in the system to further enhance and sustain the productivity as well as to tap new sources of growth in agricultural productivity. The CA adoption also offers avenues for much needed diversification through crop intensification, relay cropping of sugarcane, pulses, vegetables etc. as intercrop with wheat and maize and to intensify and diversify the RW system. The CA based resource conservation technologies (RCTs) also help in integrating crop, livestock, land and water management research in both low-and high-potential environments. Spread of these technologies is taking place in the irrigated regions of the Indo-Gangetic plains where the rice-wheat cropping system dominates. Zero-till seed-cum fertiliser drills for sowing wheat in rice-wheat systems have received the majority of attention in the development and promotion of conservation technologies. Additional interventions include alternatives to the rice-wheat system, raised bed planting techniques, land levelling assisted by laser technology, residue management techniques, etc.

According to reports, the amount of wheat planted with the zero-till drill has been growing quickly (Sangar et al., 2005), and 25% to 30% of the wheat grown in rice-wheat-growing regions of the Indo-Gangetic plains of India is currently zero-tilled. The farmers in the northwest are also progressively implementing raised-bed farming and laser ground levelling.

14.2.3 Benefits of Conservation Agriculture:

Conservation farming seems to be the ideal solution for global problems. It improves crop productivity, the environment, and biodiversity. Farmers are increasingly using this farming method for its effectiveness:

- Improve soil structuring.
- Increasing soil’s organic matter.
- Enhance soil infiltration.
- Improve soil nutrients.
- Protection against soil erosion.
- Decrease weed population.
- Organic crop protection saves biodiversity.
- Reduce farm finance.

A. Economic Benefits:

The introduction of conservation agriculture has three important economic benefits:

- Save time and reduce labor cost.
- Reduce technical cost., fuel, machinery, etc.
- High efficiency lower input, high output.

B. Agronomic Benefits:

The introduction of conservation farming leads to an increase in soil productivity:

- Increase soil organic matter.
- Increase conservation of soil water.
- Improve soil structure.
- Improve crop root anchoring.

C. Environmental Benefits:

Adaptation of conservation agriculture improves environment and biodiversity:

- Reduce soil erosion.
- Reduce infrastructure maintenance cost, roads, dams, power plants.
- Improve water quality.
- Filter atmosphere and improve air quality.
- Increase soil bio-diversity.
- Restore soil carbon content.

14.2.4 Prospects of Conservation Agriculture:

Now a days different countries do so many things to meet the food and energy needs for coming decades which will have great impact on natural resources bases, global climate change and energy security for India and world. A shift to no-till conservation agriculture is perceived to be of much fundamental value in meeting these challenges. Asian farmers/researchers will continue to need assistance to reorient their agriculture and practices for producing more with less cost through adoption of less vulnerable choices and pathways. Therefore, business as usual with conventional agriculture practices does not seem a sustainable option for sustainable gains in food-grain production, and hence CA-based crop management solutions adapted to local needs will have to play a critical role in most ecological and socio-economic settings of Asian Agriculture. The promotion of CA under Indian/Asian context has the following prospects:

A. Reduction in cost of cultivation – it is the key factor contributing to rapid adoption of zero-till technology. Cost reduction is to save money in accounts of diesel, labour and input costs, especially herbicides.
B. Reduction incidence of weeds – due to adoption of zero tillage it reduces weed incidence and it reduce herbicides.
C. Saving in water and nutrients – It shows that significant fertiliser and water savings are made possible by zero-till planting, especially for crops that are laser levelled and planted in beds. These savings can range from 20% to 30%. No-till soils had higher soil water contents than conventionally tilled soils, which suggested that less water had evaporated during the earlier period. Also, they discovered that the soil water content under no-till was around 20% higher than under conventional tillage over the course of growing seasons.
D. Increased yields were consistently higher in properly maintained zero-till planted crops than in traditionally prepared fields for identical planting dates. Due to concomitant effects like the prevention of soil degradation, improved soil fertility, improved soil moisture regime (due to increased rain water infiltration, water holding capacity, and reduced evaporation loss), and the advantages of crop rotation, CA has been reported to increase the yield level of crops. Nevertheless, during the early stages of adoption, there are no yield gains and potentially a yield decline.
E. Environmental benefits – Crop residue burning, which produces significant amounts of greenhouse gases including CO2, CH4, and N2O, can be completely eliminated by conservation agricultural practises like zero-till and surface managed crop residue

systems. Burning crop leftovers causes a significant loss of plant nutrients that, with good management, might be recycled. Crop residue burning on a large scale is also a severe health risk.

F. Crop diversification opportunities – Adopting Conservation Agriculture systems offers opportunities for crop diversification. Cropping sequences/rotations and agroforestry systems when adopted in appropriate spatial and temporal patterns can further enhance natural ecological processes.

G. Resource improvement – No tillage when combined with surface management of crop residues begins the processes where by slow decomposition of residues results in soil structural improvement and increased recycling and availability of plant nutrients. Surface residues acting as mulch, moderate soil temperatures, reduce evaporation, and improve biological activity.

14.2.5 Constraints in Adoption of Conservation Agriculture:

Farmers in a country or region, where CA is not practiced, face a number of problems which make adoption difficult. These problems are of diverse nature, such as intellectual, social, biophysical and technical, financial, infrastructural and policy. Most farmers are facing, several of these problems, if not all, at the same time to the effect that only very few bold pioneer farmers adopt CA. Farmers are not in the position to start with a blank sheet and to weigh objectively the merits and disadvantages of CA against conventional tillage farming.

A. Intellectual Constraints to Adoption:

New technologies that are quickly adopted often have obvious advantages, resulting in rapid acceptance and enthusiasm. In many cases, this enthusiasm fades once the new technology is understood and the drawbacks become apparent. CA works in the opposite direction: it contradicts so much of what a farmer has learned and been told that the benefits of CA are not immediately apparent. However, once the gradual adoption process begins, CA's performance improves over time. The more experience producers have with CA, the more convinced and positive they are about it. The less practical experience people have with CA, the more critical and negative their attitude towards it. A study carried out with European and American no-till farmers and agricultural experts came to similar conclusions. It was found that the experts, mostly without practical experience in CA, anticipated many problems for its adoption. In their opinion, the problems outweighed the benefits, resulting in an overall negative attitude. Farmers who were actually practising CA and had experience with the system, on the other hand, had an overall positive perception, with the benefits clearly outweighing the problems (Tebrugge and Bohrnsen 2000). CA has two intellectual barriers to overcome: the first is that the CA concept and principles are counterintuitive and contradict the common tillage-based farming experience, which has worked for generations and has frequently created cultural values and rural traditions; the second is a lack of experiential knowledge about CA and the mechanism to acquire it. Soil tillage, and particularly the plough, has in most countries become part of the culture of crop production. Ploughing, cultivation and tillage are often synonyms for growing a crop. Cropland is referred to as "arable" land, which is Latin for "plough able" land. The plough was part of the very early developments of agriculture and has the character of a brand symbol for what is 'correct'. People find it difficult to accept that the plough is suddenly dangerous and that crops can grow without tilling the land. Overcoming this "mental compaction" is frequently much more difficult than actually beginning no-till farming (Landers 2001). It's difficult to imagine a soil becoming softer and more structured without being tilled unless you've seen it happen. The second intellectual impediment to adoption is simply a lack of sufficient experiential knowledge about it and the means of acquiring it.

CA covers about 7% of agricultural land worldwide. Adoption is concentrated in a few countries, eventually exceeding 50%, while adoption in the rest of the world is less than 2%. This explains why most people have never seen a CA system in action. CA is rarely mentioned in the media because it is not yet represented in any labels or certification schemes and has no direct relevance to consumers. CA is also not included in university curricula, even at prestigious agricultural universities. This explains why, despite having more than twice the adoption rate of organic farming, public awareness of CA is much lower. Even most agricultural professionals and many farmers have never heard of CA, or have only vague ideas about it. Permanent no-tillage farming and CA are frequently unfamiliar to farmers and thus do not appear on their radar. For actual CA adoption, the farmer would need to know not only about CA elements in general, but also how to implement CA elements under the specific conditions of an individual farm. This knowledge is not typically available as an off-the-shelf technology package. Worse, CA is a complex and labor-intensive farming concept in which crop management must be planned ahead of time and is mostly proactive rather than reactive, as in traditional tillage-based systems. In tillage-based systems, soil compaction or uneven surfaces are corrected with tillage; in no-till systems, they must be avoided from the start. Weed and pest management in conventional tillage systems is frequently based on chemical or mechanical control as a response to the incidence, whereas in CA, the incidence of weeds and other pests is reduced through crop rotation planning. This increased complexity necessitates the acquisition of experience and knowledge. This learning process and experiential knowledge has thus involved a lot of trial and error for early adopters until sufficient local experience and knowledge has been accumulated to make the adoption easier. However, farmers, not scientists, are best suited to develop solutions to these practical problems. Farmers' own adaptive "research and development" process typically produces more timely and applicable results than the so-called "Green Revolution" approach of leaving the development of a standard technology package "ready for adoption" to the scientific community.

B. Social Constraints to Adoption:

Farmers in developing countries are mostly conservative and risk opposition to this adoption. If any farmer doing different method of agriculture from others will therefore risk being excluded from the community. This leads to social isolation and even to mocking, only very strong farmers can take a step forward. Even after seeing the success in individual farmer fields due to aversion created in their mind and due peer pressure other farmers not following. The pressure can be so bad that the community gets jealous of the success and instead of also adopting it, it leads to boycott including using ‘black magic’ and placing bad spells on the fields. For adoption of this process no need of any progressive farmer who can prove the success, but the farmers should socialize and integrated in the community. Other issues include traditional land tenure systems, in which no individual owns land, which makes it difficult for farmers to invest in long-term soil health and productivity improvement. Furthermore, communal grazing rights, which frequently include the right to graze on crop residues or cover crops after the harvest of the main crop, create conflicts that make the adoption of CA practises difficult. These issues can be significant barriers to CA adoption, and conflicts arising, for example, from alternative uses of crop residues as mulch or animal feed cannot be resolved through orders or directives. Physical barriers, such as fences, may not be the best solution if they contradict the traditional social values of the respective cultures. Much more important in the process is that the entire community first understands the issues, as well as the changes and benefits associated with adopting CA, and then works together to find solutions.

C. Input Constraints:

Access to equipment, seeds, fertilisers, and herbicides is a major barrier to expanding CA in Africa. CA does not always necessitate more equipment than traditional agriculture, but some of the equipment is unique and not always available. The most notable differences are found in land preparation and seeding. In silty or clayey soils, the soil surface is only penetrated in precisely targeted seeding lines or pits. Seeds are then deposited or inserted directly into the ground through the mulch or ground cover layer. Some conventional agriculture tools (e.g., certain weeding tools) can also be used for CA, while others can be modified for CA (e.g., hand hoes can be made narrower to dig CA planting basins). Equipment costs are relatively low for nonmechanized CA involving simple hand tools (if the requisite equipment is available at all). When using animal- or tractor-powered implements, costs skyrocket. Access to (or affordability of) inorganic fertilisers, pesticides, and herbicides may also be a barrier to practising CA in the most productive way. However, one of the primary benefits of CA is that it can increase yields in situations where agrochemicals are unavailable or prohibitively expensive by encouraging biological processes and management practises that improve soil fertility, pest control, and weed control. Nitrogen-fixing plants, which can include shrubs, annual herbaceous plants, or trees like *Faidherbia albida*, are an essential component of most CA systems. Intercropping with these species boosts yields, soil health, and soil chemical and biological properties while decreasing weed and pest problems. Despite these advantages, spontaneous adoption of cover crops for soil fertility enhancement is uncommon; instead, the plants must provide some direct benefit, such as human food or animal fodder.

D. Biophysical and Technical Constraints:

Although the concept of CA is universal, this does not imply that techniques and practises for every condition are readily available. Depending on the specific farming situation and agro-ecological conditions, the actual CA practise must be developed locally in most cases. Farmers in each location must discover and decide on crop rotations, cover crop selections, and crop-livestock integration issues. A wide range of issues arise, frequently involving weed management, residue management, equipment handling and settings, and planting parameters such as timing and depth, all of which must be discovered for the first time. As a result, when CA is first introduced in a region, extension agents and advisors are unable to provide specific advice on practises and must instead develop these practises in collaboration with farmers. On the other hand, if properly applied, such an approach is much faster and more sustainable than the development of specific practises by scientists, because it taps into the vast pool of experience and innovation potential of the farmer community.

Some cover crops have been developed from weeds, and farmers have developed practises such as growing paddy rice or potatoes under no-till in CA without scientists even considering such innovations. CA with higher levels of fertilizer than conventional maize production has the potential to raise yields, but cash constraints are a barrier to widespread fertilizer use (regardless of tillage method). Most farmers in Mozambique grow maize without fertilizer (Bias & Donovan, 2003). The benefits from fertilizer use depend on soil conditions. Fertilizer use in Africa is generally low because of both demand side and supply side factors. Demand is often weak because of "the low -levels and high variability of crop yields on the one hand and the high level of fertilizer prices relative to crop prices on the other."

Aside from financial or other constraints, another technical constraint is the simple lack of certain technologies or inputs. There are no cover crop seeds available in many countries where farmers begin with CA. The availability of equipment, particularly notill direct seeding equipment, is also frequently an issue. Most situations now have technologies available somewhere in the world. However, in some areas, farmers may be unaware of these technologies or may not have access to them. This is usually where external assistance, such as knowledge sharing, or even the introduction of specific technologies, such as direct seeding equipment, is required.

E. Financial Constraints:

Although CA is typically more profitable than conventional farming practises, there are still financial barriers to adoption, depending on the availability of capital to invest in this change of production system. These constraints exist at all farm size levels, albeit to varying degrees and for various purposes. Converting a manufacturing system to CA is a long-term investment. In many cases, the change is motivated by the degradation of natural resources, particularly soil and water, as a result of previous tillage-based agriculture. To begin with CA and successfully restore soil life and health, some initial investment in the land may be required, such as ripping existing compactions, correcting soil pH or extreme nutrient deficiencies, levelling and shaping the soil surface for the cropping system envisaged under CA. The capital for this type of investment is not available, particularly for small subsistence farmers. Furthermore, the farmer requires new equipment, as most of the existing equipment is becoming obsolete and will most likely not find an attractive second -hand market. The larger the farmer, the more important this barrier, because a no-till seed drill, for example, is significantly more expensive than a conventional one. This conflict between the potential improved profit margin on one hand and the very concrete and actual investment requirements on the other often leads to farmers deciding not to switch to CA, even if they are convinced of the benefits.

In general, CA is longer-term more profitable than traditional farming. Nevertheless, obtaining these long-term advantages could necessitate an upfront investment, which is frequently too costly or dangerous for small farmers to make on their own. Due to worries about household food security, vulnerable farmers are extremely risk conservative, and there is limited space for error. However, while many farmers experience benefits in the first year of using CA, others take three to seven years to see a boost in yields or profitability. Farmers occasionally decide to stop using CA at this time, thus long-term adoption is more likely when CA offers large benefits in the first or second year. When CA is promoted along with sound agronomic procedures, improved seeds, and occasionally inorganic fertilisers, the likelihood of such an immediate benefit increases. Credit facilities are one solution in these cases, but sometimes the availability of contractor services or technical advice on how to adapt and modify existing equipment as a low-cost intermediate solution to begin with can also be beneficial. Modification of existing equipment has, for example, provided an entry point for some farmers in Brazil and Kazakhstan to begin with CA and then, after benefiting from higher profitability, invest in proper equipment at a later stage. Homemade solutions for simple CA farm tools, particularly for small farmers, are an important component of CA adoption in Paraguay (Lange and Meza, 2004).

F. Infrastructural Constraints:

Conservation agriculture also necessitates some exogenous inputs in order to achieve high output levels. CA improves crop growth conditions and increases the efficiency of natural resources and input use, but it is not a 'perpetual motion' process that would allow crop intensification from endogenous resources. In order to increase production intensity, inputs should be available near the production area, processing units, and markets where produce is sold. Conservation agriculture produces better results than conventional agriculture even when no external inputs are used, but the difference is not significant. Some inputs, such as fertiliser types, will differ only marginally from the requirements of conventional tillage-based farming. Herbicides, seeds for cover- and rotational crops, and especially equipment for direct seeding, planting, and residue management, on the other hand, are frequently completely different from those used in the past and must be introduced into markets. This necessitates not only a good input supply infrastructure, but also a proactive attitude on the part of the supply sector, such as dealers and manufacturers. It necessitates collaboration between the farming and input supply sectors, as well as some supportive policies.

G. Policy Constraints:

CA adoption can occur spontaneously, but it usually takes a long time to reach significant levels. Adequate policies can significantly shorten the adoption process, primarily by removing the previously mentioned constraints. This can be accomplished through information and training campaigns, appropriate legislation and regulatory frameworks, research and development, incentive and credit programmes, and other means. However, in most cases, policymakers are also unaware of CA, and many existing policies work against CA adoption. Commodity subsidies, which reduce farmers' incentives to use diversified crop rotations, mandatory prescription for soil tillage by law, or a lack of coordination between different government sectors are typical examples. In some cases, countries have legislation in place that supports CA as part of a sustainable agriculture programme. If those countries have a programme to modernise and mechanise agriculture, the first items introduced under such a mechanisation programme are usually tractors with ploughs or disc harrows. This not only sends the wrong signal, but it also works directly against the introduction and promotion of CA, while also passing up an opportunity to introduce tractors with no-till seeders instead of ploughs, assisting in overcoming this technological constraint. Even in countries where many farmers practise CA, policymakers frequently lack awareness of the practise, and in some cases, existing policies work against it. Countries with their own agricultural machinery manufacturing sector frequently levy high import taxes on agricultural machinery to protect their own industry. This industry frequently lacks suitable CA equipment in the short term, but due to high import taxes, farmers who want to adopt CA are unable to import equipment from abroad. In other cases, the import tax on raw materials may be so high that local manufacturing of CA equipment becomes impossible. To avoid such contradictory policies, policymakers and legislators must be made aware of CA and its ramifications. Where farmers do not farm their own land but rent land from others, there are additional issues with CA implementation: the accumulation of soil organic matter under CA is an investment in soil fertility and carbon stocks, which is currently not recognised by policymakers but is increasingly recognised by other farmers. Farmers who still plough know that the mineralization of organic matter acts as a source of plant nutrients, allowing them to "mine" these lands with lower fertiliser costs. This allows them to pay a higher rent for CA land than the CA farmer can. Such cases can be found in both "developing" African and "developed" European countries. To avoid this, some policy instruments are required to hold landowners responsible for maintaining soil fertility and carbon stock in the soil, which is difficult to achieve in the absence of agricultural carbon markets.

14.3 Conservation Agriculture's Challenges:

Challenges in conservation agriculture Conservation agriculture as an upcoming paradigm for raising crops will require an innovative system perspective to deal with diverse, flexible and context specific needs of technologies and their management. Conservation agriculture R&D (Research and Development), thus will call for several innovative features to address the challenge.

A. Understanding the system – Unlike to conventional methods, conservation agriculture is far more difficult. The fundamental barrier to the adoption of CA systems has been site-specific expertise. Understanding the fundamental processes and component interactions that affect how well the system as a whole performs will be crucial to managing these systems effectively. For instance, crop leftovers that are kept on the surface operate as mulch, reducing the amount of water that evaporates from the soil and preserving a stable soil temperature regime. Crop leftovers can be a simple source of organic matter for decomposition, but they can also harbour pest populations that are undesirable or otherwise change the ecology of the system. No-tillage systems will influence depth of penetration and distribution of the root system which, in turn, will influence water and nutrient uptake and mineral cycling. Thus, the need is to recognize conservation agriculture as a system and develop management strategies.
B. Building a system and farming system perspective – A system perspective is built working in partnership with farmers. A core group of scientists, farmers, extension workers and other stakeholders working in partnership mode will therefore be critical in developing and promoting new technologies. This is somewhat different than in conventional agricultural R&D, the system is to set research priorities and allocate resources within a framework, and little attention is given to build relationships and seek linkages with partners working in complementary fields.
C. Technological challenges - While the basic principles that underpin conservation agriculture practises, such as no tillage and surface managed crop residues, are well understood, the key challenge is implementing these practises in a variety of farming situations. These difficulties are related to the development, standardisation, and

adoption of farm machinery for seeding with minimal soil disturbance, as well as the development of crop harvesting and management systems.

D. Site specificity - Although adaptation strategies for conservation agriculture systems will be highly site specific, learning across sites will be a powerful way of understanding why certain technologies or practises are effective in one set of situations but not in another. This learning process will hasten the development of a knowledge base for sustainable resource management.

E. Long-term research perspective - Conservation agriculture practises, such as no-tillage and surface-maintained crop residues, result in resource improvement gradually, with benefits accruing over time. Indeed, benefits in terms of yield increase may not be realised in many cases during the early stages of evaluating the impact of conservation agriculture practises. Understanding the dynamics of change and the interactions between physical, chemical, and biological processes is essential for developing better soil-water and nutrient management strategies (Abrol and Sangar, 2006). As a result, conservation agriculture research must have a longer time horizon.

14.4 Implications and Sustainability uses:

Conservation agriculture entails a significant departure from traditional farming practises. Policy analysis is required to understand how CA technologies integrate with other technologies, as well as how policy instruments and institutional arrangements encourage or discourage CA (Raina et al., 2005).

CA provides a means of halting and reversing the downward spiral of resource depletion by decreasing factor productivity, lowering cultivation costs, and making agriculture more resource-efficient, competitive, and sustainable.

While R&D efforts over the last decade have aided in increasing farmer acceptance of zero tillage for wheat in rice-wheat cropping systems, this has raised a number of institutional, technological, and policy issues that must be addressed if CA practises are to be adopted on a large scale in the region on a sustained basis.

- CA technologies affect the plant growing microenvironment significantly. Changes in moisture regimes, root environment, the appearance of novel diseases, and a shift in the insect-pest situation are just a few examples. Plant types that are suitable for the new environment and meet specific mechanisation needs may differ. Complementary crop development programmes aimed at generating cultivars better suited to new systems are required. Farmers' participation in research appears promise for finding and producing crop types that are suited to a specific environment or place.
- Support for the adaptation and validation of CA technologies in local environments: Adaptive research is necessary to match CA concepts and practises to local situations. This should be done in partnership with local communities and other stakeholders. Crop species, crop and cover crop selection and management, rotations, soil cover maintenance, and CA equipment should all be considered. In India, resource-poor and small-holder farmers lack economic access to new seeds, herbicides, and sowing machinery, among other things (Sharma et al., 2012). This necessitates a policy framework that makes crucial inputs readily available.

- There is a need for generating a good resource database with agencies involved complementing each others' work. Besides resources, systematic monitoring of the socio-economic, environmental and institutional changes should become an integral part of the major projects on CA.
- Credit and subsidies: Another critical factor in the successful implementation of CA is the availability of financing to farmers to purchase equipment, machinery, and inputs at affordable interest rates from banks and credit agencies. At the same time, the government should provide a subsidy for farmers to purchase such equipment. For example, the Chinese government has recently undertaken a number of regulatory and economic measures to promote CA practises in the Yellow River Basin, including a subsidy on CA machinery and effective farmer training (Yan et al., 2009). This resulted in a significant increase in CA area. Presently, over 80% of the area under maize production in Shanxi, Shandong, and Henan provinces is dependent on no-till seeder.
- Promote payments for environmental services (PES) and fines for faulty practices: Adopters of CA improve the environment through carbon sequestration, prevention of soil erosion or the encouragement of groundwater recharge. It provides ecosystem services, thus, farmers could be rewarded for such services, which have a great impact on the quality of life for all.
- Scaling up conservation agriculture practises: Attempts to adapt CA concepts and technological components to the region's different agro-ecological, socio-economic, and farming systems began a few decades ago. More support from stakeholders, especially policymakers and decision-makers at the local, national, and regional levels, will facilitate CA expansion and let farmers to reap additional benefits from the technology. For more than a decade, substantial CA research has been undertaken in India, primarily at the Indian Agricultural Research Institute. Unfortunately, its reach among farmers is extremely restricted. There is a need to consider the challenges encountered during implementation and design a strategy that involves all parties involved. The majority of cases where reforms in favour of CA have happened have had limited success. According to FAO (2001), this is due in part to unfavorable policy conditions. One of the causes for the slow adoption of technology among farmers was the majority of farmers' previous inclination or mindset towards tillage (Hobbs and Govaerts, 2010).
- CA allows for diverse cropping systems in various agro-ecoregions. Developing, upgrading, and standardizing equipment for planting, fertilizer placement, and harvesting while ensuring minimal soil disturbance in residue management for varied edaphic situations will be critical to CA's success. Bullock hauled equipment will be more useful for small landholders in various scenarios, such as in steep stretches. Ensuring quality and availability of equipment through appropriate incentives will be important. In these situations, the subsidy support from national or local government to firms for developing low cost machines will help in the promotion of CA technologies.

Conservation agriculture technologies are the future of sustainable agriculture. There are potential benefits of conservation agriculture across different agro-eco-regions and farmers groups. The benefits range from nano-level (improving soil properties) to micro-level (saving inputs, reducing cost of production, increasing farm income), and macro-level by reducing poverty, improving food security, alleviating global warming. There is a need for a global movement for promoting conservation agriculture. In India, the concept of conservation agriculture may be integrated with various government programs by sensitizing policy advisors, professionals and financial institutions. The benefits of conservation agriculture need to be effectively communicated to all the stakeholders for its widespread adoption by the farming community. Failing that the sustainability of agriculture would be under threat and adversely affect natural resources and agricultural production. The most affected would be the under privileged and poor farmers in unfavorable and marginal areas. So it can be concluded that conservation agriculture is most need for Indian agricultural land for longer utilization and effective crop production

14.5 Conclusion:

Conservation agriculture represents a new paradigm for agricultural research and development that differs from the traditional one, which was primarily focused on meeting specific food grain production targets in India. A paradigm shift has become necessary in light of widespread resource degradation issues that have accompanied previous strategies to boost production with little regard for resource integrity. Integrating productivity, resource conservation, soil quality, and environmental concerns is now critical to long-term productivity growth. In terms of knowledge base, developing and promoting CA systems will be extremely difficult.

The traditional approach to agricultural research and development in India has been replaced by a new approach that promotes conservation agriculture. It is becoming increasingly important to incorporate issues of productivity, resource conservation, soil quality, and the environment into continuous productivity increases. It will be difficult to develop and promote CA systems without a solid knowledge base. Conservation agriculture provides a chance to prevent and reverse the downward spiral of resource degradation by lowering cultivation costs and increasing resource use efficiency, competitiveness, and sustainability in agriculture. The new mission must emphasise resource conservation while increasing output.

Despite the obvious productivity, economic, environmental, and social benefits of CA, adoption does not occur on its own. Individual farmers have valid reasons not to implement CA in their specific farm situation. The obstacles range in origin from intellectual, social, financial, biophysical and technical, infrastructural, to policy issues. Knowing the bottlenecks and problems allows for the development of strategies to overcome them. Crisis and emergency situations, which appear to be becoming more common in a climate change scenario, as well as political pressures for more sustainable use of natural resources and environmental protection on the one hand, and improving and eventually attaining food security on the other, provide opportunities to harness these pressures for supporting the adoption and spread of CA and assisting in overcoming existing adoption barriers. As a result, the growing challenges confronting the world, ranging from the recent sudden global crisis caused by soaring food prices, high energy and input costs, rising environmental concerns, and climate change issues, provide policymakers with justification to implement supportive policies and institutional services, even including direct payments to farmers for environmental services from agricultural land use, which could be linked to the introduction of sustainable farming methods such as CA. In this way the actual global challenges are providing at the same time opportunities to accelerate the adoption process of CA and to shorten the initial slow uptake phase. Conservation agriculture could decrease soil detachment and increase water infiltration that implies a decrease of water runoff; consequently, soil erosion would be reduced. Effects of conservation agriculture on reducing erosion were mainly caused by crop residues retained on the soil surface.

14.6 References:

1. Abrol, I. P. & Sangar, S. (2006). Sustaining Indian agriculture-conservation agriculture the way forward. Current Science, 91(8), 1020-2015.
2. African Conservation Tillage Network. (2011). 2011-11-10. www.act-africa.org. Aina, P. O. (1979). Soil changes resulting from long-term management practices in western Nigeria. Soil Science Society of America Journal, 43, 173-177.
3. Arshad M A, Franzluebbers A J, Azooz R H. 1999. Components of surface soil structure under conventional and no-tillage in northwestern Canada. Soil and Tillage Research, 53, 41-47.
4. Baudron, F., M. Corbeels, F. Monicat, and K.E. Giller. 2009. Cotton expansion and biodiversity loss in African savannahs, opportunities and challenges for conservation agriculture: a review paper based on two case studies. Biodiversity Conservation 18: 2625-2644.
5. Baumhardt R L, Lascano R J. 1996. Rain infiltration as affected by wheat residue amount and distribution in ridged tillage.
6. Behera, U. K., Amgain, L. P. & Sharma, A. R. (2010). Conservation agriculture: principles, practices and environmental benefits. In Behera, U. K., Das, T. K., & Sharma, A. R. (Eds.), Conservation Agriculture (pp. 28-41). Division of Agronomy, Indian Agricultural Research Institute, New Delhi – 110012, 216 p.
7. Behera, U. K., Sharma, A. R. & Mahapatra, I. C. (2007). Crop diversification for efficient resource management in India: Problems, Prospects and Policy. Journal of Sustainable Agriculture, 30(3), 97-217.
8. Ben-Hammouda, M., M'Hedbi, K., Kammassi, M. and Gouili, H. (2007) Direct drilling: an agro-environmental approach to prevent land degradation and sustainable production. Proceedings of the International Workshop on Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas, ACSAD, 7–9 May, Damascus, Syria, pp. 37–46.
9. Bias, C.,& Donovan, C. (2003). Gaps and opportunities for agricultural sector development in Mozambique. (Vol. Research Report 54E). Maputo: Mader Directorate of Economics, Department of Policy Analysis (mader/de/Dap)
10. Boatman, N., Stoate, C. Gooch, R., Carvalho, C. R., Borralho, R., de, Snoo, G., & Eden, P. (1999). The environmental impacts of arable crop production in the European Union: practical options for improvement. A report prepared for Directorate-General XI of the European Commission. De Vita, P., Di Paolo, E., Fecondo, G., Di Fonzo, N., & Pisante, M. (2007). No-tillage and conventional tillage effects on durum wheat yield, grain quality and soil moisture content in Southern Italy. Soil & Tillage Research, 92, 69-78.
11. Castro Filho C, Lourenço A, Guimarães M de F, Fonseca I C B. 2002. Aggregate stability under different management systems in a red Latosol in the State of Parana, Brasil. Soil and Tillage Research,65, 45-51.
12. Derpsch, R. (2001). Keynote: Frontiers in conservation tillage and advances in conservation practice. In Stott, D. E., Mohtar, R. H., and Steinhart, G. C. (Eds.), Sustaining the global farm. Selected papers from the 10th International Soil

Conservation Organisation Meeting held May 24-29, 1999 at Purdue University and the USSA-ARS National Soil Erosion Research Laboratory.

13. Derpsch, R., Friedrich, T., Kassam, A. & Li, H.W. (2010). Current status of adoption of notill farming in the world and some of its main benefits. International Journal of Agricultural and Biological Engineering, 3, 1-25.
14. Derpsch, R., Friedrich, T., Landers, J. N., Rainbow, R., Reicosky, D. C., Sa´, J. C. M., Sturny, W. G., Wall, P., Ward, R. C. & Weiss, K., (2011). About the necessity of adequately defining no-tillage – a discussion paper. In Proc. 5th World Congr. Conserv. Agric., 26-29 September 2011, Brisbane, Australia.
15. Dexter A R. 2004. Soil physical quality. Part I. Theory, effects of soil texture, density, and organic matter, and effects on root growth. Geoderma, 120, 201-214.
16. Dumanski, J., Peiretti, R., Benetis, J., McGarry, D., & Pieri. C. (2006). The paradigm of conservation tillage. Proceedings of World Association of Soil and Water Conservation, P1, 58-64.
17. Ernstein, O., Sayer, K., Wall, P., Dixon, J. and Hellin, J. (2008) Adapting no-tillage agriculture to the smallholder maize and wheat farmers in the tropics and sub-tropics. In: T. Goddard, M.A. Zoebisch, Y.T. Gan, W. Ellis, A. Watson and S. Sombatpanit (eds) No-Till Farming Systems. Special Publication No. 3 (pp. 253– 277). Bangkok: World Association of Soil and Water Conservation (WASWC).
18. FAO. (2001). Conservation Agriculture Case Studies in Latin America and Africa. Introduction. FAO Soils Bulletin No. 78. Rome: FAO.
19. FAO. (2005). Drought-resistant soils: Optimization of soil moisture for sustainable plant production. In Proc Electronic Conference Organized by the FAO Land and Water Development Division. FAO Land and Water Bulletin Vol. 11. Rome: FAO.
20. FAO. (2012). Food and Agriculture Organization of the United Nations, 2012. Available online at http://www.fao.org/ag/ca/6c.html.
21. Gathala, M. K., Ladha, J. K., Kumar, V., Saharawat, Y. S., Kumar, V., Sharma, P. K., Sharma, S., & Pathak, H. (2011a). Tillage and Crop Establishment Affects Sustainability of South Asian Rice-Wheat System. Agronomy Journal, 103, 961-672.
22. Gathala, M. K., Ladha, J. K., Saharawat, Y. S., Kumar, V., Kumar, V., Sharma, P. K. (2011b). Effect of Tillage and Crop Establishment Methods on Physical Properties of a Medium-Textured Soil under a Seven-Year Rice – Wheat Rotation. Soil Science Society of America Journal, 75, 1851-1862.
23. Ghosh, P. K., Das, A., Saha, R., Kharkrang, E., Tripathy, A. K., Munda, G. C., & Ngachan, S.V. (2010). Conservation agriculture towards achieving food security in north east India. Current Science, 99(7), 915-921.
24. Gupta, R. & Jat, M. L. (2010). Conservation agriculture: addressing emerging challenges of resource degradation and food security in South Asia. In Behera, U.K., Das, T.K., & Sharma, A.R. (Eds.), Conservation Agriculture (pp.1-18). Division of Agronomy, Indian Agricultural Research Institute, New Delhi – 110012, 216 p.
25. Hobbs, P. R., & Govaerts, B. (2010). How conservation agriculture can contribute to buffering climate change. In M. P. Reynolds (Ed.), Climate Change and Crop Production (pp. 177-199). CAB International 2010.
26. Hobbs, P. R., & Gupta, R. K. (2004). Problems and challenges of no-till farming for the rice-wheat systems of the Indo-Gangetic Plains in South Asia. In R. Lal, P. Hobbs, N. Uphoff, & D.O. Hansen (Eds.), Sustainable Agriculture and the Rice-Wheat System (pp. 101-119). Columbus, Ohio, and New York, USA: Ohio State University and Marcel Dekker, Inc. J

27. Jat, M. L., Gathala, M. K., Ladha, J. K., Saharawat, Y. S., Jat, A.S., Kumar Vipin, Sharma, S. K., Kumar V., & Gupta, R. (2009a). Evaluation of Precision Land Leveling and Double Zero-Till Systems in Rice-Wheat Rotation: Water use, Productivity, Profitability and Soil Physical Properties. Soil and Tillage Research, 105, 112-121.
28. Jat, M. L., Malik, R.K., Saharawat, Y.S., Gupta, R. Bhag, M., & Raj Paroda. (2012). Proceedings of Regional Dialogue on Conservation Agricultural in South Asia, New Delhi, India, APAARI, CIMMYT, ICAR, p 32.
29. Kassam, A. H., & Friedrich, T. (2009). Perspectives on Nutrient Management in Conservation Agriculture. Invited paper, IV World Congress on Conservation Agriculture, 4-7 February 2009, New Delhi, India.
30. Lal, R. (2013). Climate-resilient agriculture and soil Organic Carbon. Indian Journal of Agronomy, 58(4), 440-450.
31. Malik, R. K., Gupta, R. K., Singh, C. M., Yadav, A., Brar, S. S., Thakur, T. C., Singh, S. S., Singh, A. K., Singh, R., & Sinha, R. K. (2005). Accelerating the Adoption of Resource Conservation Technologies in Rice Wheat System of the Indo-Gangetic Plains. Proceedings of Project Workshop, Directorate of Extension Education, Chaudhary Charan Singh Haryana Agricultural University (CCSHAU), June 1-2, 2005. Hisar, India: CCSHAU.
32. Pathak, H., Saharawat, Y.S., Gathala, M., & Ladha, J.K. (2011). Impact of resource-conserving technologies on productivity and greenhouse gas emission in rice-wheat system. Greenhouse Gases: Science and Technology, 1, 261-277.
33. Raina, R.S., Sulaiman, R., Hall, A.J., & Sangar, S. (2005). Policy and institutional requirements for transition to conservation agriculture: An innovation systems perspective. In Abrol, I. P., Gupta, R. K., & Mallik, R. K. (Eds.), Conservation Agriculture – Status and Prospects (pp. 224-232). Centre for Advancement of Sustainable Agriculture, New Delhi, 2005.
34. RWC-CIMMYT. (2005). Agenda Notes. 13th Regional Technical Coordination Committee Meeting. RWC-CIMMYT, Dhaka, Bangladesh.
35. Saharawat, Y.S., Ladha, J.K., Pathak, H., Gathala, M., Chaudhary, N., & Jat, M. L. (2012). Simulation of resource-conserving technologies on productivity, income and greenhouse gas emission in rice-wheat system. Journal of Soil Science and Environmental Management, 3(1), 9-22.
36. Sangar, S., Abrol, J. P., & Gupta, R. K. (2005). Conservation Agriculture: Conserving Resources Enhancing Productivity, 19 p. CASA, NASC Complex, New Delhi.
37. Sharma, A. R., Jat, M. L., Saharawat, Y.S., Singh, V. P., & Singh, R. (2012). Conservation agriculture for improving productivity and resource-use efficiency: prospects and research needs in Indian context. Indian Journal of Agronomy, 57 (IAC Special Issue), 131-140.
38. Sharma, A.R., Singh, R., & Dhyani, S.K. (2005). Conservation tillage and mulching for optimizing productivity in maize-wheat cropping system in the outer western Himalaya region – a review. Indian Journal Soil Conservation, 33(1), 35-41.
39. Sidhu, H.S., Singh, M., Humphreys, E., Singh, Y., Singh, B., Dhillon, S. S., Blackwell, J., Bector, V. M., & Singh, S. (2007). The happy seeder enables direct drilling of wheat into rice straw. Australian Journal of Experimental Agriculture, 47, 844-854.
40. Stoop, W.A.,Adam, A. and Kassam, A.H. 2008. Comparing rice production systems: a challenge for agronomic research and for the dissemination of knowledge-intensive farming practices, Submitted to Agricultural Water Management. The IVth World Congress on Conservation Agriculture, New Delhi, February 2009.

41. Tebrügge F, Düring R A. 1999. Reducing tillage intensity-a review of results from a long-term study in Germany. Soil and Tillage Research, 53, 15-28.
42. Tebrügge, F. 2000. Bodenbearbeitung: Langfristige Auswirkungen ausgewählter Systeme. AGRARfinanz 7, S. 6-7.
43. Tebrügge, F. and Böhrnsen, A. 2000. Direktsaat -Beurteilung durch Landwirte und Experten in der EU und Nebraska. Landtechnik 55, 1, S. 17-19.
44. Thiombiano. L., and M. Meshack. 2009. Scaling-up conservation agriculture in Africa: strategy and approaches. FAO Subregional Office for Eastern Africa, Addis Ababa.
45. Thomas, G.A., Titmarsh, G.W., Freebairn, D.M., Radford, B.J., 2007. No-tillage and conservation farming practices in grain growing areas of Queensland—a review of 40 years of development. Aust. J. Exp. Agric. 47, 887–898.
46. Twomlow S, Urolov JC, JenrichM and Oldrieve B. 2008. Lessons from the field – Zimbabwe's Conservation Agriculture Task Force. Journal of SAT Agricultural Research 6.
47. Van den Berg, H. and Jiggins, J. 2007. Investing in farmers The impacts of Farmer Field Schools in relation to integrated pest management. World Development, 35, 663-686.
48. Wall, P.C., 2007. Tailoring Conservation Agriculture to the needs of small farmers in developing countries: An analysis of issues. J. Crop Improve. 19, 137–155.
49. Wassmann, R., Jagadish, S.V. K., Sumfleth, K., Pathak, H., Howell, G., Ismail, A., Serraj, R., Redona, E., Singh, R. K., & Heuer, S. (2009). Regional vulnerability of climate change impacts on Asian rice production and scope for adaptation. Advances in Agronomy, 102, 91-133.
50. Wershaw R L. 1993. Model for humus in soils and sediment. Environmental Science & Technology,27, 814-816.
51. Wolff, P., & Stein, T. M. (1998). Water efficiency and conservation in agriculture – opportunities and limitations. Agriculture and Rural Development, 5(2), 17-20.
52. Yadvinder-Singh, Bijay-Singh, & Timsina, J. (2005). Crop residue management for nutrient cycling and improving soil productivity in rice-based cropping systems in the tropics. Advances in Agronomy, 85, 269-407.
53. Yan Changrong, Wenqing He, Xurong Mei, Dixon John, Qin Liu, Shuang Liu, & Enke Liu. (2009). Critical research for dryland conservation agriculture in the Yellow river basin, China: Recent results. In Proc. 4th World Congress on Conservation Agriculture "Innovations for Improving Efficiency, Equity and Environment" (pp. 51-59). New Delhi, India.
54. Zhao J F, Huang G B, Xin P, Xie K Z, Xu A X. 2007. Conservation tillage effects on run-off and soil erosion. Bulletin of Soil and Water Conservation, 27, 16-19. (in Chinese)
55. Zibilske L M, Bradford J M, Smart J R. 2002. Conservation tillage induced changes in organic carbon, total nitrogen and available phosphorus in a semi-arid alkaline subtropical soil. Soil and Tillage Research, 66, 153-163.

15. Water Management Practices Under Climate Change

Sushanta Sarkar

Technical Officer, GKMS Project,
Bihar Agricultural College,
Bhagalpur, Bihar.

Abstract:

Water is considered as the most critical resource for sustainable agricultural development worldwide. Irrigated areas are increasing day-by-day, while fresh water supplies are diverted from agriculture to meet the increasing demand of domestic use and industry. Furthermore, the irrigation use efficiency is very low as less than 65 % of the applied water is actually used by the crops. Application of proper water management practices is a priority for agriculture in arid areas. So, under climate change and water scarcity conditions extra effort should be given over time to introduce policies aiming to increase water use efficiency through better water management practices. Better management usually refers to improvement of water allocation and efficiency of irrigation water. The former is related to adequate pricing, while the latter one depends on the type of irrigation method, scheduling of water application and weather condition. Different agricultural practices, such as soil management, irrigation application and disease-pest control are related with the sustainable water management in agriculture. The adoption of sustainable water management is not only a technological problem but involves many other considerations related to social behavior of rural communities, the economic constrains, legal and institutional framework. Sustainable water management in agriculture can be achieved by adopting different management practices, such as improvements in irrigation application, water pricing, reuse of wastewater, soil and plant practices, farmers' participation in water management and capacity building.

Keywords:

Irrigation, Water efficiency, Water reuse, Innovation, Capacity building.

15.1 Introduction:

Water is one of the most essential natural resources of the planet. Water is also the most critical resource for sustainable development in most of the developing countries. The quantities that are needed for drinking and sanitation purpose of humans are relatively small, and much larger quantities of water are required for many other purposes. It is essential not only for agriculture, industry and economic growth of a country, but also it is the most important component of the environment and ecosystem, with significant impact on overall wealth and nature conservation. Agricultural and industrial activities critically depend on a sufficient amount of fresh water that is withdrawn from rivers, lakes and groundwater aquifers.

Currently, the rapid growth of world population along with the extension of irrigation dependent agriculture, development of industrial sector and climate change are stressing the quantity and quality of the natural water systems. Due to the increasing problems, human have begun to realize that they can no longer follow "use and discard" methodology either with water resources or any other natural resources. As a result, the need for water management has become evident. Climate change has already started to affect the hydrological cycle and the availability of freshwater for agriculture. So, proper water management practices play crucial roles in the food production and the management of ecosystems. Over the last century global irrigated area has increased more than six fold from approximately 40 million hectares in 1900 to more than 260 million hectares in 2000. Today more than 40% of the world's food comes from the irrigated cropland which is 18% of the total cultivated crop land. Irrigated area is increased by almost 1% every year and the demand for irrigation water will increase by 13.6% by 2025 (Jensen, 1993). On the other hand about 8-15% of fresh water supply will be diverted from agricultural sector to meet the increased demand of domestic and industrial use. On the other hand the efficiency of irrigation is very low, only 65% of the applied water is used by the crop (Figure 15.1). So, to overcome shortage of irrigation water for agriculture, it is essential to increase the water use efficiency in the crop field and to use marginal water for irrigation.

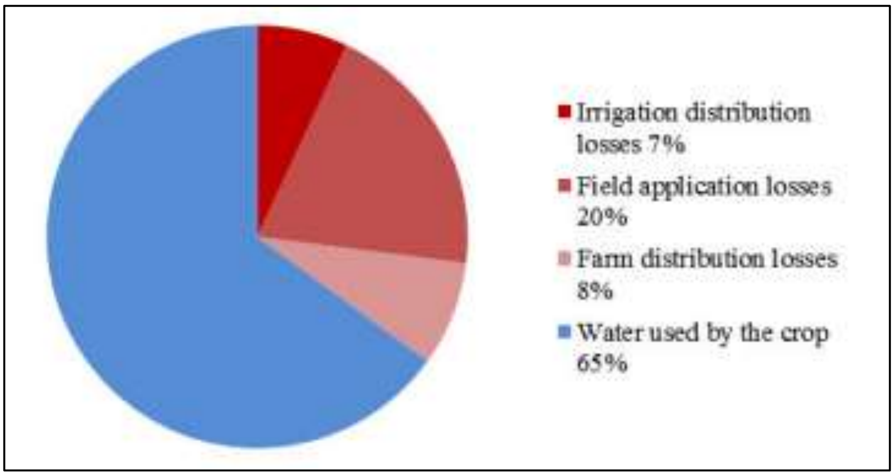


Figure 15.1: Water Losses in Agriculture

15.2 Water Management and Climate Change:

According to the Intergovernmental Panel on Climate Change (IPCC, 2007), climate change is a significant threat to all nations, in particular, developing nations that are dependent on agriculture for subsistence. Climate change appears as an additional threat to water security because changes in rainfall and other climatic variables due to climate change leads to significant changes in fresh water supply in many regions (6–11). However, the effect of climate change on water resources is uncertain for different reasons. Observed data and a number of climate projections show that changes in water quantity and quality due to climate change are expected to impact negative affect on food security and increase the vulnerability of poor farmers, especially in arid and semi-arid regions. In many countries, agricultural production is already being adversely affected by climate change (FAO, 2016a). Higher temperature, less supply of water, more frequent occurrence of droughts and floods are likely to reduce yields in many areas. However, there are many non-climatic factors such as expanding population and urbanization, increasing competition for natural resources, improvement in agronomic management practices, technological innovations, global economic growth, trade and food prices that strongly influence agricultural production. These non-climatic factors have more instant impacts on water resources than those caused by climate change (Bates *et al*., 2008). For this reason, it is more important to understand the current status of water management before assessing the impacts of climate change. From agricultural water supplies to flood management and ecosystem protection, climate change is affecting all aspects of water resource management. Rising average air temperature, loss of snowpack, frequency of flood events and rising sea level are some of the impacts of climate change that have broad implication for water resource management.

15.3 Water and Agricultural Production:

Currently about 70% of the total water used in agriculture is mainly applied for irrigation. Although irrigation has been practiced from the ancient era, most of the irrigated lands were introduced in the 20th century. In the 1980s, the global rate of increase in irrigated area slowed considerably due to high cost of irrigation system construction, depletion of irrigation water, soil salinization and the problems of environmental protection. However, as the world population is increasing at a rapid rate, irrigation has an important role in increasing land use efficiency. Thus in the future, irrigated farming is expected to expand rapidly with subsequent increase of water demand for irrigation.

Irrigation is not sustainable if water supply is not reliable, especially in the areas where water scarcity is the major problem for development of irrigation. So, extra Effort is needed to find economically suitable crops which can grow using minimal water, to use management practices that can minimize losses of water by evaporation from the soil and percolation of water beyond the depth of root zone and also to minimize losses of water from storage and delivery systems. Nowadays, during a period of dramatic changes in uncertainty of the water resources there is a need to provide encouragement and support to farmers to move from their traditional high-water demand cropping system and irrigation practices to modern technologies, less water demanded cropping systems.

Under scarcity of available water considerable efforts have been devoted over time to introduce different policies aiming to increase water use efficiency based on the assertion that can be achieved using less water through better management practices. Better management practices usually refer to improvement of allocate and irrigation water efficiency. The former is related to adequate pricing, while the latter depends on the type of irrigation method, timing of water application and prevailing weather condition. The yield response curve of any specific crop depends on various factors, such as weather condition, soil type and the reduction in the agricultural inputs like fertilizers and pesticides (Figure 15.2). Therefore, it is difficult for a farmer to tell whether the yield loss is due to water deficit or not. Over-irrigation can cause water-logging condition for the crop, loss of nutrients due to leaching or deep percolation, contamination of the aquifers from washout agrochemicals, favourable environment for development of diseases, reduction of crop yield, increase in production cost also can create temporal water shortage to other farmers.

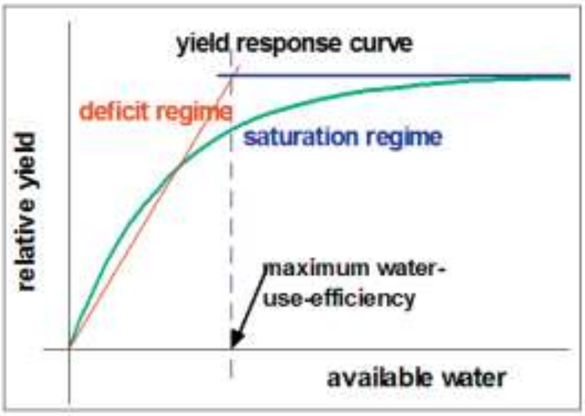


Figure 15.2: Plant Yield Response to Water

15.4 Water Management in Agriculture:

Water management in agriculture aims to match water needs and water availability in quality and quantity, in space and time, at reasonable cost and with acceptable environmental impact. Its adoption depends on social behaviour and economic constrains of rural communities, legal and institutional framework, agricultural practices and technological problems.

Under water management practices most attention is given to irrigation scheduling (when to irrigate and how much water to apply) giving minor importance to irrigation method (how to apply the water in the field). Many parameters like climatic condition, water availability in the soil, crop growth stage and its sensitivity to water stress determine irrigation frequency (when to irrigate). However, the frequency depends on the irrigation method and both irrigation scheduling and irrigation method are inter-related.

15.4.1 Localized Irrigation:

Localized irrigation is widely used as one of the most efficient methods of irrigation (Keller and Blienser, 1990). Localized irrigation systems such as trickle or drip irrigation, micro-sprayers apply the water to individual plants by plastic pipes usually laid on the ground surface. With drip irrigation system water is applied through small emitter openings from plastic pipes with a slow discharge rate of ≤ 12 l/h). With micro-sprayer or micro-sprinkler irrigation system water is sprayed over the crop plants with a discharge rate 12 to 200 l/h. The aims behind the localized irrigation are mainly the application of water directly into the root zone under the condition of low water availability, the avoidance of water losses during or after water application and the reduction of the water application cost because of less labour requirement.

Studies in diverse countries like India, United States, Israel and Spain have shown that drip irrigation can reduce water use by 30 to 70% and raises crop yield almost by 20 to 90% (Postel *et al.*, 2001).

Combination of water saving and higher yield typically increases the water use efficiency at least by 50% that makes drip irrigation system a leading technology in the global challenge of increasing crop production in the face of climate change and serious water scarcity.

Although the area under localized irrigation has expanded 50 times over the last two decades, it still represents less than 6% of the world's total irrigated area. The main reasons to its less expansion are the initial high investment cost (ranging from 1500 to 2500 € per hectare) and the high sensitivity to clogging.

Improvements in localized irrigation aiming to reduce the volume of water applied and increase the water use efficiency, the use of micro-sprayers in the soils having high infiltration rate, the adjustment of timing and duration of water application according to the soil and crop characteristics, the control of pressure and discharge variations, the use of appropriate filters and emitters, the adoption of proper maintenance, automation, chemigation (easy control of weeds and soil borne diseases) and fertigation (efficient fertilizer application).

15.4.2 Irrigation Scheduling:

Irrigation scheduling is a decision making process for deciding when to irrigate the crops and how much water to apply. It forms the sole means for conserving water and it is the key to improve the performance and sustainability of the irrigation systems. It requires good knowledge about the water requirements of the crops and the characteristics of soil and crops that determines when to irrigate and how much water to apply (Figure 15.3).

In most of the cases, the farmer's skill determines the effectiveness of the irrigation scheduling at the field level. By adopting appropriate irrigation scheduling runoff, deep percolation and leaching out of fertilizers out of the crop root zone can be controlled, water logging can be avoided, water and energy saving can be done as less water is used, higher yield can be obtained and rising of saline water table can also be avoided. Irrigation scheduling is more important in water scarce regions than under condition of abundant water, since any excess use of water is a potential cause for deficit for other uses or users.

Irrigation techniques and tools vary greatly and have different characteristics relative to their applicability and effectiveness. Timing and depth of irrigation scheduling can be decided by using several approaches based on measurement of soil water, soil water balance and plant stress indicators in combination with different models.

However, many of these models need further developments before they can be used in practice. Most of them require technical support by extension programmes, extension workers and technological expertise of the farmers. However, still in most of the countries these programmes do not exist because they are expensive, trained extension workers are lacking, farmer's knowledge and awareness of water saving in irrigation is not enough and the institutional mechanisms developed for irrigation management give low priority to the actual farming systems. Therefore, large limitations occur for their use in the farmers' practices. A brief description of irrigation scheduling techniques is reported below.

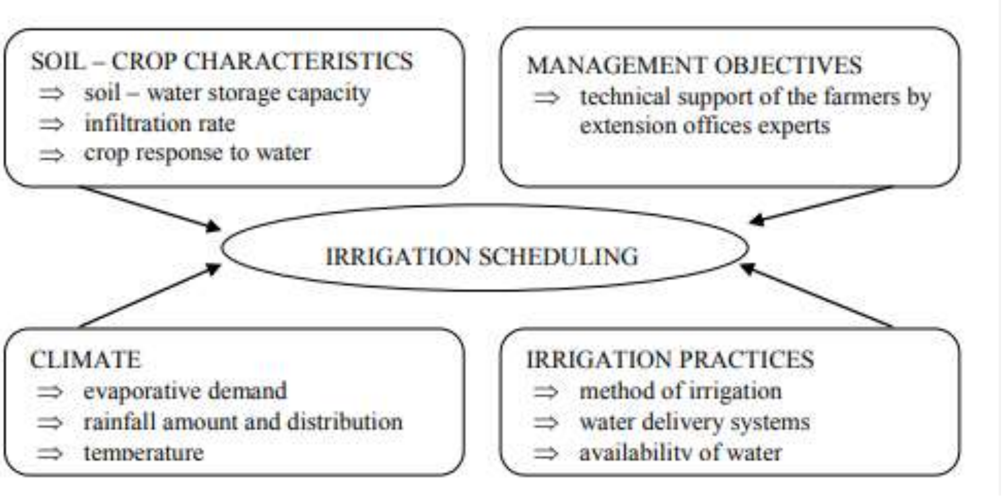


Figure 15.3: Irrigation Scheduling Components

A. Soil water estimates and measurements:

Soil water affects plant growth directly through its controlling effect on plant water status. There are two ways to measure the availability of soil water for the plants: by measuring the soil water content and soil water potential (how strongly soil water is retained in the soil). The accuracy of the information depends on the sampling methods and to the selection of location. Soil water estimates and measurements used for irrigation scheduling include: measurement of soil water content and soil water potential with tensiometers, soil spectrometers or pressure transducers, soil appearance and feel, remotely sensed soil moisture.

B. Crop Stress Parameters:

Instead of estimating or measuring the soil water parameters, it is possible to receive a signal from the plants itself indicating the time of irrigation. This message can either come from an individual plant tissue (where a correct sampling is required) or from the whole canopy.

Crop stress parameters include canopy temperature, leaf water content and leaf water potential, sap flow measurement, changes in stem or fruit diameter and crop stress identified by remote sensing (Deumier *et al*., 1996; Itier *et al.*, 1993).

C. Weather Parameters:

Local or regional weather parameters are widely used for scheduling irrigation. Weather data and empirical equations that are locally calibrated are used to estimate accurate reference evapotranspiration (ETo) for a given area and then crop evapotranspiration (ETc) is estimated using appropriate crop coefficient according to the crop growth stage for a particular crop. On the basis of the crop evapotranspiration rate irrigation scheduling is done. This technique reduces the excess use of water.

D. Soil – Water Balance:

The aim of soil water balance approach is to measure the water content in the crop root zone by water conservation equation: Δ (AWC × Root depth) = Balance of entering + outgoing water fluxes, where AWC is the available water content. Climate data, soil and crop characteristics are used to produce typical irrigation scheduling calendars by sophisticated models.

This approach can be applied for individual farms and also for large regional irrigation schemes. However, it needs expert persons, support by extension services and link with information systems. Its effectiveness is high and depends on technological development and support services of the farm. Some examples of commercial software based on soil-water balance approach for irrigation scheduling are IMS (Hess, 1996), SIMIS (FAO, 1999b). MARKVAND, SALTMED (Ragab, 2002).

E. Effective Irrigation Scheduling:

It is proved that appropriate irrigation scheduling can lead to improvement in irrigation water use efficiency, especially at farm level. The farmers should control the timing and the depth of irrigation. However, the practical application of the irrigation methods has been far below expectation.

The main constrains to effective implementation of crop-based and water-saving irrigation scheduling are the lack of flexibility either due to rigid scheduling or the system limitations, the high cost of irrigation scheduling (cost for technology and labour covers more than 30% of the total), the lack of education and training about the irrigation management among the farmers, the lack of interactive communication between researchers, extension workers and farmers and finally the lack of demonstration and technology transfer. One of the major obstacles to effective irrigation scheduling is the inability of delivery systems to deliver water at the farm with the flexibility and reliability required. In modern irrigation networks, water is available only on demand basis, although discharge may be limited due to technical or economic reasons. The farmers are free to select and adopt the irrigation methods which they consider more appropriate to their crops and farm conditions. However, in case of limited water supply or drought, proper effective irrigation scheduling must be minted to check excess water use. Finally, government and different agencies are making effort to disseminate knowledge, upgrade training at all levels, transfer technology, incite decision-makers to changes.

14.4.3 Fertigation:

The application of fertilizers through irrigation water is called fertigation which has become a common practice in modern agriculture. Localized irrigation systems which are highly efficient for water application, are also quite suitable for fertigation. The soluble fertilizers at required concentrations are applied through the irrigation system to the soil. But there are some disadvantages which include the non-uniform chemical distribution when irrigation designs are not adequate and the over-fertilization when irrigation is not based on actual crop requirement.

15.4.4 Deficit Irrigation Practices:

In the past, irrigation scheduling did not consider limitations of the water supplies. Then irrigation scheduling was done based on covering the full water requirements of the crops. However, in arid and semi-arid regions especially in the developing areas increasing demands for water for municipal and industrial use reduce steadily water allocation to agriculture. Thus, water availability for crops is usually becoming limited and certainly not enough to get maximum crop yields. So, irrigation strategies not based on full water requirements of crops should be adopted for more effective use of available water. Such irrigation management practices include deficit irrigation, partial root drying and subsurface irrigation.

A. Regulated Deficit Irrigation:

Regulated deficit irrigation (RDI) is a strategy under which crops are allowed to sustain some water deficit and yield reduction. Under regulated deficit irrigation system the crop plants are exposed to certain degree of water stress either during a particular growth phase or throughout the growing period. The main objectives of RDI are to increase water use efficiency (WUE) of the crop by eliminating irrigation schedules that have little impact on crop yield and to improve control on vegetative growth for improving fruit size and quality. The resulting reduction of yield may be small compared with the benefits obtained through diverting the saved water to irrigate other crops for which water would be insufficient under conventional irrigation practices.

The adoption of deficit irrigation needs appropriate knowledge on crop ET, crop response to water deficit including identification of critical crop growth stages and the economic impact of yield reduction strategies. Before implementing RDI it is necessary to know the crop yield response to water deficit during a particular growth stage or whole period. Crop yield response to deficit irrigation is explained by the equation $Y/Y_m = 1\text{-}K_y\ [1\text{-}ET_a/ET_m]$ (Stewart *et al*., 1977), where Y and Y_m are the expected and maximum crop yield, ET_a and ET_m are the actual and maximum ET, and K_y is the crop response factor. K_y gives an indication of whether the crop is tolerant to water stress and it depends on crop species, variety, growth stage and irrigation method. High yielding varieties are more sensitive to water stress. Crops or varieties with short growing periods are more suitable for RDI. Furthermore, to ensure successful RDI, the water retention capacity of the soil should also be considered. RDI must be applied during the period when shoot growth is rapid and fruit growth is slow. RDI can be applied successfully for row crops like potato, maize, soybean, sugar beet, sunflower and tree crops like grapevines, citrus, peaches, olives etc.

B. Partial Root Drying:

Partial root drying (PRD), first applied to grapevines, is a new irrigation technique that allows one half of the crop's root system to dry while the other half is irrigated. Wet and dry sides of the root system alternate on a 7-14 day cycle. During water stress grapevine's first line of defence is to close its stomata to reduce transpiration. The principal compound that regulates this response is abscisic acid (ABA). As soil water availability falls, the drying roots starts to synthesize ABA and transported it to the leaves through the transpiration stream (Loveys *et al.,* 1999). Stomata respond by reducing aperture, thereby restricting water loss. Improvement of WUE results from partial closure of stomata. Switching of the wet and dry sectors of root zone on regular basis is necessary. PRD can be successfully applied with drip irrigation and even with subsurface irrigation in grapevines and with furrow irrigation in citrus and pear.

15.4.5 Subsurface Drip Irrigation:

Subsurface drip irrigation is a low-pressure, low volume irrigation system that uses buried tubes to supply water. The water moves out of the tubes by the soil matrix suction force. Wetting occurs around the tubes and then water moves out in the soil in all directions. The potential advantages of subsurface drip irrigation are: a) conservation of water, b) enhancement in fertilizer use efficiency, c) uniform and highly efficient application of irrigation water, d) elimination of surface infiltration problem and evaporation losses, e) flexibility in providing frequent and light irrigation, f) less weeds infestation, g) low pressure requirement for operation. The main disadvantages are: a) high cost of initial installation and b) increased possibility for clogging especially when poor quality water is used. Subsurface drip irrigation system is especially suitable for high value fruit and vegetable crops, turfs and landscapes. The tubes are installed below the soil surface either by digging the ditches or by special device pulled by the tractor. The depth of installation depends on soil characteristics and crop species ranging from 15-20 cm for vegetable crops and 30-50 cm for fruit crops.

15.4.6 Agricultural Practices:

Different agricultural practices such as soil management, fertilizer application and disease and pest control are related with the water management in a sustainable way to reduce water losses without hampering the environment. Today agricultural practices are characterized by the abuse of fertilizers. Farmers very rarely carry out soil and plant analysis to clarify the proper quantity and type of fertilizer needed for each crop because this process increases the cost of agricultural production. Agrochemicals, such as herbicides and pesticides are also excessively used endangering the quality of the surface water and negatively affecting the environment. There are a large number of traditional and modern soil and crop management practices for water conservation (like runoff control, improvement of soil infiltration, increase water holding capacity of soil, control of soil water evaporation) and erosion control in agriculture. The soil management practices consist of:

a. Soil surface tillage: Shallow tillage practices are done to produce a rough soil surface which permits short time storage of the rainfall in excess to the infiltration.

b. Contour tillage: Soil cultivation is done and small furrows and ridges are made along the land contour that prevents runoff. This technique is also effective to control erosion and may be applied to row crops and also to small grains where field slopes are low.

c. Conservation tillage: No-tillage or reduced tillage is done where residues of the previous crop are kept on the soil. The crop residues act as mulch which protects the soil from direct impact of raindrops controlling crusting and sealing processes. Conservation tillage helps to maintain high organic matter level in the soil. It is also highly effective in improving soil infiltration rate and controlling soil erosion.

d. Mulching: Mulching with crop residues on soil surface slowdowns water flow over the field, reduces evaporation losses, improves infiltration rate and also contributes to weed control.

e. Organic matter: Increasing or maintaining the amount of organic matter in the upper layer of the soils provides better soil aggregation, increases water retention capacity of the soils and reduces crusting or sealing on soil surface.

f. Fine material or hydrophilic chemicals: Addition of fine material or hydrophilic chemicals to the coarse soils increases the water retention capacity of the soils and also controls deep percolation. Thus, water availability in the soils which have low water holding capacity is increased.

g. Acidity control: Acidity control of the soils by the application of lime and similarly application of gypsum to the soils with high pH favour more intensive and deep rooting, better crop development and improve soil aggregation, thus some increase in soil water availability.

h. Weed control: Adoption of appropriate weed control techniques is done to alleviate competition for available soil water and transpiration losses by weeds.

15.5 Recommendations for Best Irrigation Practices:

The supply of water for irrigating the crops is decreasing steadily due to competition with demands of municipal and industrial sectors. Therefore, human resources management, technology and policy innovation are needed to increase the use efficiency of the available water. Sustainable water management in agriculture can be achieved by:

a. Reduction of water losses: Water leakages from the water reserves should be detected via advanced technologies like telemetry systems, remote sensing, GIS etc. Old water projects experiencing water losses should be modernized and rehabilitated.

b. Improve the efficiency of irrigation system: Improvements in sprinkler irrigation system (efficiency up to 85%) include the correction of sprinkler spacing, use of pressure regulators, monitoring and adjustment of pressure equipment, the design for pressure variation not exceeding 20% of the average sprinkler pressure, application of irrigation during no windy periods, use of smaller spacing and large sprinkler drops, adoption of application rates smaller than the infiltration rate of the soil and proper maintenance of the system. Improvements in localized irrigation systems include reduction of the volume of water applied by using a single drip line for a double row crop to increase the water productivity, use of micro-sprayers in soils with high infiltration rate, adjustment of duration and timing of water application to soil and crop, control of pressure and discharge variations, use of appropriate filters to the water quality, adoption of automation and careful maintenance.

c. Increase water use efficiency: Increase in water use efficiency can be achieved with the use of localized irrigation systems by the farmers with or without subsidies, proper irrigation scheduling according to actual requirements of the crops, introduction of appropriate agronomical practices according to the climate and the application of salinity and acidity management techniques.

d. Adoption of innovative irrigation techniques: In regions with water scarcity, irrigation techniques not necessarily based on full crop water requirements like subsurface irrigation or regulated deficit irrigation must be adopted. Fertigation (efficient application of fertilizers) and chemigation (easy control of weeds and soil borne diseases) should also be promoted among the rural farmers.

e. **Water pricing policy:** An increasing block tariff charging system, that discourages water use levels exceeding critical water requirements of the crops, must be introduced. It will be the basis for promoting water conservation, reducing water losses and mobilizing water resources. But it could affect cropping patterns, efficiency of water management, income distribution and generation of additional revenue for operating and maintenance of water projects.

f. **Reuse of marginal waters *(*reclaimed or brackish) for irrigation:** Reclaimed waters can be used under some restrictions for irrigation of trees and fodder crops. Treated sewage should be looked upon with skepticism by the farmers. They instead prefer to use surface or groundwater for irrigation. Special effort is needed for educating farmers to accept treated sewage. In addition the tariff for these sources of water should be lower than the tariff of the primary sources. This may not be difficult to achieve because the primary and secondary levels of treatment are regarded as sunk costs since they are required by the new WFD. When using low quality irrigation water like brackish or saline water an integrating approach for crop (salt tolerant varieties) field management (suitable tillage practices) and suitable irrigation system should be adopted.

g. **Wider and effective participation of the public:** Need wider and more effective participation of Government sectors and NGOs in decision-making and the preparation of water management plans, monitoring the implementation and generally in the management of water. The participation of these groups raises support on the part of the body politics and also promotes success in possible conflict resolutions.

h. **Capacity building:** The existing “capacity building” is under poor condition. It needs appropriate competent personnel, advance technologically based devices and facilities, legal guidelines, efficient administrative and effective processes for the sustainable management of the water resources. It includes:

- Education and training of professionals, technical staffs, decision makers and others including non-public organizations is necessary for sustainable water management.
- Institutions should be staffed with qualified manpower like managers, engineers, technicians etc.
- Water authorities should apply updated technologies, advanced devices and programs e.g. GIS, remote sensing etc. These advanced techniques help water managers in their decision- making.
- Water authorities should participate in the formulation of agricultural policies because the development of water and land should be fully integrated. In practice, agricultural decisions are water decisions and vice versa.

15.6 Conclusion:

Climate change already starts to hamper agriculture, especially in the areas under arid and semiarid climatic regions. Thus the reduction in rainfall and the increase in temperature cause reductions in yield and profit, as crops are impacted by water and heat stress. Under this perspective, implementation of appropriate adaptation and mitigation strategies will help to reduce these negative impacts ensuring the economic and environmental sustainability of the current agricultural system. Correct water management strategies or soil management practices of conservation agriculture are some of the measures recommended.

To identify those management strategies more suitable for each crop and location, a correct characterization of the agricultural systems will be critical. Thus crop phenology and its sensitivity to water or heat stress, soil characteristics, availability of water resources are some knowledge requirements that must be considered for implementation of water management practices under climate change.

15.7 References:

1. Deumier J.M., Leroy P. and Peyremorte P. (1996). Tools for improving management of irrigated agricultural crop systems. In: *Irrigation Scheduling: From Theory to Practice*, Proceedings ICID/FAO Workshop, Sept. 1995, Rome. Water Report No. 8, FAO, Rome.
2. FAO, 1999. The state of food insecurity in the world. Rome, Italy.
3. FAO, 1999b. Land and Water Digital Media Series no 6. (www.fao.org).
4. Hess T. M. (1996). A microcomputer scheduling program for supplementary irrigation. *Computers and Electronics in Agriculture* 15: 233 – 243.
5. Itier B., Flura D. and Belabess K. (1993). An alternative way for C.W.S.I. calculation to improve relative evapotranspiration estimates: results of an experiment over soybean. *Acta Hortic*., 335, 333-340.
6. Jensen M.E. (1993). The impacts of irrigation and drainage on the environment. 5th Gulhati Memorial Lecture. 15th ICID Congress, The Hague, ICID, New Delhi.
7. Loveys B.R., Dry P.R. and McCarthy M.G. (1999). Using plant physiology to improve water use efficiency of horticultural crops. *Acta Hort.* 537: 187-199.
8. Postel S., Polak P., Gonzales F. and Keller J. (2001). Drip irrigation for small farmers. A new initiative to alleviate hunger and poverty. *Water Intern.* 26 (1): 3-13.
9. Ragab, R. (2002). A Holistic Generic Integrated Approach for Irrigation, Crop and Field Management: The SALTMED Model. J. of Environmental Modelling & software, 17:345-361.
10. Stewart J.I., Cuenca R.H., Pruitt W.O., Hagan R.M. and Tosso L. (1977). Determination and utilization of water production functions on principal California crops. W-67 California Contributing Project Report, Davis, University of California, USA.

ISBN: 978-81-19149-59-9

16. Weed Management Under Conservation Agriculture: Identifying Strategies for Smallholder Farmers

Bhumika Arora

Department of Botany,
Akal University,
Bathinda, Punjab, India.

Babita, Gajanand Modi

School of Basic and Applied Science,
RNB Global University,
Bikaner, Rajasthan, India.

Nivedan Bhardwaj

Department of Zoology,
Chaudhary Devi Lal University,
Sirsa, Haryana, India.

Abstract:

Sustainable crop production is necessary for both environmental and global food security. Due to its sustainable practices, including scheduled crop rotations, permanent soil cover, and integrated weed management, conservation agriculture (CA) is becoming more and more popular all over the world. Additionally, CA can promote soil water retention and lessen erosion, which will improve water quality and decrease runoff. Adopting CA methods can also support biodiversity and improve soil carbon sequestration, aiding in the fight against climate change.

The use of more herbicides has been associated with weed control in conservation agriculture in other nations, but problems with chemical access, herbicide resistance, and environmental consequences, there is the need for more effective weed elimination methods that may be used by smallholder farmers. Climate, soil type, and the availability of resources were taken into account while evaluating the regional applicability of these weed management tactics. The analysis also took into account the unique difficulties encountered by rainfed smallholder farmers, such as their limited access to inputs and shortages of labour.

There are still several solutions lacking in this chapter which are necessary for smallholder farmers. This combination expected to reduce weed competition while also being financially sensible and long-lasting. To ensure correct use and continuous success of these strategies, it is also necessary to offer farmers support and training.

Keywords:

Conservation agriculture, smallholder farmer, control strategies, weed, sustainable.

16.1 Introduction:

Over the upcoming years, a confluence of challenges, increasing migration and population growth, labour shortages, decreased food scarcity, climate change, and agricultural output, will affect agriculture, especially smallholder agriculture in emerging nations. In terms of putting into practice sustainable farming methods. This entails using practices that improve soil health and minimize chemical inputs, such as crop rotation, conservation tillage, and organic farming techniques. In order to increase knowledge of the value of sustainable agriculture and inspire farmers to adopt such techniques for long-term food security, it is also important to participate in research and education. Crop production is a crucial part of agriculture, which ensures the global food supply. The first and most important agronomic element that results in optimal crop production is effective soil management. The term "conventional tillage," has been described as a system that includes primary deep cultivation and secondary agriculture operations, is firmly connected with modern agriculture (Holland, 2004). Agriculture's use of tillage dates back thousands of years, when it was primarily used to benefit animals and productive areas near rivers. (Hillel, 1992). Tillage is the process of modifying the soil to improve the aggregates for the development and also for suitable well-prepared seed bed before planting. It serves a variety of purposes and promote appropriate emergence of seeds due to optimal positioning that provides sufficient nutrition, light, and water (Reicosky and Allmaras, 2003). Further, through tillage, additionally the soil gets modified with a number of substances.. Moreover, it helps to prevent and treat diseases and pests that propagate from soil (Owens, 2001) and play crucial role in conventional agriculture.

Several scenarios available in which farmers have benefited from the employment of this technology, including (i) decreased manufacturing costs (Malik et al., 2005); (ii) improved soil quality, or soil physical, chemical, and biological conditions (Kaschuk et al., 2010); (iii) higher carbon sequestration and the accumulation of soil organic matter (Saharawat et al., 2012); (iv) a decrease in the occurrence of weeds (Malik et al., 2005); (v) enhanced the nutrient and water utilization efficiency (Kaschuk et al., 2010). The management of weeds has been established as an essential CA component and calls for specific treatment. Moreover, weeds serve as a heaven for insects and other pests that spread disease, which lowers crop quality and raises the possibility of crop failure. The various natural and artificial habitats that tillage offers to weeds are both varied and diverse. From ancient times, tillage has been utilized as an efficient tool and plays a significant part in weed management. Tillage techniques are still quite successful, and numerous modern agriculturalists and weeders have rendered mechanical weed control easier. (Wallace and Bellinder, 1992). According to FAO (2002), Low mechanical soil disturbance, continuing organic soil cover, and species diversification through rotation of crops and integrating are the three tenets of CA. CA offers recommendations for crop-growing that is environmentally friendly manner rather than a rigid set of standards, and these recommendations can be adjusted to match particular local conditions and requirements. These recommendations enable farmers to modify CA techniques in accordance with local factors, like the variety of soil, rainfall patterns, and the resources that are obtainable (Wall, 2007). Furthermore, CA urges biodiversity and aids in the preservation of natural resources like water and nutrients. Additionally, it can help to mitigate climate change by lowering the release of greenhouse gases by retaining carbon in the soil. (Thierfelder et al, 2015).

CA needs sustained efforts to manage weed infestations at first, but after a particular threshold level is maintained, it becomes simpler to do so. To effectively control weeds, integrated measures must be considered and optimized. It is critical to investigate the environmental, natural, and social components of herbicides. Also, a methodical strategy is required to maximize various management alternatives depending on the Agro-ecosystem's ecological and geographical aspects. That helps in the identification of new routes for long-term control and site-specific weed management. Future work in this area must be targeted on providing all-encompassing answers while keeping an eye on the disparities.

16.2 Weed Control in Sustainable Farming: A Challenge:

Although CA is becoming more well-known for its beneficial impact on soil conservation, many farmers around the world are still unaware of it. For those who are familiar with the idea, managing weeds presents a significant problem. In the long run, literature on minimal or zero-tillage crop production systems may not apply to well-managed CA systems. It is critical to plan for these challenges, especially in the early years, until the soil seed bank is depleted. Minimal and no-tillage encourages the growth of perennial weeds, which leads to for a long time weed problems. (Thierfelder et al., 2018). Moreover, Even in the early years of CA implementation, small-seeded weeds that require light to emerge from dormancy would probably take over as the leading species of weeds in limited and no-tillage systems. As a result, successful weed control is regarded as a significant issue that determines the success of systems based on minimum and zero cultivation as well as CA (Giller et al., 2009). According to various publications, Herbicides serve for suppressing weeds, reduce innate output loss, and deal with manpower shortages in majority countries has been credited with the success of the implementation of a minimum and minimal cultivation system (Nakamoto et al., 2006). In fact, herbicides are usually seen as a replacement for the main type of tillage performed in tillage-based systems for pre-planting control of weeds in minimum and no-tillage systems (Scopel et al., 2013). The use of burn-down herbicides to eradicate the vegetation prior to planting is common, even if cover crops are grown for plowing and control of weeds. Herbicides such as fluometuron, glyphosate, and paraquat are frequently utilized for controlling weeds as an alternative to main tillage. Several of the herbicides on the following list, such as those that are slightly or moderately toxic and may be detrimental to human health and the natural world, are still unidentified. Indeed, the difficulty in applying herbicides for weed control within minimum and zero-tillage systems in California is made more difficult by the fact that minimal cultivation or ridge-till platforms cannot physically incorporate herbicides into the soil, hindering herbicide options to only post-emergence usages. Herbicide use has resulted in various weed species developing resistance in affluent and minimal cultivation systems, as well as documented instances of the same weed species developing multiple resistance to different herbicides (Binimelis et al., 2009). For instance, cutleaf evening primose (*Oenothera laciniate* Hill) has developed resistance to glyphosate and paraquat (Anderson, 2005). Thus, it is important to offer alternatives to herbicides in order to encourage the use of CA in agriculture where herbicide resistance has already developed. The commercialization of glyphosate-resistant crops has made it easier the removal of weeds and, in certain regions, led to the widespread use of minimum and minimal cultivation farming; however, the drawback is that numerous application of the weed killer are now common in spite of other weed management techniques (including those sprayed prior to crop emergence as well as in-season therapies for controlling weeds that might grow after crop planting). The usage of a single herbicide resulted in such a strong selection pressure that glyphosate-resistant weeds appeared very quickly (Johnson et al., 2009). However, there is a conundrum for farmers that employ CA in a climate where glyphosate resistance has arisen, decreasing the use of herbicides. Weed pressure will be minimized in CA systems because of their focus on crop rotation. Clearly, the pressure of weeds, plant resilience, or intrinsic production losses might discourage farmers from accepting conservation tactics such as seeding directly unless the control of weeds is handled sustainably in CA, especially in the initial stages. Degradation of soil and erosion, in reality, threaten biodiversity, agricultural sustainability, and long-term global security of food. (Montgomery and Dirt, 2007). CA seems to be a suitable strategy to prevent Erosion and deterioration of soil and to enhance soil health (Conservation Agriculture, 2018).

16.3 Weed Management Strategies:

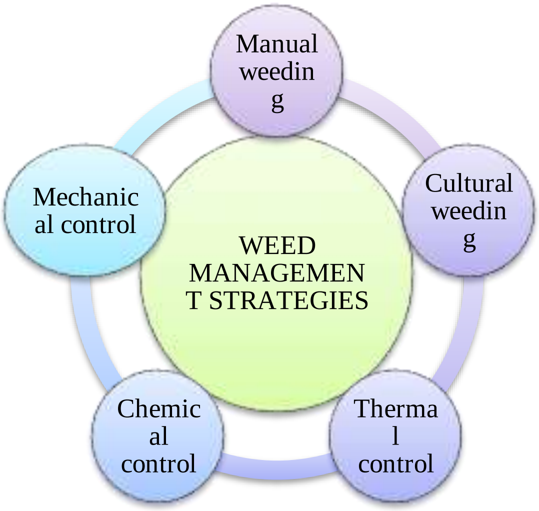


Figure 16.1: Various Strategies for Weed Management

16.3.1 Manual Weeding:

The most popular weed control methods used by smallholder farmers are manual and mechanical (sometimes including animal traction) (Gianessi et al. 2009). For smallholder farmers, hand cultivating or hand hauling is a common controlling instrument for mechanical weed control (Mashingaidze et al., 2012). Because to increased weed pressure in the early years of CA adoption, manpower requirements for mechanical control of weed in CA platform may rise (Nyamangara et al., 2014). Depending on the weed management approach employed, these labor requirements often vary greatly. Farmers that use hand hoes for controlling weeds must use the implement to shallowly wipe the soil surface rather than a digging action, which may take more time. For smallholder farmers adopting CA technology, is a major obstacle due to lack of labor to control weed populations (Giller et al., 2009). Avoiding weeding can have a significant adverse effect on yields of crops due to weeds competing with the main crop for nutrients, light, and water. By timely weeding fields, farmers with a sufficient labor supply can increase the advantages of manual or automated weed management (Vogel, 1994). As an instance, high-intensity weeding was carried out four times during the growing season in a semi-arid region of Zimbabwe: a week prior planting, one week after planting, five weeks after planting, and shortly prior harvest. The results showed that the early season weed densities of the moldboard-plow and minimal tillage systems were comparable (Mashingaidze et al., 2012). Weeding at a high intensity is difficult for farmers with limited resources and manpower, though. The higher labor requirements for weeding disproportionately affect women and children (Giller et al., 2009). Furthermore, compared to traditional tillage systems, higher weed densities are occasionally observed in CA systems even when high-intensity weeding tactics are used, and emphasizing the necessity for alternate weed management methods (Mashingaidze et al., 2012).

16.3.2 Mechanical Control via Animal Traction:

Where draft animals are available, appropriate mechanical cultivators for weed management are frequently used in place of conventional tillage (Riches et al., 1997). While cultivators are not as efficient compared to conventional tillage techniques for determining weed-free planting beds, they are able minimize weed pressure. Smallholder farmers might profit from animal-drawn cultivators like soil rippers, which are equipment fixed on a frame that has multiple tines. They are capable of mechanically disturbing small and emerging weeds, which can be an efficient method of mechanical weed management (Mafongoya et al., 2016). Mechanical cultivators have the disadvantage that they are ineffective and impracticable when there are significant amounts of plant leftovers present (Erenstein, 2003). As a result, they are only appropriate when there is little residue cover, which is frequently the case of semi-arid regions(Mazvimavi et al., 2010). Smallholder farmers may be given access to mechanical cultivators by Cooperatives, agricultural agencies, and vendors of services. Small-scale cultivators would not be able to make the necessary large-scale investments without this strategy. Also, it would shorten the time that farmers in a community would have to wait to use weeding tools (Najafi and Torabi Dastgerduei, 2015). As weed populations are increasing, the timing of seedbed preparation is critical for decreasing crop-weed conflict are heavily influenced by the timing of crop planting (Mhlanga et al., 2016). Given the fact that a lot of small-scale farmers have farms of fewer than five acres, restricted shared ownership or service provision of low-powered or draught-powered devices that disturbs the soil as little as feasible may be the most practical way to offer farmers with access to automated planting and weed management technologies. (Baudron et al., 2015). Government and non-profit organizations (NGOs)-led initiatives might boost access to small-scale machinery by improving regional industry.

As an example, FAO fieldwork in Tanzania and Kenya sought to create relationships with markets and a local manufacturing sector for other CA products, like the hand jab planter (Sims et al., 2012).

16.3.3 Chemical Control:

The accessibility of chemical weed management techniques has been primarily credited for the CA system's achievement (Swenson and Moore, 2009). However, evaluating the potential long-term consequences of based entirely on herbicides is essential as excessive reliance may result in the development greater resistant to herbicides in weed populations. In addition, with integrated weed management strategies that include chemical, mechanical, and cultural control techniques may minimize the harmful effects of herbicide use while maintaining effective control of weeds. (Gianessi et al., 2009). The major issues of the next part are the use of herbicides and seed coatings for weed control, as well as how they could be used effectively without harming local agro ecosystems.

A Herbicides:

For CA systems to be successful throughout the Americas and Australia, herbicide application has been essential (Llewellyn et al., 2012). Herbicide usage should be governed by an integrated weed management strategy, which includes optimal application rates and timing for herbicide applications (Norsworthy et al., 2012). With training, extension agents and researchers must address barriers to herbicide application and access, including as geographic accessibility, and safe chemical handling. The authors also noted that paraquat or glyphosate alone were less successful than interaction and permanent herbicide arrangements, such as atrazine, against annual grasses and broadleaf plants. Yet only some crops can employ residual herbicides, therefore their usage must be carefully studied. When creating an herbicide treatment program, factors including Weed density, the most prevalent species, and producer expertise would all need to be considered. Moreover some studies suggest utilizing cover crops to help in herbicide application (Chauhan et al. 2012). The cover crop is killed and used as cover when a non-selective herbicide like glyphosate is used, lowering weed growth and germination.Also, governments could promote the production of generic forms of non-patented herbicides such as glyphosate, which might improve access and possibly result in cheaper prices (Little, 2010). To be effective, herbicide quality and safety would need to be guaranteed through the setup of testing infrastructure and the implementation of quality standards. Many application techniques, such as weed wipers, can increase the effectiveness of an herbicide.

B Seed Coating:

Herbicide use may be facilitated by the adoption of herbicide-resistant seeds, but smallholder farmers must first have access to this technology (Kanampiu et al., 2003). Additionally, the subsequent growing seasons revealed no lingering impacts on maize seeds that were not herbicide-resistant. Hence, seed coatings seem to be a more focused and efficient strategy to attack some parasitic weed species, Although research into the effects of seed coverings on other important weed and used for farming species would be advantageous. Maize resistant to imazapyr was created via traditional breeding techniques, as opposed to genetic editing, which makes this strategy farmers and governments are going to consider it more appropriate that are unwilling or unable to use crops that have been modified. In short, chemically controlling weeds is an important tool for many farmers using CA, but smallholders' access to seed coating and pesticide technologies needs to be extended. Nonetheless, herbicides can effectively reduce weeds, particularly those that are resistant to manual or mechanical methods of weed control (e.g., couch grass). To minimize inappropriate application that could harm crops, lessen herbicide resistance, and prevent adverse environmental effects, farmers must be instructed in their safe usage (Mtambanengwe et al., 2015). Despite knowing that they are inefficient against non-parasitic weeds, herbicide seed coatings can help manage parasitic weed species like Striga spp.

16.3.4 Cultural Control:

Cropping systems are used in cultural weed management to lessen weed pressure. In many cases, cultural management techniques cost less than chemical techniques and benefit the soil more by incorporating biological material and nitrogen that has been organically fixed (Norsworthy et al., 2012). Crop rotations, enhanced crop rivalry by means of the use of growing and the fertilization process schedules, residue from agriculture preservation for controlling emerging invasive plants, intercropping strategies to increase crop productivity, and their harvest weed seed control for minimizing species-specific weed pressures will be addressed in the following chapter. For smallholder farmers who lack access to herbicides or do not generate enough biomass to retain Crop waste as a weed-control agent, crop competition is an affordable weed management technique (Mhlanga et al., 2016). When population growth is feasible, crop competition can be increased. Planting and fertilization schedules can also help smallholder farmers in using management techniques when crop and weed varieties are most actively competing (Kumar et al., 2013). Research on the impact of fertilization on crop competitiveness are conflicting, and the outcome is heavily influenced by The agricultural product and the most prevalent weed species (Walker and Buchanan, 1982). It was discovered that earlier planting and N-fertilizer application at the winter wheat stem elongation stage reduced In comparison to N-fertilizer application at the tillering stage, *Veronica hederifolia L.* biomass has risen while crop biomass yield was improved. (Liebman and Davis, 2000). A study on weed interference with hybrid maize, on the other hand, observed that less N fertilization led in higher crop yields of maize with fewer weed interference. (Tollenaar et al., 1994). As a result, additional investigation and observation of weed population patterns in relation to planting and fertilization date adjustments are required prior to making recommendations to landowners.

A. Crop Rotations:

The competition of weeds with crops can be decreased and weed development made harder by maintaining live soil cover via rotations of crops (Blackshaw et al., 2008). In addition to biological nitrogen fixation, Rotating cover crops with leguminous plants promotes food diversity (for both people and animals) (Govaerts et al., 2009). Crop rotation gazes like it's extremely advantageous in areas that are semi-arid, while the literature shows that its effectiveness as a weed control approach fluctuates. The limited growing season in semi-arid areas (often from November to April) makes it difficult to implement certain rotation of crops strategies (Mupangwa et al., 2016), therefore, crops might be rotated annually. Yet, if farmers see the changes to their soils, the advantages of rotation of crop as a device for

control and soil improvement might exceed anticipated hazards from implementing a rotating system. Crops must be rotated annually because the short growing season in semi-arid regions (typically from November to April) makes it challenging to use various crop rotation schemes. Yet, if farmers see the changes to their soils, the advantages of rotation of crop as a tool for control of weed and Sand enhancement could be greater than the risks associated with putting a rotating system into place (Thierfelder and Wall, 2010). Many research have been done to investigate the impact of these agricultural methods on weed populations, which involve intercropping, as rotation of crops, and residue from crops preservation. The dearth of research in the regions emphasizes the significance of this field even more, since it will aid farmers in more effectively implementing these tactics in their particular environments.

16.4 Conclusion:

Controlling weeds is one of the most important obstacles to successful crop production, especially in CA system applications. Successful implementation of CA in smallholder agricultural systems is improbable without efficient weed management and control techniques. Weed management in massive agricultural systems is not suitable for small-scale farmers due to a lack of financial resources, knowledge of, and accessibility to herbicides. While control of weeds is an important obstacle in the beginning stages of CA conversion, which is managed by small-scale producers. The scope and breadth of their implementation, as well as the selection of weed control methods used, are dictated by the farming circumstances of the farmers to whom all of the options have to be tailored. Weed pressure typically decreases when the first weed-related difficulties of converting to CA are under control, making it simpler for smallholder farmers to continue. Farmers still need to stick to CA guidelines and procedures throughout the years in order to successfully eradicate weeds. Farmers must modify their long-standing practices and how they handle their land in order to adopt CA, otherwise, the benefits will not be realized. Therefore, it is important to assist farmers in implementing effective weed control techniques, such as preventing weeds from establishing seed, preserving crop residue cover, and routinely adopting rotations or intercropping with crop species that are competitive. Farmers will be able to benefit from CA if they can find appropriate weed control techniques and boost their adoption, which may increase their long-term resilience to various stresses.

16.5 References:

1. Anderson, R. L. (2005). A multi-tactic approach to manage weed population dynamics in crop rotations. *Agronomy Journal*, *97*(6), 1579-1583.
2. Baudron, F., Sims, B., Justice, S., Kahan, D. G., Rose, R., Mkomwa, S., et al. (2015). Re-examining appropriate mechanization in Eastern and Southern Africa: two-wheel

tractors, conservation agriculture, and private sector involvement. *Food Security*, *7*, 889-904.

3. Binimelis, R., Pengue, W., & Monterroso, I. (2009). "Transgenic treadmill": responses to the emergence and spread of glyphosate-resistant johnsongrass in Argentina. G*eoforum*, *40*(4), 623-633.
4. Blackshaw, R. E., Harker, K. N., O'Donovan, J. T., Beckie, H. J., & Smith, E. G. (2008). Ongoing development of integrated weed management systems on the Canadian prairies. *Weed Science*, *56*(1), 146-150.
5. Chauhan, B. S., Singh, R. G., & Mahajan, G. (2012). Ecology and management of weeds under conservation agriculture: a review. *Crop Protection*, *38*, 57-65.
6. Conservation Agriculture. Available online: www.fao.org/ag/ca.
7. Elsgaard, L., Jørgensen, M. H., & Elmholt, S. (2010). Effects of band-steaming on microbial activity and abundance in organic farming soil. *Agriculture, Ecosystems andEnvironment*, *137*(3-4), 223-230.
8. Erenstein, O. (2003). Smallholder conservation farming in the tropics and sub-tropics: a guide to the development and dissemination of mulching with crop residues and cover crops. *Agriculture, Ecosystems and Environment*, *100*(1), 17-37.
9. FAO (2002) Conservation agriculture: case studies in Latin America and Africa. FAO Soils Bulletin 78 FAO, Rome.
10. Gianessi, L. (2009). Solving Africa's weed problem: increasing crop production & improving the lives of women. In T., Bruce, C., Foyer, N., Halford, A., Keys, K.,Kunert, D., Lawlor, M., Parry, & G., Russell(Eds.),*Proceedings of agriculture: Africa's engine for growth-plant science and biotechnology hold the key* (pp-9–23).The CropLife Foundation, Washington, DC, USA.
11. Giller, K. E., Witter, E., Corbeels, M., & Tittonell, P. (2009). Conservation agriculture and smallholder farming in Africa: the heretics' view. *Field Crops Research*, *114*(1), 23-34.
12. Govaerts, B., Verhulst, N., Castellanos-Navarrete, A., Sayre, K. D., Dixon, J., et al. (2009). Conservation agriculture and soil carbon sequestration: between myth and farmer reality. *Critical Reviews in Plant Sciences*, *28*(3), 97–122.
13. Hillel, D. (1992). *Out of the Earth: Civilization and the Life of the Soil*. University of California Press.
14. Holland, J. M. (2004). The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. *Agriculture, Ecosystems andEnvironment*, *103*(1), 1-25.
15. Johnson, W. G., Davis, V. M., Kruger, G. R., & Weller, S. C. (2009). Influence of glyphosate-resistant cropping systems on weed species shifts and glyphosate-resistant weed populations. *European Journal of Agronomy*, *31*(3), 162-172.
16. Kanampiu, F. K., Kabambe, V., Massawe, C., Jasi, L., Friesen, D., Ransom, J. K., et al. (2003). Multi-site, multi-season field tests demonstrate that herbicide seed-coating herbicide-resistance maize controls Striga spp. and increases yields in several African countries. *Crop Protection*, *22*(5), 697-706.
17. Kaschuk, G., Alberton, O., & Hungria, M. (2010). Three decades of soil microbial biomass studies in Brazilian ecosystems: lessons learned about soil quality and indications for improving sustainability. *Soil Biology and Biochemistry*, *42*(1), 1-13.
18. Kolberg, R. L., & Wiles, L. J. (2002). Effect of steam application on cropland weeds. *Weed Technology*, *16*(1), 43-49.

19. Kumar, V., Singh, S., Chhokar, R. S., Malik, R. K., Brainard, D. C., & Ladha, J. K. (2013). Weed management strategies to reduce herbicide use in zero-till rice–wheat cropping systems of the Indo-Gangetic Plains. *Weed Technology*, *27*(1), 241-254.
20. Liebman, M., & Davis, A. S. (2000). Integration of soil, crop and weed management in low-external-input farming systems. *Weed Research-Oxford*, *40*(1), 27-48.
21. Little, A. D. (2010). Technology brief-seed coating. In *ISHA technology briefs: Innovations in soil health for Sub-Saharan Africa*(pp-1-24). Meridian Institute, Washington, DC.
22. Llewellyn, R. S., D'Emden, F. H., & Kuehne, G. (2012). Extensive use of no-tillage in grain growing regions of Australia. *Field Crops Research*, *132*, 204-212.
23. Mafongoya, P., Rusinamhodzi, L., Siziba, S., Thierfelder, C., Mvumi, B. M., Nhau, B., et al. (2016). Maize productivity and profitability in conservation agriculture systems across agro-ecological regions in Zimbabwe: a review of knowledge and practice. *Agriculture, Ecosystems andEnvironment*, *220*, 211-225.
24. Malik, R. K., Gupta, R. K., Singh, C. M., Yadav, A., Brar, S. S., Thakur, T. C., et al. (2005). Accelerating the adoption of resource conservation technologies in rice wheat system of the Indo-Gangetic Plains. In *Proceedings of Project Workshop, Directorate of Extension Education, Chaudhary Charan Singh Haryana Agricultural University (CCSHAU)* (pp. 1-2).
25. Mashingaidze, N., Madakadze, C., Twomlow, S., Nyamangara, J., & Hove, L. (2012). Crop yield and weed growth under conservation agriculture in semi-arid Zimbabwe. *Soil and Tillage Research*, *124*, 102-110.
26. Mazvimavi, K., Ndlovu, P. V., Nyathi, P., & Minde, I. J. (2010). *Conservation agriculture practices and adoption by smallholder farmers in Zimbabwe*.
27. Melander, B., & Kristensen, J. K. (2011). Soil steaming effects on weed seedling emergence under the influence of soil type, soil moisture, soil structure and heat duration. *Annals of Applied Biology*, *158*(2), 194-203.
28. Mhlanga, B., Chauhan, B. S., & Thierfelder, C. (2016). Weed management in maize using crop competition: A review. *Crop Protection*, *88*, 28-36.
29. Mhlanga, B., Cheesman, S., Maasdorp, B., Muoni, T., Mabasa, S., Mangosho, E., & Thierfelder, C. (2015). Weed community responses to rotations with cover crops in maize-based conservation agriculture systems of Zimbabwe. *Crop Protection*, *69*, 1-8.
30. Montgomery, D.R. (2007). Dirt, the Erosion of Civilizations; University of California Press: Berkely, CA, USA.
31. Mtambanengwe, F., Nezomba, H., Tauro, T., Chagumaira, C., Manzeke, M. G., & Mapfumo, P. (2015). Mulching and fertilization effects on weed dynamics under conservation agriculture-based maize cropping in Zimbabwe. *Environments*, *2*(3), 399-414.
32. Mupangwa, W., Walker, S., Masvaya, E., Magombeyi, M., & Munguambe, P. (2016). Rainfall risk and the potential of reduced tillage systems to conserve soil water in semi-arid cropping systems of southern Africa. *AIMS Agriculture and Food*, *1*(01), 85-101.
33. Najafi, B.,& Torabi Dastgerduei, S. (2015). Optimization of machinery use on farms with emphasis on timeliness costs. *Journal of Agriculture Science and Technology, 17*(3), 533–541.
34. Nakamoto, T., Yamagishi, J., & Miura, F. (2006). Effect of reduced tillage on weeds and soil organisms in winter wheat and summer maize cropping on Humic Andosols in Central Japan. *Soil and Tillage Research*, *85*(1-2), 94-106.

35. Norsworthy, J. K., Ward, S. M., Shaw, D. R., Llewellyn, R. S., Nichols, R. L., Webster, T. M., et al. (2012). Reducing the risks of herbicide resistance: best management practices and recommendations. *Weed Science*, *60*, 31-62.
36. Nyamangara, J., Mashingaidze, N., Masvaya, E. N., Nyengerai, K., Kunzekweguta, M., Tirivavi, R., & Mazvimavi, K. (2014). Weed growth and labor demand under hand-hoe based reduced tillage in smallholder farmers' fields in Zimbabwe. *Agriculture, Ecosystems and Environment*, *187*, 146-154.
37. Owens, H. I. (2001). *Tillage: From plow to chisel and no-tillage,* (pp-1930-1999). MidWest Plan Service, Iowa State University.
38. Reicosky, D. C.,& Allmaras, R. R. (2003). Advances in tillage research in North American cropping systems. *Journal of Crop Production, 8*, 75-125.
39. Riches, C. R., Twomlow, S. J., & Dhliwayo, H. (1997). Low-input weed management and conservation tillage in semi-arid Zimbabwe. *Experimental Agriculture*, *33*(2), 173-187.
40. Saharawat, Y. S., Ladha, J. K., Pathak, H., Gathala, M. K., Chaudhary, N., & Jat, M. L. (2012). Simulation of resource-conserving technologies on productivity, income and greenhouse gas GHG emission in rice-wheat system.
41. Scopel, E., Triomphe, B., Affholder, F., Da Silva, F. A. M., Corbeels, M., Xavier, J. H. V., et al. (2013). Conservation agriculture cropping systems in temperate and tropical conditions, performances and impacts. A review. *Agronomy for Sustainable Development*, *33*, 113-130.
42. Sherestha, A., Lanini, T., Wright, S., Vargas, R., Mitchle, J., 2006. Publication 8200 available on the ANR communication services (online). Available at: http:// anrcatalog.ucdavis,edu. last checked on 07.05.13.
43. Sims, B. G., Bhatti, A. M., Mkomwa, S., & Kienzle, J. (2012). Development of mechanization options for smallholder farmers: examples of local manufacturing opportunities for sub-Saharan Africa. In *International Conference of Agricultural Engineering*.
44. Swenson, S., & Moore, K. M. (2009). Developing conservation agriculture production systems: an analysis of local networks.
45. Thierfelder, C., & Wall, P. C. (2010). Rotation in conservation agriculture systems of Zambia: effects on soil quality and water relations. *Experimental Agriculture*, *46*(3), 309-325.
46. Thierfelder, C., Baudron, F., Setimela, P., Nyagumbo, I., Mupangwa, W., Mhlanga, B., et al. (2018). Complementary practices supporting conservation agriculture in southern Africa. A review. *Agronomy for Sustainable Development*, *38*, 1-22.
47. Thierfelder, C., Matemba-Mutasa, R., & Rusinamhodzi, L. (2015). Yield response of maize (Zea mays L.) to conservation agriculture cropping system in Southern Africa. *Soil and Tillage Research*, *146*, 230-242.
48. Tollenaar, M., Nissanka, S. P., Aguilera, A., Weise, S. F., & Swanton, C. J. (1994). Effect of weed interference and soil nitrogen on four maize hybrids. *Agronomy Journal*, *86*(4), 596-601.
49. Vencill, W. K., & Banks, P. A. (1994). Effects of tillage systems and weed management on weed populations in grain sorghum (Sorghum bicolor). *Weed Science*, *42*(4), 541-547.
50. Vogel, H. (1994). Weeds in single-crop conservation farming in Zimbabwe. *Soil and Tillage Research*, *31*(2-3), 169-185.

51. Walker, R. H., & Buchanan, G. A. (1982). Crop manipulation in integrated weed management systems. *Weed Science*, *30*, 17-24.
52. Wall, P. C. (2007). Tailoring conservation agriculture to the needs of small farmers in developing countries: an analysis of issues. *Journal of Crop Improvement*, *19*(1-2), 137-155.
53. Wallace, R. W., & Bellinder, R. R. (1992). Alternative tillage and herbicide options for successful weed control in vegetables. *Horticultural Science, 27,* 745-749.

ISBN: 978-81-19149-59-9

17. Digital Farming in Agriculture

Bidyapati Thangjam, K. K. Jha

Research Scholar and Professor
Department of Agricultural Extension Education
School of Agricultural Sciences,
Medziphema Campus Nagaland University.

Abstract:

Digital technology helps the farms to become more resilient and sustainable while satisfying global food demand. The adoption of new technology in agriculture, such as the Internet of Things (IoT), Artificial Intelligence (AI), robotic systems, RS (Remote Sensing), and drones, which operate automatically and semi-automatically performing operations and gathering data aimed at increasing the efficiency and predictability in agriculture thus digital farming is the key to meet the growing food demand and farm resource availability.

Digital agriculture offers enormous potential to advance agricultural growth by lowering the amount of labor needed to raise crops and managing more effectively. The study provided evidence of the successful application of digital technology, such as AI, drones, and RS technology in agriculture, which can help to reinvent and reshape farming to fulfil the world's food need. Many farmers across the world, particularly in industrialized nations, rely on the application and management of smart agriculture. To end hunger in the current circumstances, digital farming has to be expanded.

Keywords:

Digital farming, agriculture and food security.

17.1 Introduction:

Global connectivity has increased significantly. One of the most potent technologies that has significantly accelerated globalisation and changed the global industries is digital tools. However, according to United Nation Department of Economic and Social Affairs there will be a huge increase in the demand for food as the world's population approaches 7.5 billion and projected to reach over 9.6 billion in 2050. Over 2 billion people still lack of an adequate nutrition, including 8% people living in Northern America and Europe (FAO, 2019). A large portion of the world's undernourished people live in Asia (381 million) and Africa (more than 250 million), where the number of malnourished people is increasing at a quicker rate than in any other region of the world, according to FAO's report (2020).

Increasing agricultural productivity, networking, and sharing agricultural information with farmers are ways to address the present food crisis by reducing farmers' risk. Digital farming can act as a strength in the agriculture to achieve significant development and meet the food need of the global population.

Digital connectivity and data are key components of a new agricultural revolution. Artificial intelligence, analytics, networked sensors, and other cutting-edge technologies have the potential to increase agricultural yields and enhance the efficiency of farm input management. Digital technology helps the farms to become more resilient and sustainable while satisfying global food demand. "Digital agriculture" refers to the use of digital technology to manage crops, animals, and other farm tasks related to developing and maintaining agricultural resources. For farmers to receive timely information that will improve agricultural output, promote food security, and improve rural livelihoods.

Digital farming contributes towards social connection, farmer empowerment, and involvement. The following benefits of digital advancements in agriculture are highlighted:

- Cost-effective, wide-scale transmission of relevant data is made possible by digital technology.
- Farmers can use digital technologies to plan and track the use of their farm equipment as well as to locate buyers and sellers for the goods they use and generate.
- Pests and diseases can be located remotely (using digital imagery from drones and satellites), and soil monitors allow for effective water management. Mobile applications also aid in farm management.
- Digital tools assist farmers in understanding and implementing best practices in agriculture, including those related to crop selection, input management, land preparation and selection, finance, transportation, packaging, and marketing of agricultural products.
- It provides a global network for the agricultural industry, bringing together farmers, scientists, researchers, and administrators to work towards a shared objective and fostering the growth of agricultural activities.

The adoption of new technology in agriculture, such as the Internet of Things (IoT), Artificial Intelligence (AI), robotic systems, RS (Remote Sensing), and drones, which operate automatically and semi-automatically performing operations and gathering data aimed at increasing the efficiency and predictability in agriculture thus digital farming is the key to meet the growing food demand and farm resource availability.

17.2 Artificial Intelligence (AI) in Agriculture:

John McCarthy first used the term "artificial intelligence" (AI) in 1956, and since then, it has been given many different definitions. However, it is defined in the rational approach as a system that automates intelligent behavior or acquires intelligence over time using computational programming and produces rational outputs to carry out specific tasks without human engagement (Bhagat *et al.* 2022).

The agriculture sector is evolving as a result of encouraging the usage of artificial intelligence. Due to advances in technology innovations, AI is already replacing the majority of manual which could simplify even the most challenging tasks to routine work and improve our quality of life. With the use of artificial intelligence (AI), we can collect and analyses enormous amounts of data on a digital platform. Using this real-time data, farmers can identify crops that require fertilizer, irrigation, or pesticides.

In India, the Saagu Baagu pilot partnership with the Government of Telangana through the World Economic Forum's Artificial Intelligence for Agriculture Innovation (AI4AI) initiative has made as first Indian state to implement a framework for scaling up emerging technologies and improving productivity, efficiency, and sustainability in the agriculture sector. By January 2023, over 7,000 farmers had signed up for the trial programmed, which mostly targeted growers of chili (World Economic Forum, 2023). AI can evaluate satellite and drone images to assist farmers in managing their livestock and agricultural crops. Farmers won't need to constantly check their crops because AI technology will inform as soon as something appears out of the norm. Using aerial imaging can also increase the efficacy and accuracy of pesticide application. By integrating AI into farming design and operation, several aspects of agriculture can improve. The following agricultural processes can benefit from artificial intelligence:

- **Soil management**: AI may be used to develop soil maps which show the interactions between the soil landscape and the quantities of soil sub surface. It is frequently employed in identifying and modifying soil factors that offer a favourable environment for the crop.
- **Market information:** AI can simplify crop selection and help farmers choose the most profitable commodity. It enables farmers to be informed about current market trends, yearly results, and customer wants, enabling them to efficiently maximise crop returns.
- **Risk management:** Farmers may lessen the risk of operational errors and crop failure with the use of AI forecasting and prediction. The probability of plant diseases is reduced by obtaining data as early as possible. Farmers can automate to detect the plant diseases and pests.
- **Plant protection and management:** AI technology assisted in choosing the most superior crop varieties and have even enhanced the selection of hybrid seed options that are most suited for farmers' requirements. AI is capable of finding and eliminating weeds, detecting and even foreseeing ailments in plants, and recommending effective pest control techniques.
- **Plant irrigation and monitoring:** We can irrigate crops more intelligently through AI, which boosts farmer output. AI is helpful for predicting the best combination of different agronomic factors, determining the best irrigation schedules and fertiliser application times.

17.3 Drones in Agriculture:

Unmanned Aerial Vehicles (UAVs) known as drones is one of the latest technologies, guided autonomously by remote control offering substantially greater range and endurance than equivalent manned systems. Drone is an aircraft with no human pilot on-board controlled by remote system (FAO and ITU, 2018). Drone are available with different camera sensors to provide detail information on what to observe in the human eye. Sensors available in this technology are RGB (red, green blue), NIR (infra-red near), RE (red edge), Thermal infrared (Aydoğan, 2018). This technology has a huge potential in agriculture in supporting evidence-based planning and in spatial data collection. In agricultural sectors UAVs can be used in crop monitoring, agricultural development site photography, variable rate applications and livestock management. It works by scanning with different sensors in a vast area at low cost to provide a wide range of information.

Drone is used for assessment of plant health, monitoring for plant and livestock's, mapping for crop identification, irrigation scheduling, spraying pesticides and fertilizers. It is a cheap and economical way to manage farming, it helps to reduce human labour and time consumption of the farm task. Drone provides a high technologies makeover to agriculture industry that drones marketplace may reach $200 billion by year 2023. Due to rapid growth of technology, it is reported that growth of Drones technology is increasing 25-32% every year especially in the area of Agriculture (Rana and Mahima, 2020).

Drone allow farmers to monitor crop with special imaging equipment called Normalized Difference Vegetation Index (NDVI). It give detailed colour information to indicate plant health, it helps farmers to take decision fast enough to save the plants. Drone can plant more efficiently by planting 400,000 trees a day with a team of two operators. South- east Asia with South Korea already used drones for approximately 30% to apply spray treatment in agriculture. Another report said that agriculture drones can spray 40-60% faster than manual spraying with saving 30-50% in chemicals and able to conserve up to 90% of water usage for agriculture (McNabb, 2020). Drones also successfully manage the seed planting process in the soil. The system of drone allows farmers to75% rooting, reducing 85% of planting costs and increasing sustainability (Food and Society, 2018). Utilization of drone in agriculture avoids the significant labor costs traditionally associated with planting activities. According to Sense Fly (a drone manufacturer specializing in agriculture) the utilization of drones by the Ocealia group resulted in a 10% average increase in crop yields. Drones with the equipment's like LiDAR (Light Image Detection and Ranging) and RADER (Radio Detection and Ranging) make them well-suited for crop spraying and some experts argue that crop spraying by drones may be up to five times faster than with regular machinery (Probst *et al.* 2018).

UAV has a huge potential in the improvement of sustainable agriculture. Drone use in the agricultural sector is expanding as part of an efficient strategy for managing agriculture sustainably. UAV technology enhanceed the cultivation and reduce the human energy requirement as the technology can perform monitoring, spraying missions, collecting information and planting thereby optimizing the efficiency of the pesticides and detecting pests and diseases (Radoglou-Grammatikis *et al.* 2020).

In India, Dahanu-Palghar tribal villages of Maharashtra have learned to use drones for organic farming, fish farming, crop rotation, bio-control, hydroponics, bio-waste management, beside also using drone-based technologies on their orchards and farms (Pathak *et al*. 2020). There are many organizations have been working continuously in order to integrate smart technology that enable transforming agriculture with cost efficient, time saving, support farmers decision and provide on demand information to the farmers and the stakeholders. Therefore, smart farming has a real potential to deliver more productive and sustainable agriculture.

17.4 Application of Drones in Farming:

- Drones assists farmers with providing an accurate real-time images and data, enabling massive crop monitoring. Additionally, it can help farmers detect issues like drought stress, nutritional deficiencies, pests, and illnesses early on.

- Drones reduce the amount of labour and time needed for farm operations by spraying pesticides, herbicides, or fertilisers to crops. This method is especially useful if the top ography or soil make it difficult to use conventional planting techniques.
- Since drones can fly close to the ground and can apply pesticides more precisely than traditional methods, they cut the amount of chemicals needed and limit runoff and drift.
- As a result of their multispectral or hyperspectral sensors, drones assist farmers identify damaged and pest plants more rapidly than they could by eye.
- Drones with thermal cameras can collect data on field moisture, and farmers may use this data to alter irrigation practises to improve crop water efficiency.

The following are a few advantages of deploying drones in farming:

- Drones save farmers time by providing real-time data and covering large areas in a single flight.
- Reduced costs for investment, early identification of pest diseases and other dangers enables farmers to take preventative measures and thus cost lower on pesticide purchases. Spot treatments on specific areas are also possible.
- Drones offer precise data and detailed, high-resolution imagery.
- Since drones can execute tasks that humans find challenging, they lower risk for farmers.
- Drones produce digital data that is simple to store and examine.
- Drones can contribute to an overall improvement in the health of crops by making crop monitoring and management more effective and accurate.

17.5 Satellite and Remote Sensing:

The development of remote sensing makes possible to collect data and analyse a phenomena or item without being in contact. According to Union of Concerned Scientists (UCS), there are 2,666 satellites actively satellites orbiting the Earth, out of this 1211 satellites are used for communications, 884 for earth observation, 312 for technology demonstration, 148 for navigation, 93 for space observation, and 18 for earth science. Satellite data might be quite helpful since it can be utilized to learn new, insightful information about several aspects of agriculture. Satellite data and photographs can be used for farm planning, evaluating crop production or field condition, whether management, mapping irrigated and non-irrigated vegetation sections. Remote sensing (RS) is a field of study that uses electromagnetic radiation as a medium of interaction to identify earth surface objects and estimate the geo-biophysical attributes (Roy *et al.* 2017). RS tool provide a valuable information about crop growth monitoring, land use pattern and changes in land cover, water resources mapping and water status under field condition, monitoring of diseases and pest infestation, forecasting of harvesting date and yield estimation, precision farming and weather forecasting purposes along with field observations. Images captured by remote sensing are used to identify weed infestations, hail damage, wind damage, pesticide harm, and plant populations. In India, Ministry of Agriculture and Farmers' Welfare effectively uses satellite remote sensing to gather crop statistics information required for the planning and decision-making of agricultural inputs. RS provides data on crop acreage estimation, crop yield and production estimation, crop condition estimation, data collection on soil parameters, cropping system research, experimental crop insurance, and other areas of agricultural production. In four distinct states-Haryana, Karnataka, Maharashtra, and Madhya Pradesh-about 250 Crop Cutting Experiences (CCEs) were completed. These initiatives give farmers an ability to make important choices during the growing season, practically prior to crop harvest (Solomom, 2020). Several applications, including automatic irrigation and greenhouse farming, are controlled with the help of these sensors technologies that are put in the fields. Through a variety of sensors, plant illnesses are identified and soil quality is tested. Farmers may produce the crop more efficiently from the information receive. According to Anilkumar *et al.* (2020), an image processing approach using MATLAB is used, for instance, to identify weedy patches and plant illnesses and users can obtain the information base on the requirement.

The following are advantages of using remote sensing for farming:

- Crop categorization, crop acreage calculation, and yield evaluation are all crucial fields in which remote sensing is highly effective.
- With the use of remote sensing, scientists and farmers can anticipate crop output in a certain area and calculate how much crop can be obtained in an area.
- By offering timely spectral information to monitor crop status, damage, and progress, remote sensing can play a significant role in agriculture.
- Crop yield estimate and modelling, which enables farmers and professionals to forecast the anticipated crop output from specific field.
- Remote sensing is now a crucial technique for assessing crop stress and for detecting pest and disease infestations.
- Farmers may obtain soil moisture data through soil mapping and soil moisture estimation, which helps them evaluate the amount of moisture in the soil and the sort of crop that can be planted there.
- The weather patterns in a certain area may be tracked using remote sensing equipment. It keeps track of the drought and monitors it.

17.6 Conclusion:

Digital agriculture offers enormous potential to advance agricultural growth by lowering the amount of labor needed to raise crops and managing more effectively. The study provided evidence of the successful application of digital technology, such as AI, drones, and RS technology in agriculture, which can help to reinvent and reshape farming to fulfil the world's food need. Many farmers across the world, particularly in industrialized nations, rely on the application and management of smart agriculture. Drone and remote sensing technology for agriculture are effectively utilized to boost farmer revenue and cut down on agricultural inputs. To end hunger in the current circumstances, digital farming has to be expanded. In addition, there are significant limitations on how to use, buy, and operate digital technology. Farmers have successfully accepted this technology, but there are also rules and license requirements, as well as a high initial cost. There are many significant obstacles to implementing digital technologies, including their high initial costs and the need for legislative changes to make them more user- and farmer-friendly. In contrast to farmers in industrialized nations, those in underdeveloped countries are less likely to favor such technology due to minimal landownership and poor economic conditions of the framers.

And such technologies are mostly used by the professional, big landholder farmer and experts for data collection, crop mapping, crop monitoring and spraying. Use of AI, RS and drone are required skills and demonstration on how to use the technology.

17.7 References:

1. Anilkumar, C. S., Suhas, G., Sushma, S., Dingra, R. K., Dingra, M. K. 2020. Modern Agriculture using Wireless Sensor Network. International Journal of Innovative Technology and Exploring Engineering. 9(4): 201-205.
2. Aydoğan, Y. 2018. Drone technology in agricultural mechanization. International Scientific Journal Mechanization in Agriculture. 2: 36-38.
3. Bhagat, P. R., Naz, F. and Magda, R. 2022. Artificial intelligence solutions enabling sustainable agriculture: A bibliometric analysis. PLoS ONE. 17(6): e0268989. https://doi.org/10.1371/journal.pone.0268989.
4. FAO and ITU, 2018. E-agriculture in Action: Drones for Agriculture. Food and Agriculture Organization of the United Nations and International Telecommunication Union Bangkok, 2018. Gerard Sylvester, http://www.fao.org/3/I8494EN/i8494en.pdf.
5. FAO, 2019. World Food and Agriculture Statistical Pocketbook 2019. Food and Agriculture Organization of the United Nations Rome, 2019, http://www.fao.org/3/ca6463en/ca6463en.pdf.
6. FAO, 2020. Food security and nutrition around the world in 2020, http://www.fao.org/3/ca9692en/online/ca9692en.html#chapter-1_1.
7. Food and Society, 2018. Sürdürülebilir tarım için bakış açınızı genişletin: Drone teknolojisi. www.barillacfn.com/en/magazine/food-and-society/drones-technology-for-the-benefit-of-sustainableagriculture, 24.04.2018.
8. McNabbon, M. 2020. Drones in Agriculture Worth More than $5 Billion by 2025. https://dronelife.com/2020/06/09/drones-in-agriculture-worth-more-than-5-billion-by-2025/.
9. Pathak, H., Kumar., G. A. K., Mohapatra., S. D., Gaikwad., B. B. and Rane, J. 2020. Use of Drones in Agriculture: Potentials, Problems and Policy Needs. Publication no. 300, ICAR-NIASM, pp 13.
10. Probst, L., Pedersen, B. and Dakkak-Arnoux, D. PwC, 2018. Digital Transformation Monitor Drones in agriculture. European Commission. European Commission, Directorate. https://ec.europa.eu/growth/tools-databases/dem/monitor/ sites/default/files/ Drones_vf.pdf.
11. Radoglou-Grammatikis, P., Sarigiannidis, P., Lagkas, T. and Moscholios, L. 2020. Compilation of UAV applications for precision agriculture. Computer Networks. 172 (2020):107148.
12. Rana, V. and Mahima, 2020. Impact of Drone Technology in Agriculture, Int.J.Curr.Microbiol.App.Sci. 9(1): 1613-1619. https://doi.org/10.20546/ijcmas.2020.901.177.
13. Roy, P. S., Behera, M. D. and Srivastav, S. K. 2017. Satellite Remote Sensing: Sensors, Applications and Techniques. Proc. Natl. Acad. Sci., India, Sect. A Phys. Sci. 87(4):465–472. https://doi.org/10.1007/s40010-017-0428-8.
14. Solomon, R. 2020. Remote Sensing Technology Continues to Expand in Indian Agriculture. https://www.precisionag.com/in-field-technologies/sensors/remote-sensing-technology-continues-to-expand-in-indian-agriculture/.

15. UNDESA (United Nation Department of Economic and Social Affairs) 2017. World Population Prospects: Key findings and advance tables, New York: UN DESA.https://population.un.org/wpp/publications/Files/WPP2017_KeyFindings.pdf.
16. World Economic Forum, 2023. AI for agriculture: How Indian farmers are harnessing emerging technologies to sustainably increase productivity | World Economic Forum (weforum.org).

ABOUT THE BOOK:

The book on "Climate-Smart Agriculture and Food Security" delves into the critical intersection of agriculture, climate change, and global food security. As the planet grapples with the escalating challenges posed by climate change, the need to adapt agricultural practices to safeguard food production becomes increasingly urgent. This comprehensive volume explores innovative strategies, technologies, and policies that can enhance the resilience of agricultural systems in the face of changing climatic conditions. From sustainable crop management techniques and water-efficient irrigation methods to the integration of digital solutions in farming, the book highlights a spectrum of approaches aimed at maximizing yields while minimizing environmental impact. By shedding light on the complex relationship between climate-smart agriculture and food security, the book serves as a vital resource for policymakers, researchers, and practitioners striving to navigate the intricate landscape of sustainable food production in a changing world.

Amidst the growing global population and the escalating repercussions of climate change, ensuring food security has emerged as a paramount concern. "Climate-Smart Agriculture and Food Security" meticulously examines how innovative agricultural practices can be harnessed to mitigate the adverse effects of climate change on food production. Drawing on a diverse array of case studies and expert analyses, the book dissects the challenges faced by smallholders, the role of biotechnology in crop resilience, and the potential for agroforestry and sustainable livestock management to bolster food security. By illuminating the symbiotic relationship between climate-smart agriculture and food security, the book underscores the pivotal role that ecologically sensitive and technologically advanced agricultural systems play in nourishing a growing global population while safeguarding the planet's fragile ecosystems.

KRIPA DRISHTI
PUBLICATIONS

Kripa-Drishti Publications
A-503 Poorva Heights, Pashan-Sus Road, Near Sai Chowk,
Pune – 411021, Maharashtra, India.
Mob: +91 8007068686
Email: editor@kdpublications.in
Web: https://www.kdpublications.in

ISBN: 978-81-19149-59-9